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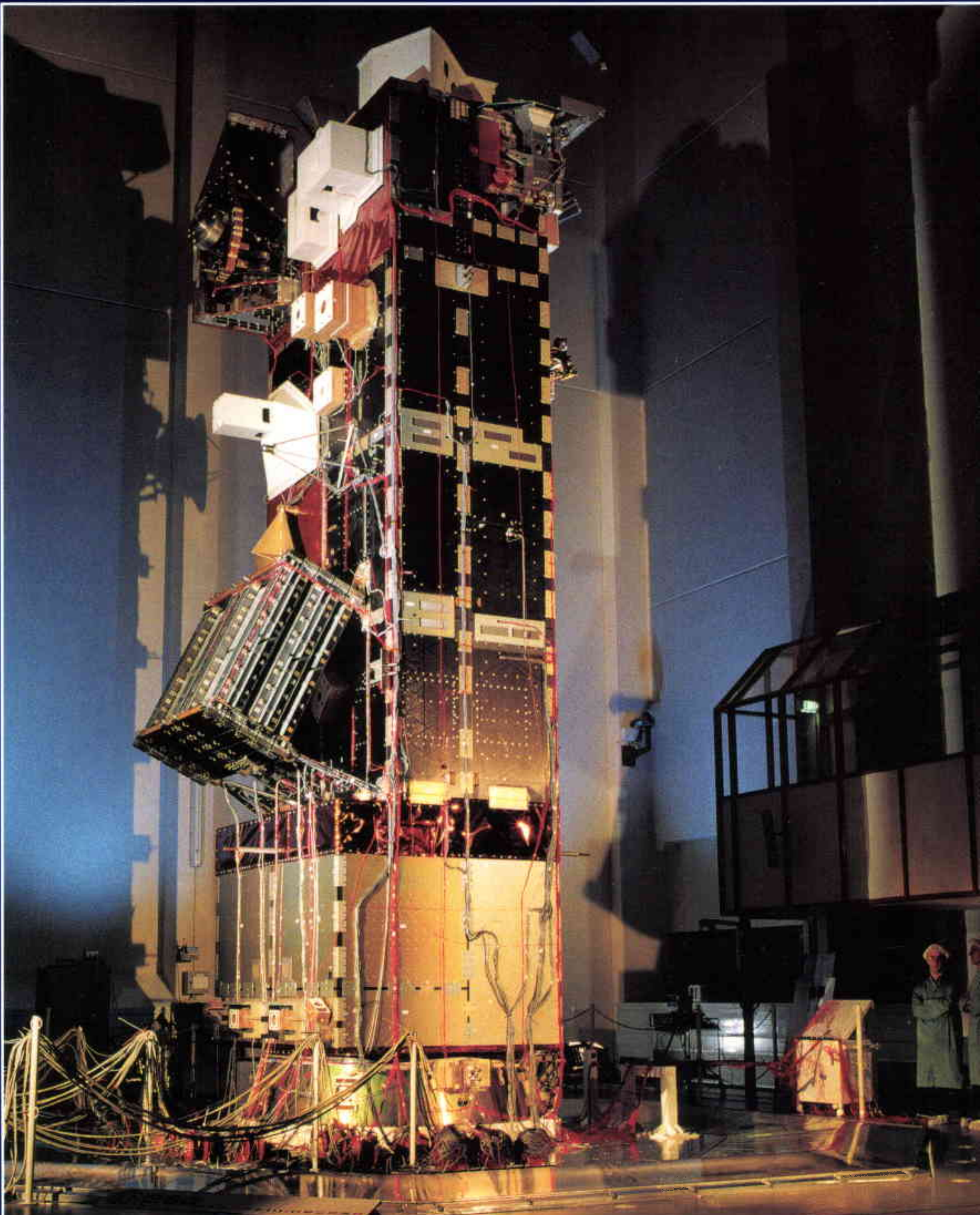

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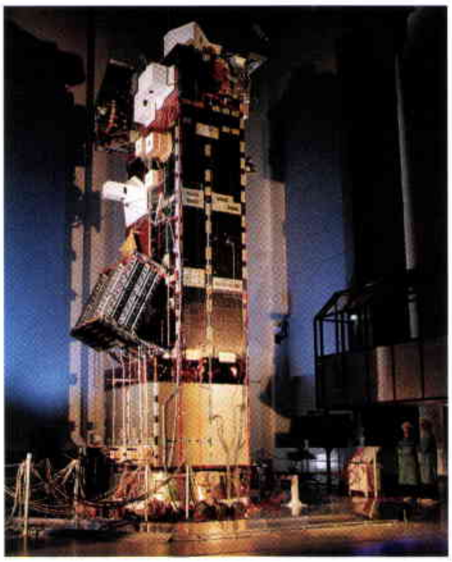

Cover: Structural model of Envisat under test at ESTEC. See article on page 20.

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Duc Guyenne
Dorothea Danesy

Layout
Carel Haakman

Graphics
Willem Versteeg

Montage
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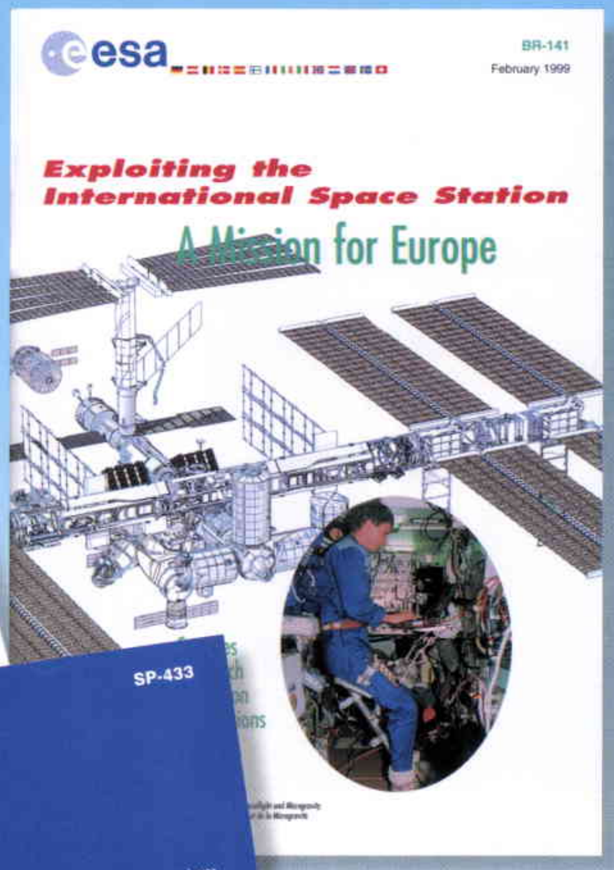

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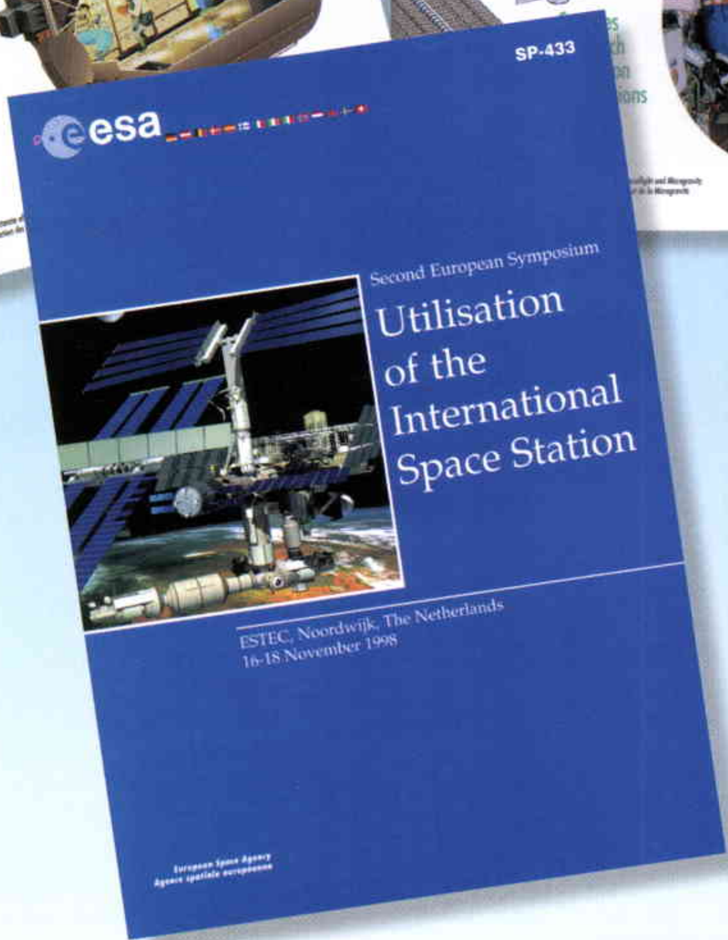

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The Ariane-5 Evolution Programme: Three Years after Toulouse

D. Coulon
Directorate for Launchers, ESA, Paris

To consolidate its success, Europe's Ariane launch vehicle must be continually adapted to meet the demands of the commercial markets that it serves. In the case of Ariane-5, a first increment to the basic launcher's capabilities was sanctioned by the ESA Council, meeting at Ministerial Level, in Granada in 1992. Preliminary studies were conducted to establish a basis for the so-called 'Ariane-5 Evolution Programme', followed by an appropriate Preparatory Programme. The Ariane-5 Evolution Programme was subsequently formally accepted at the Council Meeting at Ministerial Level in Toulouse in October 1995.

In April 1998, the decision was taken to accelerate the Ariane-5 Evolution Programme whilst still maintaining schedule compatibility with the development of the cryogenic upper stage, in response to the pressing needs of the satellite launch market. The first flight of this new, more performant member of the Ariane launcher family is scheduled for May 2002.

Introduction

The primary objective in embarking on the development of Ariane-5 Evolution back in 1995 was to increase the vehicle's payload performance from 5970 to 7400 kg in Geostationary Transfer Orbit (GTO), and to maintain Europe's already solid industrial base in the launcher field, especially in propulsion technology.

Since the uprated vehicle was to be a close derivative of the original Ariane-5, the changes envisaged were the following:

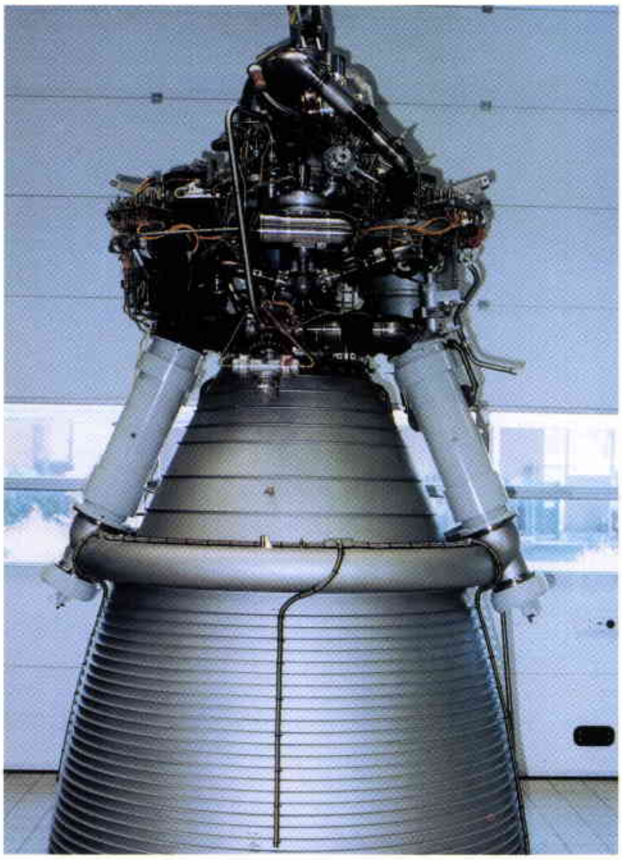
- On the cryogenic stage, the common bulkhead between the oxygen and hydrogen tanks is being lowered by about 65 cm, enabling the mass of oxygen carried to be increased by 16 tonnes to cope with the increased mixing ratio of the Mark-2 version of the Vulcain engine.
- A Vulcain Mark-2 engine is being derived from the current Vulcain, with the thrust increased from 1145 to 1350 kN by increasing the oxygen flow rate. The mixing ratio is raised from 5.3 to 6.2. The oxygen turbopump is the subsystem undergoing the most significant changes. The combustion chamber is being adapted to accommodate the new flow rates. Finally, the expansion ratio of the divergent is being increased by 30% with the turbine exhaust gases reintroduced.
- The Ariane-5E solid boosters are being enhanced by the introduction of welded joints between the cylindrical sections that make up the booster segments, replacing the original seals. This modification produces a significant mass saving, an increase in reliability and lower production costs.
- A new dual-launch system, known as Sylda-5, is proposed for Ariane-5E. This structure lies entirely within the fairing and can accommodate a satellite with a diameter of 4 m in the lower position. Sylda-5 provides a mass saving of 350 kg compared with the current Speltra.

The programme approach

The programme content began with the launch-system activities, including a set of general studies leading to an updating of system specifications and preliminary definition of electrical-system adaptations presented at the System Design Review.

For the cryogenic main stage, this activity consisted of layout studies and mechanical and functional studies, including the updating of the relevant specifications. The Integrated Equipped Tanks preliminary design effort is proceeding, with tank-pressure optimisation being performed to balance propulsion needs against tank panel welding-technology limitations. The Preliminary Design Review took place in November 1998.

The Vulcain-2 studies have covered the engine system, the oxygen and hydrogen turbopumps, the combustion chamber, the divergent and other equipment items. Preliminary Design Reviews were held throughout 1997 as the various activities were completed.



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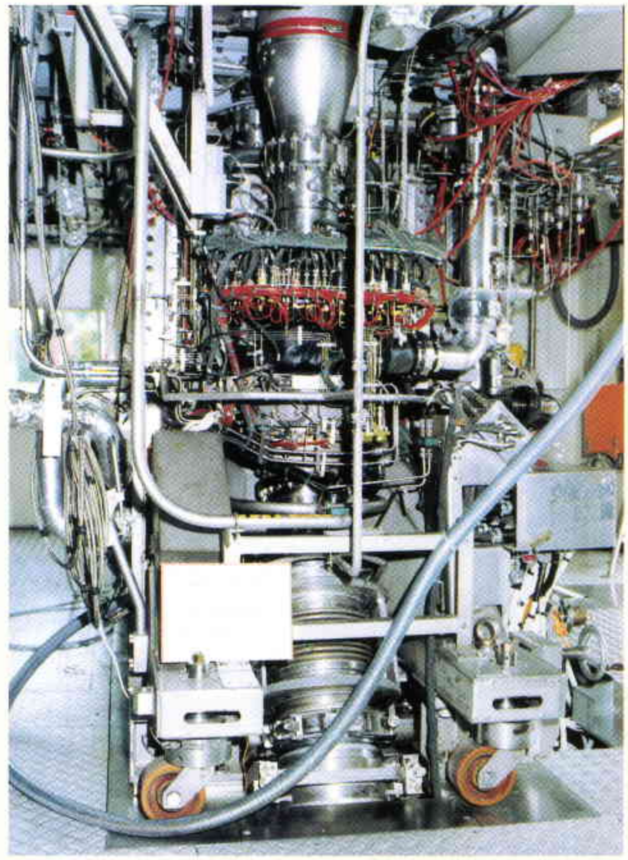

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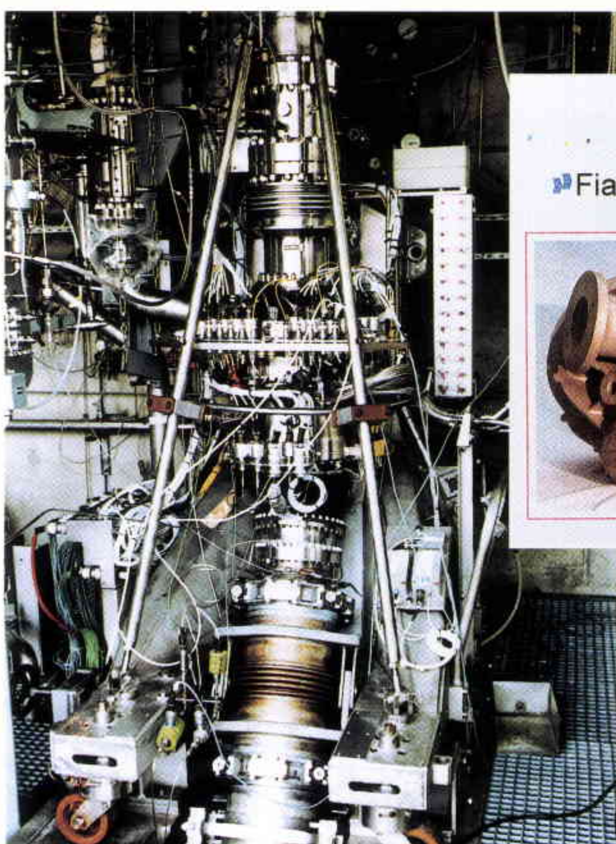

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Figure 1. The Vulcain-2 engine mock-up
Figure 2. The hydrogen turbopump at the PF52 test facility

Figure 3. The oxygen turbopump at the P5 test facility

Figure 4. Oxygen turbopump components

The 20% thrust increase sought from the Vulcain-2 engine implies a 25% increase in the power of the hydrogen turbine, which corresponds in turn to a 9% rise in hydrogen flow through the combustion chamber. This higher flow rate is achieved via a 16% hydrogen inlet pressure increase, driving the pump at a rotation speed of 35 680 rpm. The 16% higher hydrogen turbine inlet pressure is generated with a 22% higher hot-gas flow from the gas generator, satisfying at the same time the 30% rise needed from the oxygen turbine. These new gas-generator performance characteristics are the result of using 72 injectors instead of 60, doing away with the high-frequency absorber to make room for the 12 extra injectors.

The test campaign for the hydrogen turbopump and the gas generator began with the 'Bilan Technique' (BT) held on 8 September 1997, and ended with the 'Commission de Revue d'Essais' on 20 February 1998. These tests demonstrated good turbine and pump behaviour at the extreme limits of the operating envelope. The latter was characterised by a speed of 40 700 rpm, developing a power of 21 MW at a hydrogen flow rate of 52.8 kg/s, compared with the nominal operating parameters of 35 680 rpm, 14.29 MW and a hydrogen flow of 44.9 kg/s. This not only demonstrated the stable behaviour of the gas generator system, but equally importantly also confirmed a comfortable margin compared with the specified needs.

On the oxygen-turbopump side, the turbine's elements have been tested under both cold and hot conditions, the pump inducer has been tested on a water test facility to verify the pump's characteristics with water instead of liquid oxygen, and the pump itself is currently undergoing cavitation testing. The first complete turbopump was delivered at the end of July 1998 for the liquid-oxygen test campaign. The first oxygen turbopump for the engine test campaign is planned to be delivered by 15 December 1998.

Manufacture of the Vulcain-2 divergent is in progress and the first unit will be delivered in March 1999 for the engine test campaign. Delivery of the thrust chamber is scheduled for 30 November 1998.

Table 1. Accelerated Ariane-5 Evolution planning

ID	Task Name	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
1	**Ariane 5 Evolution**										
2	System										
3	**EPC**										
4	Stage development										
5	**Vulcain2**										
6	design										
7	1 st engine manufacturing										
8	TPLH2 tests										
9	TPLOX tests										
10	Engine tests										
11	**EAP**										
12	**Welding**										
13	Feasability,preliminary design										
14	Investments										
15	Qualification test										
16	**S1 overloading**										
17	Development										
18	ARTA test										
19	**First Flight A5E**										
20	**Sylda5**										
21	Development										
22	First Flight V504										

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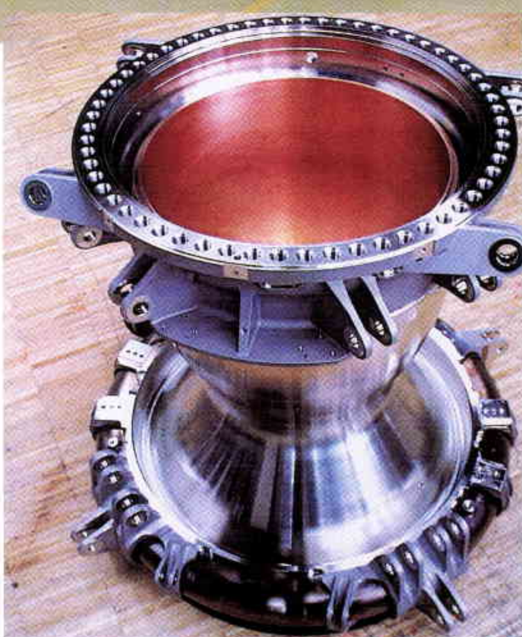
Figure 6. Vulcain and Vulcain-2 nozzle extensions in the Integration Hall

Figure 7. The complete thrust chamber

Figure 8. Sylda-5 and Speltra in the Integration Hall



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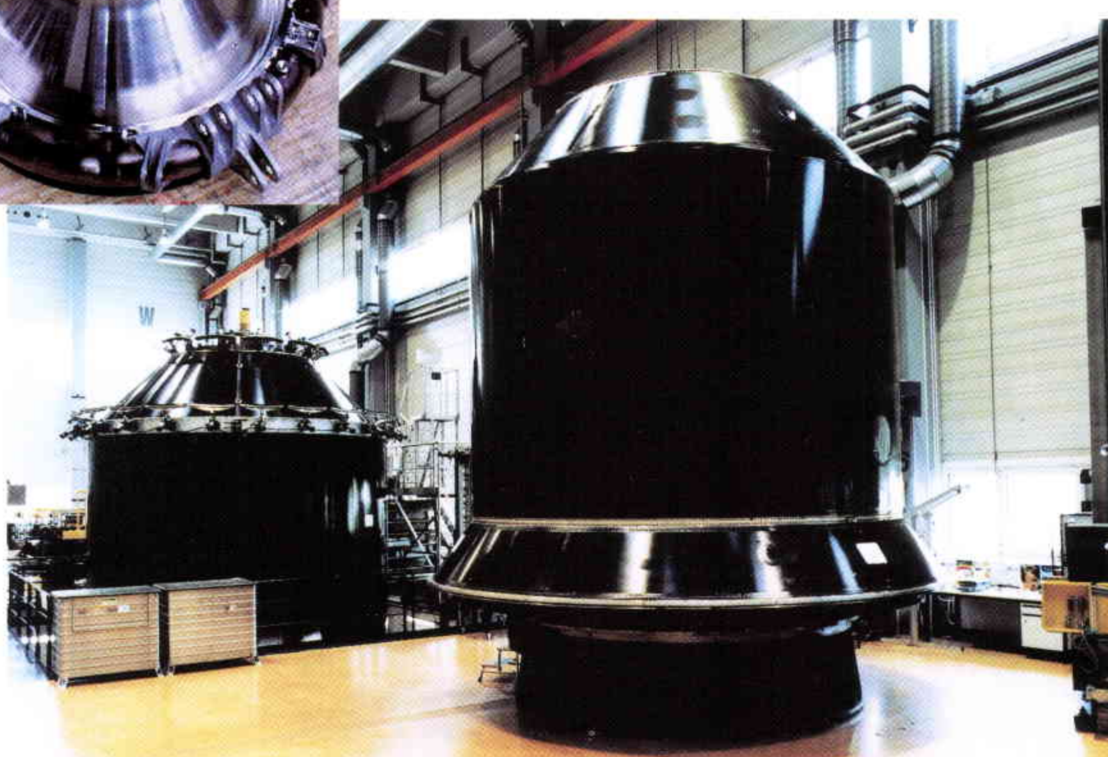

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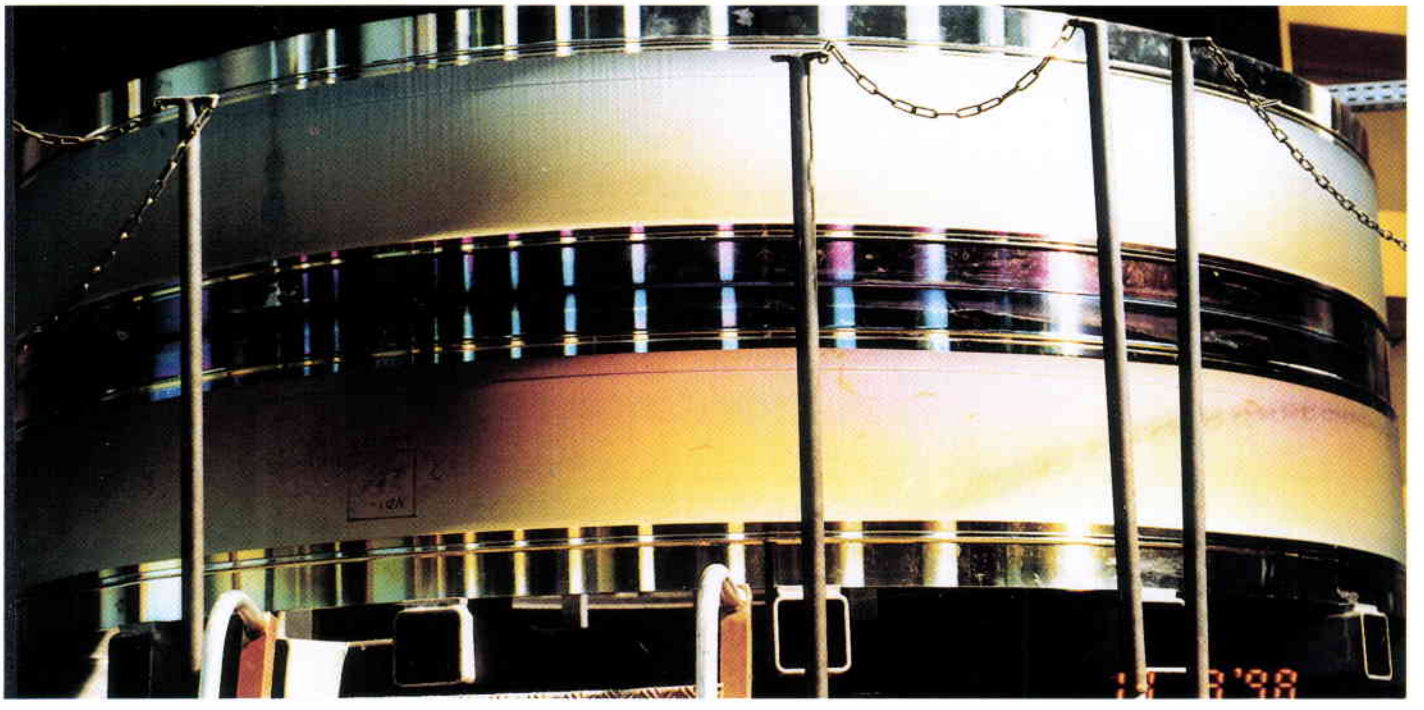


Figure 9. Welded joints of cylindrical sections of booster segment (full-scale feasibility demonstration)

Work on the solid-booster welded barrel sections has consisted of feasibility studies and the testing of the welding processes. The segments to be made up of welded sections have been defined and the production tooling changed accordingly. The feasibility of the welding and the checking of critical mechanical characteristics were demonstrated by testing at reduced scale. The full-scale demonstration testing was completed in time for the Preliminary Design Review, scheduled for October 1998. This will be followed by the sanctioning of investment in the necessary production tools. Based on the revised development timetable, the first Ariane-5E solid-rocket motor components will be delivered in June 2001.

The complete development of the Sylda-5 structure for the Ariane-5E dual-launch system formed part of the initial Preparatory Programme, thereby avoiding the need to divide the work into phases. This was feasible both because of the short development time needed and the fact that the changed system could easily be put into production independently of other changes to the Ariane-5E launcher.

The Qualification Commission, meeting in October 1998, accepted the first unit and Sylda-5 will be used for the first time on flight Ariane-504 at the beginning of 1999.

Conclusion

As we hope the above brief summary has demonstrated, work on the Ariane-5 Evolution Programme has been proceeding apace since formal endorsement of the Programme at the end of 1995. The decision early in 1998 to speed up the Programme has meant the introduction of a new development plan, with major impacts on both development and production activities. Nevertheless, with the cooperation and support of our industrial partners, production work on the critical Vulcain-2 engine has been advanced by two months, allowing the engine test campaign to be completed by the end of 1999, to be compatible with the proposed new target flight date for the first Ariane-5E of May 2002. Part of the time-saving on the Vulcain-2 engine development programme is being achieved by using two test facilities in parallel, helped by the industrial contractors accepting to deliver equipment about two months earlier than originally foreseen.

Possible Future European Launchers – A Process of Convergence*

C. Dujarric
Directorate for Launchers, ESA, Paris

The FESTIP system studies were drawing to a conclusion at the end of 1998 and the main findings are outlined in this article. The concept recommendations issued to guide the definition of tasks for the Future Launchers Technologies Programme (FLTP), which is expected to take over European activity in this field from 1999 onwards, are also discussed and put into context.

Introduction

Europe has so far responded to the changes in the launcher market by applying an evolutionary approach to its Ariane family of expendable launchers. Successive launcher versions have been developed which have progressively integrated the best European technologies available into a proven system architecture. The most recent member of the family, Ariane-5, is now entering commercial service and will keep Europe competitive in the short term. To this same end, improvements to Ariane-5 are already being planned that will make it even more powerful, more flexible, and less costly (see the article on Ariane-5 Evolution, in this Bulletin).

The same kind of approach is being followed in the USA with the EELV, but they are also striving towards a breakthrough with reusable launchers. Their goal is to drastically cut launch costs, and their hope is to make space access a routine operation. It is therefore extremely important that Europe establishes its approach to reusable launchers as soon as possible and prepares itself technologically to take up this new challenge. It was for that purpose that the Future European Space Transportation Investigations Programme (FESTIP) was established in 1994, with four primary goals:

- to determine which launcher system concepts could become technically feasible for Europe in the near future
- to check whether these launchers would be commercially attractive, and to assess their development costs
- to identify which technology developments would be required to pave the way for these launchers in Europe
- to already start technology development in those areas in which the technical requirements are common to most future launcher concepts, such as structures, materials, aerodynamics, propulsion, and heat management.

FESTIP system requirements

The choice of concept will be very dependent on the top-level requirements placed on the future launchers. There may be particular European requirements that cause our choice to diverge from the American, Russian, or Japanese preferences. The top priority for Europe is to preserve its competitiveness on the launchers market in the medium term, and consequently the initial version of the Future European Launcher must be designed for commercial missions. Certain design constraints associated with governmental missions (e.g. missions to the Space Station, man on board) should not be imposed on the Future European Launcher because that would penalise its commercial competitiveness. In addition, payload recovery from orbit back down to Earth is not yet seen as a significant commercial market demand.

The top-level system requirement is therefore to obtain the lowest possible specific recurrent launch cost, well below what can be achieved through improvements to expendable launchers. Reusability is seen as a means of achieving this reduction, but not as a requirement in itself. Semi-reusable compromises are therefore possible.

It is difficult today to predict the launch market prevailing in 20 to 30 years' time. As it is planned to start development of the Future European Launcher no earlier than 2007, it is not realistic to start investigating a single preferred configuration in detail at this stage. Nevertheless, we still need to define accurately now the critical technological requirements that will enable these future launchers to be realised.

* Based on a presentation made at the Third European Symposium on Aerothermodynamics for Space Vehicles, ESTEC, Noordwijk, Netherlands, 24-26 November 1998.

In the FESTIP system study, this apparent contradiction was solved by defining performance requirements for concept comparison purposes only, which were arbitrary but realistic. All concepts of interest were designed according to these requirements. Then families of concepts were defined with common technological needs and the most attractive families were chosen. The tolerance to performance-requirement changes of the concept feasibility and of the concept families comparison was then verified.

The following performance requirements were applied within FESTIP to the design of possible launcher concepts:

- 2 tons of payload in polar Low Earth Orbit (LEO)
- 7 tons of payload in equatorial LEO.

Two major additional system requirements were that:

- the Future European Launcher will operate from Kourou, to take advantage of the exceptional position of the European spaceport
- the launcher is required to have a full abort capability in case of single engine failure, allowing the launcher and its payload to be safely recovered for maintenance and re-launch.

Design standards were established to ensure comparability between the concepts, based on those technologies that we thought could be developed and validated in Europe by 2005. Standardised margins were defined at each system or subsystem level according to the technical uncertainties, assumptions were made regarding element reusability, and an operational scenario was established based on a very conservative assumption of 24 missions per year.

The programmatic assumptions are very important for the concept selection. By the time development of the new European launcher is assumed to start in 2007, US competitors may already be offering launch services with a reusable vehicle. Europe's technological ambitions are therefore limited by the need to have the main launcher technologies validated by 2007, taking into account present European know-how, and the expected near-term budget for technology preparation. A reasonable goal for Europe is therefore to have its future launcher operational by 2017 – 2020, with stepwise development strategies in place to preserve the more ambitious, longer term goals.

Generally speaking, the design and economic assumptions made in the FESTIP system study were much more conservative than is normally the case elsewhere for reusable launchers, in order to be sure that, even when taking such a prudent view, it is still worthwhile for Europe to be engaged in this new reusable-launcher endeavour.

Concept pre-selection

All possible reusable launcher concept families were considered equally at the beginning of the system study. However, in order to limit the scope of the study, those concepts that could not satisfy the main requirements or programmatic constraints presented above were not subjected to a concept design study within FESTIP. This was the case, for example, for:

- *Air-breathing SSTO concepts*
  These Single Stage to Orbit concepts were eliminated on the grounds of technological difficulty (as was the NASP concept in the USA).
- *Concepts using existing/ planned commercial aircraft to carry an upper stage*
  These concepts are not tolerant to performance requirement changes, because the carrier aircraft introduces a performance limitation and constrains launcher performance growth potential (even with the largest existing aircraft, the An-225, the expected payload is only 5 to 7 ton in equatorial LEO).
- *Concepts based on parachute recovery (e.g. Kistler-type concepts)*
  Parachute recovery was found to be incompatible with the masses to be recovered with the various concepts. In addition, the hazards associated with ground impacts after launch from Kourou are incompatible with the reusability objectives of FESTIP concepts, which are mandatory to ensure commercial viability.

Initial convergence for air-breathing propulsion

A large number of air-breathing engines are possible candidates for the propulsion of the first stage of a Two Stage to Orbit (TSTO) launcher. Since it was impossible to perform concept design studies for each engine type, a pre-selection was required, based on technical and programmatic considerations. In order to compare the various propulsion systems objectively, the views of European specialists in the field on the relative merits and challenges of each approach were solicited. The results of this consultation with respect to technology applicability, allowed the air-breathing propulsion technologies to be ranked according to the effort required and time to availability (Fig. 1).

Propulsion systems for which European industry has no practical experience in comparable or related systems (e.g. LACE and air collection) have not been retained. If a development decision is to be prepared for 2007, it does not seem reasonable to start now exploring a brand new (for Europe) technological field with unknown design difficulties and uncertain system benefits.

All things considered, the most realistic air-breathing engine for a near-term European TSTO launcher was found to be an advanced large turbojet for operation up to Mach 4.

Concept design studies

The FESTIP system work included the iteration of the technical features of each launcher concept until the system requirements and design standards were met with the required margins, and its design was self-consistent (i.e. no discrepancies remained between the design features assumed or calculated in each speciality). Detailed studies were performed for the following attributes: structural design, propulsion, aerodynamics, flight mechanics, design layout, mass and budgets, performances, RAMS, subsystems. In addition, the operations aspects were analysed for each concept, and detailed development and operational cost assessments were made.

Eight concepts were eventually chosen for detailed design studies. They represent all of the concept families that passed the pre-selection process and are potentially compliant with our requirements:

(i) Concept FSSC-1: SSTO rocket winged body, vertical takeoff, horizontal landing in several variants:
- staged combustion engines with 150 bar chamber pressure
- staged combustion engines with 245 bar chamber pressure
- tri-propellant engines.

(ii) Concept FSSC-3: SSTO rocket vertical takeoff, vertical landing

(iii) Concept FSSC-4: SSTO rocket winged body, horizontal takeoff from sled, horizontal landing

(iv) Concept FSSC-5: SSTO rocket lifting body, vertical takeoff, horizontal landing; two variants, with aerospike and staged combustion engines

(v) Concept FSSC-9: TSTO fully reusable rocket, vertical takeoff, horizontal landing

Technology Demand

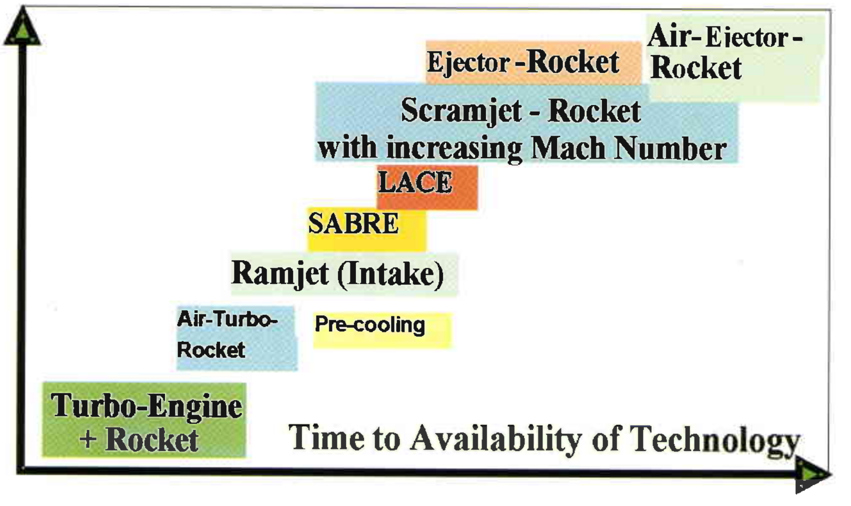


Figure 1. Technology ranking for air-breathing engines

(vi) Concept FSSC-12: TSTO fully reusable with air-breathing first stage; two variants: simple geometry and cross-feeding, advanced aerodynamics geometry

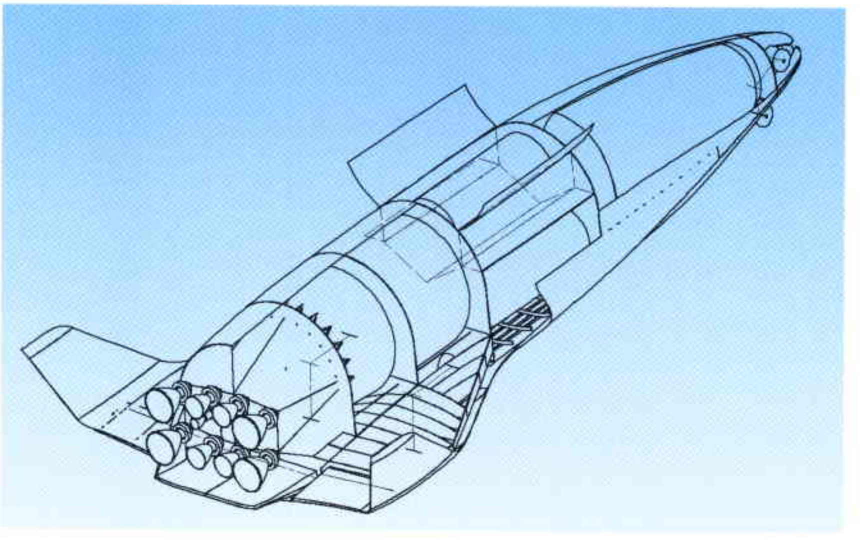
(vii) Concept FSSC-15: suborbital single-stage rocket; four variants: once-around, half around, trans-Atlantic hopper with today's technology, and trans-Atlantic hopper with advanced technology

(viii) Concept FSSC-16: TSTO rocket concept family: stepwise development from semi reusable to fully reusable; semi-reusable variants studied for several technology levels, while the fully reusable concept features a siamese geometry.

Findings for each concept

Detailed findings are available to European industry in the FESTIP reports. The major findings can be summarised as follows:

Figure 2. FSSC-1



FSSC-1 (Fig. 2)
The winged-body SSTO concept will certainly become commercially attractive at some point. For it to be technically feasible, however, a more advanced technology than presently available in Europe is required. The main problem with SSTOs is their sensitivity to the assumed technology level, making it very difficult to predict exactly when the technology level will be sufficient in Europe to design such a vehicle.

Comparing the different variants of FSSC-1,we found that:

- The performance gains obtained with higher-pressure engines do not pay off when engine reusability constraints and operating costs are considered.
- With the present study constraints, the tri-propellant engines lead to a heavier, more complex and less reusable concept, which is found not to be cost-effective.

Figure 3. FSSC-3

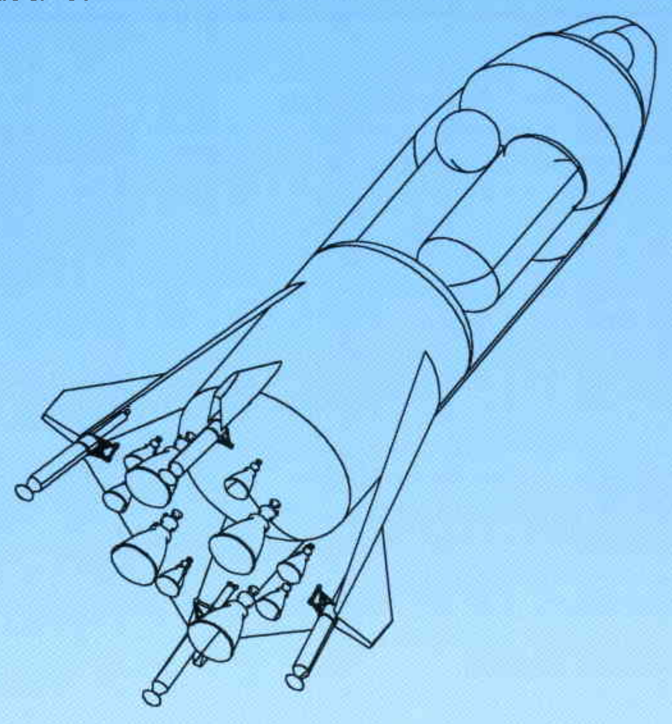
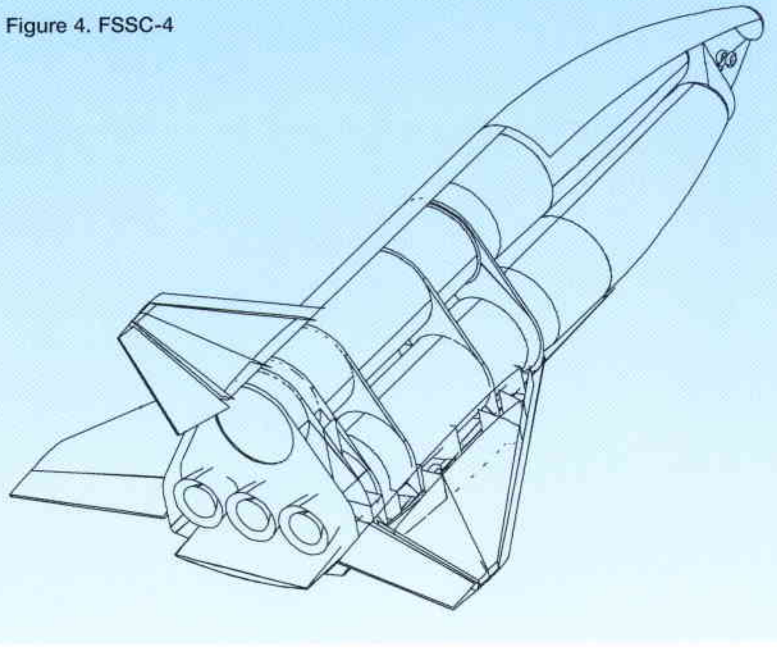


Figure 4. FSSC-4



FSSC-3 (Fig. 3)
The correct internal layout and geometry is difficult to determine for this concept, and needs to be further consolidated by wind-tunnel testing. The orbital performance of such concepts is relatively high for their dry mass, but their cross-range manoeuvring and guidance during re-entry are also problematic. The landing accuracy requires special attention, with consequences at system level. The complexity of the propulsion systems leads to high development costs (use of aerospike propulsion could have advantages). Specific launch costs are not significantly lower than for a winged-body configuration. The overall impression when comparing this vertical-landing concept with other winged concepts was that the absence of wings generates more design problems than it has advantages (this, however, is a very subjective judgement, validity of which could be limited only to the FESTIP configurations).

FSSC-4 (Fig. 4)
The feature distinguishing this concept from FSSC-1 is its horizontal takeoff from a sled. This is actually very beneficial, because it reduces the thrust required at takeoff, and therefore engine mass and cost. In addition, the classical centre-of-mass problems can be more easily solved. The use of the sled at takeoff to avoid needing heavy landing gear is seen more as a psychological barrier than a technical difficulty. This takeoff mode is very innovative for a space launcher and other innovative inherent technical features of the concept are the aeroshell structure and rear payload integration, which are beneficial in terms of reducing recurrent operating costs.

FSSC-5 (Figs. 5, 6)
The design team was disappointed to discover that this concept, inspired by the Venturestar geometry, cannot be made both feasible and economically viable with the technology presently available or foreseeable in the near term in Europe. The tanks are heavy and complex and the thrust-to-weight ratio achievable with the aerospike engine is a major unknown. An attempt was therefore made to replace the aerospike engine with conventional high-pressure staged combustion engines, but the result was not very promising from an economic point of view.

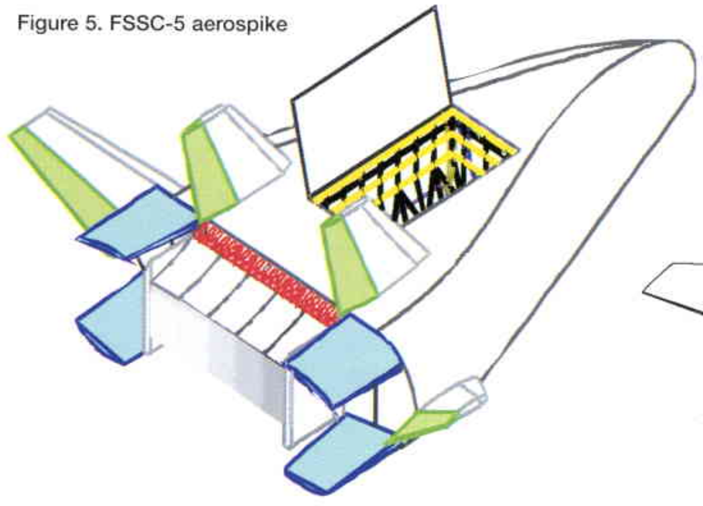


Figure 5. FSSC-5 aerospike

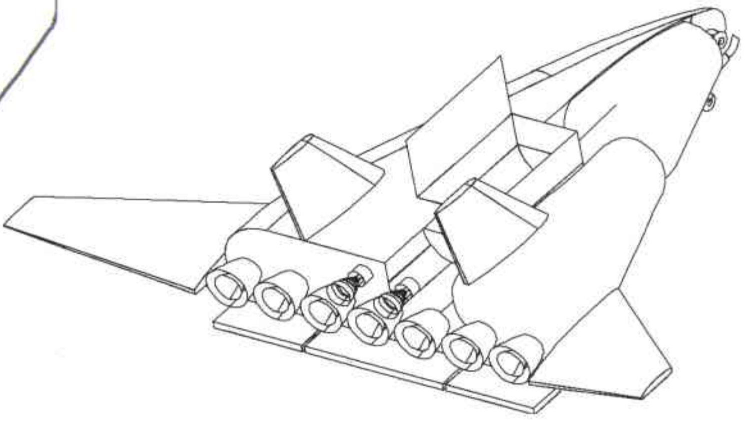


Figure 6. FSSC-5 rocket

FSSC-9 (Fig. 7)
This concept was found to be technically within reach, its design being rather conservative, but it was not fully compliant with the abort requirements. The development and operations costs were high mainly because the concept was not totally optimised. The lessons learned from this concept were integrated into the FSSC-16 design to try to obtain a more attractive TSTO concept.

FSSC-12 (Figs. 8,9)
This TSTO concept was the only air-breathing concept studied within FESTIP. The staging at Mach 4 is an optimisation to limit the technological challenge of the air-breathing engine, but creates integration problems with two stages of comparable dimensions. Robust design solutions have been found, but development costs (including the new engine) are very high, and the operating costs not very attractive. This concept has, however, the best capabilities for launch abort.

FSSC-15 (Fig. 10)
This concept is a single-stage fully reusable launcher, which does not reach orbital velocity. Its ascent phase is immediately followed by the ejection of a kick stage which boosts the payload to its final orbit, while the reusable stage immediately re-enters. The amount of propellant required on board the launcher is therefore much lower than for an SSTO, and the concept yields higher performances and is more robust to technological assumption uncertainties. Several variants of this sub-orbital concept have been studied, with the following results:

- The once-around or half-around variants are nearly the same size and involve the same technological challenge as the fully orbital SSTO. Consequently, they can be considered particular operating modes of a full SSTO concept, offering increased performance capabilities.
- The trans-Atlantic hopper seems very attractive from a development and operational cost point of view. This concept is a specifically European option, as its feasibility relies on the availability of potential landing sites in ESA Member State territories at the right geographical locations around the world. Technical feasibility seems to involve no fundamental difficulties, assuming only very limited improvements to today's European know-how. More advanced technologies can be integrated later for performance improvement.

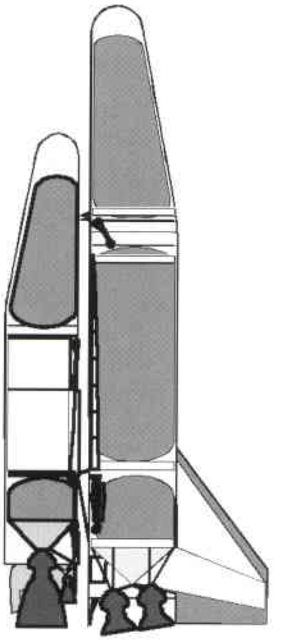


Figure 7. FSSC-9

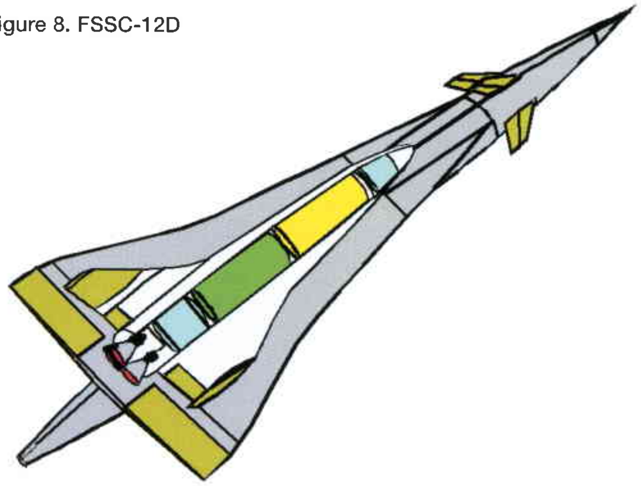


Figure 8. FSSC-12D

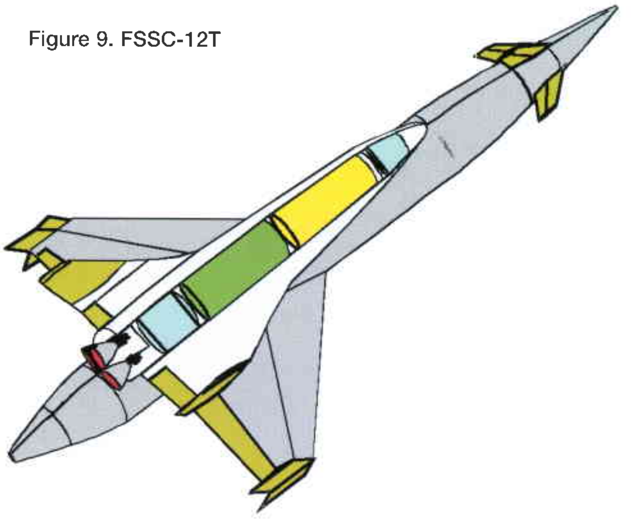


Figure 9. FSSC-12T

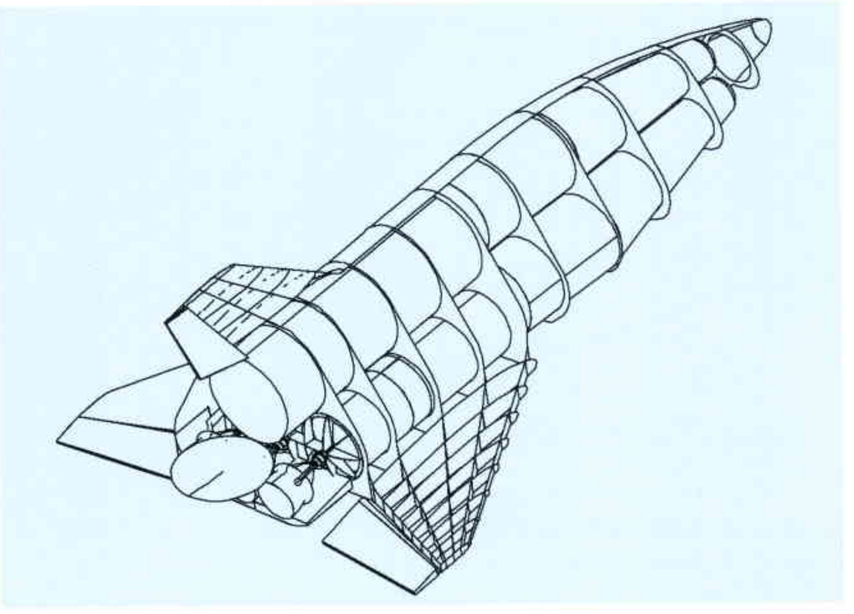


Figure 10. FSSC-15

FSSC-16 (Figs. 11,12)
The semi-reusable version of this concept could become feasible in the near term. However, the assumed use of an Ariane-5 core stage imposes performance levels comparable with Ariane-5. The double launch may not be the optimal strategy for a reusable launcher, and its very high level of performance may still be inadequate for constellation replenishment missions. Improved adaptability of the concept to changing mission requirements calls for a new expendable stage, and then the development costs need to be reassessed. The projected operational costs show a moderate improvement with respect to present expendable launchers. The fully reusable version can be developed at a later stage, using the first stage developed for the semi-reusable version. More advanced technologies will be required, however, to achieve a fully reusable concept able to reach a stable orbit. It is still unclear in how far the siamese concept can be applied, since it puts an additional constraint on the performance levels achievable in the long term.

Concept selection criteria; global comparison and preferred concept families
The selection criteria for the concepts to be studied further during the FLTP are:
- Concept technical feasibility in Europe, assuming an affordable technology preparation phase until the planned development decision in 2007.
- Affordability of the concept development (using Ariane-5 as a comparative reference).
- Recurrent-launch-cost projections compared to competitors.
- Adaptability of the concept to the potential evolution in market needs.

Application of these criteria to the FESTIP concepts leads to the following conclusions:

With respect to technical feasibility:
Some comments have already been given for each individual concept, but the overall conclusions are as follows. The technological challenges are high for all SSTO concepts compared to present European know-how, and there is considerable uncertainty regarding the

Figure 11. FSSC-16ASR

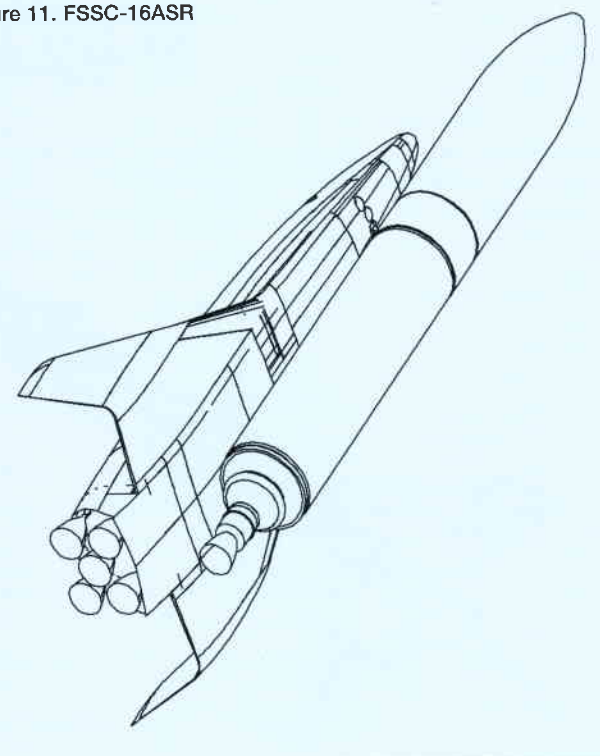
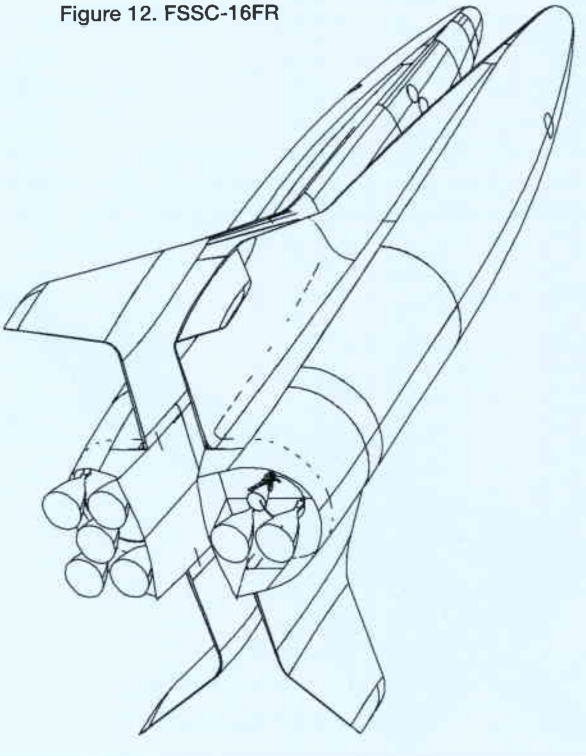


Figure 12. FSSC-16FR



final size feasible for such vehicles. It was concluded that Europe could not prepare the technologies required to start the development of an SSTO by 2007 within a reasonable budget.

A high-pressure (245 bar) staged combustion engine meeting the 60-mission reusability objective was also found to be an unreasonable target for Europe within the time constraints. Even a 150-bar chamber pressure engine was considered challenging. The most conservative approach is to adapt Vulcain engines for reusability.

With respect to affordability and cost-reduction perspectives:
A quality index proportional to the inverse of the product of specific launch cost into equatorial orbit and concept development cost, as shown in Figure 13, gives an idea of the relative economic attractiveness of the various concepts: the higher the index, the more attractive the concept from an economic point of view.

As can be seen from Figure 13:

- The air-breathing TSTO concept, although technically feasible, is not competitive.
- Semi-reusable concepts are of interest when compared to the SSTO concepts, since their higher operational cost is compensated by a lower development cost.
- The suborbital-hopper concepts are particularly interesting because they combine a low development cost and a low specific launch cost. They therefore achieve a better rating than any of the SSTO concepts.
- TSTO Concept 9 was insufficiently optimised, which explains its very poor rating. The lessons learned from that concept did, however, allow better optimisation of TSTO concept 16 FR, which achieved a better rating, but still below those of SSTOs.
- Concept 5 is an exception among the SSTOs: its poor rating results from the design problems described above.

Figure 14 shows a relative qualitative evaluation of uncertainties in design, and hence in concept costings, resulting from:
- the inherent sensitivity of each concept to the design parameters
- the uncertainties due to the amount of technological progress required
- the available design margins and backup options at system level.

With respect to adaptability to new missions:
All concepts can, in principle, be scaled to meet different performance requirements, with the exception of the FSSC-16 family where, for the reasons already discussed, the solution would be a new expendable stage, with the penalty of increased development costs.

Technology requirements for the FLTP
The FESTIP concepts comparison therefore shows that two families are particularly interesting, since they seem within reach technically for Europe in the medium term: the FSSC-16 semi-reusable and the FSSC-15 trans-Atlantic hopper concepts, both of which include a partial-reusability feature.

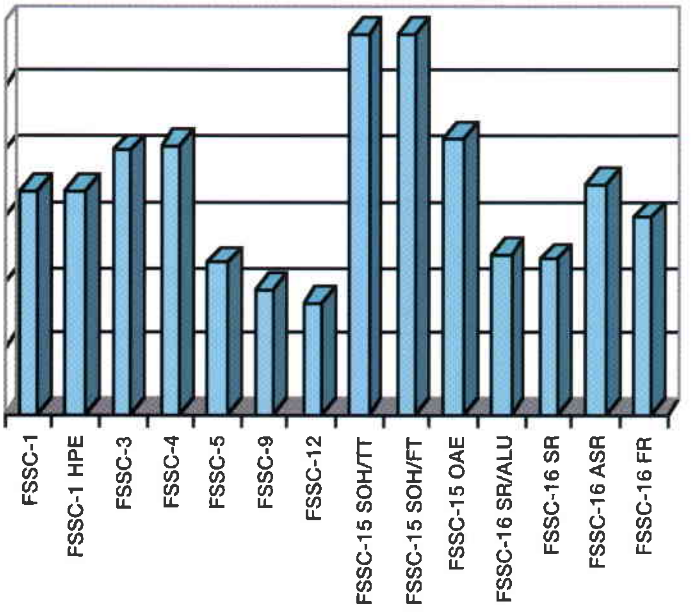


Figure 13. Economic attractiveness of the various concepts

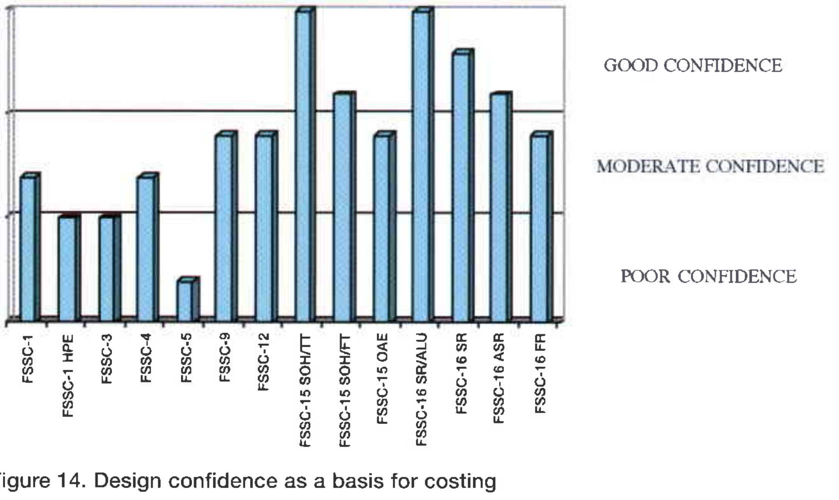


Figure 14. Design confidence as a basis for costing

The FLTP concept design effort should focus on confirmation of their economic interest and improvement of their adaptability to missions of potential interest. The FLTP technology effort should focus on the technologies needed for these two families. The detailed technological requirements for the preferred concepts are identified in a document called the 'Technology Development and Verification Plan', which proposes a development strategy, testing requirements, achievable schedule, and indicates anticipated technology-preparation costs, as well as a listing of the facilities required to support the development.

The requirements for new technologies in Europe for the semi-reusable concept mainly concern the transformation of the Vulcain motor into a reusable engine, the manufacturing of composite tanks, health monitoring, and experience in rocket-vehicle reusability.

For the suborbital hopper, the main requirements are the transformation of the Vulcain into a reusable engine, large composite primary structures, re-entry technologies (aerothermodynamics and thermal-protection systems), health monitoring, and experience in rocket-vehicle reusability. There is therefore a common core of technology requirements on which new work should be started immediately within the FLTP, while an activity is maintained over the envelope of the requirements until a definitive choice of the future launcher concept for Europe can be made.

In-flight testing requirements

In-flight experimentation, validation and demonstration will be required to gain enough confidence in the new technologies' maturity and their integration into a functional system. Before committing to the Future Launcher's development, it will be necessary to confirm via relevant practical flight experience that the anticipated launch-cost reductions are not unrealistic. The key objectives for the in-flight experimentation are thence:

1. To provide visible and indisputable evidence of European industry's ability to design and manufacture a test vehicle with technical features similar to those of possible Future European Launchers.

2. To provide hands-on experience in the recurrent operation of a test vehicle using the key technologies required for possible Future European Launchers, and to provide operational data supporting a better assessment of the anticipated operational cost savings.

3. To place those newly developed technologies that cannot be fully validated by ground testing in a realistic working environment for their validation.

4. To motivate the European engineering teams through the near-term realisation of hardware and to offer the technology teams a challenge that is rewarded by visible in flight success.

The major constraints affecting in-flight experimentation are:

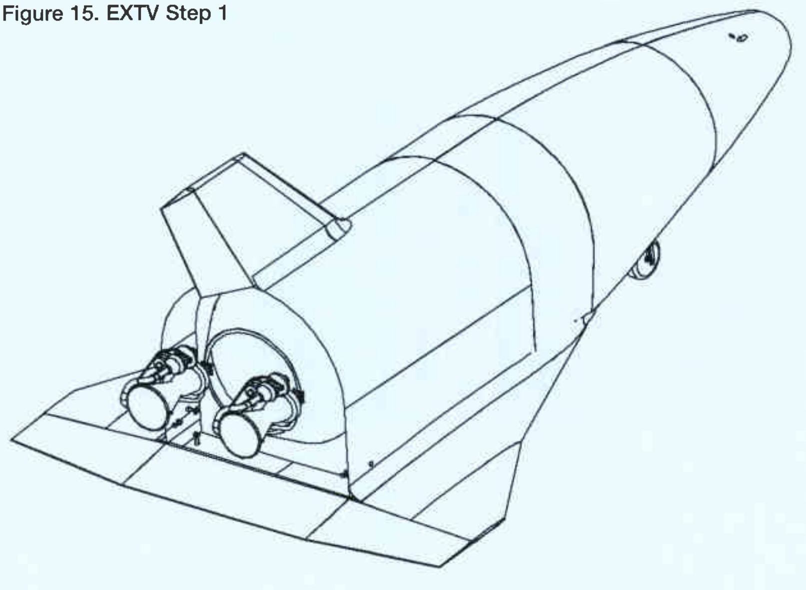
- to consolidate conclusions in time for the possible go-ahead to develop an operational launcher, a decision presently targetted for 2007
- to maintain affordability vis-a-vis the budget available for the technology development.

To comply with these constraints, a stepwise implementation is proposed:

The first step in in-flight experimentation should address those requirements that are independent of the final concept selected, which thereby constitute a common core for in-flight testing needs. The proposed European Experimental Test Vehicle (EXTV) Step 1 shown in Figure 15 can meet those requirements.

The FESTIP EXTV is a relatively small rocket-propelled vehicle (4.2 tons dry mass, 10 tons gross take-off mass), designed for frequent flights at speeds up to Mach 4. It takes off horizontally using its own propulsion, and lands horizontally. Its main purpose is to acquire experience in the recurrent use of high-speed

Figure 15. EXTV Step 1



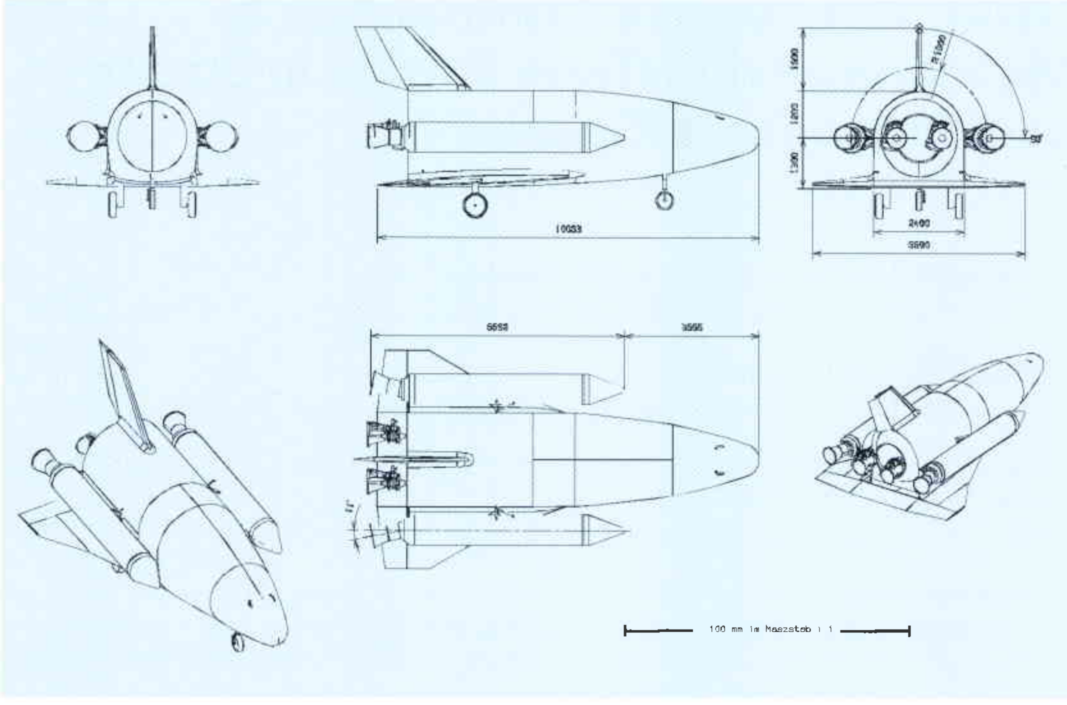


Figure 16. EXTV Step 2

reusable rocket vehicles. This know-how is urgently needed because it has implications not only for the design of future launchers, but also for our judgement as to whether their development is worthwhile. Meeting these core in-flight test needs must therefore be one of the priorities of the FLTP.

Should the suborbital-hopper finally be chosen as the preferred concept for the operational launcher, a second in-flight-experimentation step will be needed to address high-speed technologies. For this, a modified EXTV fitted with additional solid boosters and thermal-protection systems, as shown in Figure 16, can be used.

Finally, if later on for other than economic reasons the Future Launcher is required to have a full orbital capability, additional in-flight testing will be required in a third step to demonstrate a complete re-entry and a safe landing. A vehicle with a similar shape and approximately the same dimensions as the EXTV (but without main propulsion) could be placed on top of a Soyuz launcher to meet these additional needs.

Conclusion

The FESTIP system study has allowed us to identify which families of concepts are most likely to enable Europe to retain its commercial competitiveness on the World launch market. We have concluded that the concept families that could be technically within Europe's reach include partial reusability features, and that these families have the potential to yield commercially competitive launchers. Two options will be analysed further during the FLTP: the semi-reusable TSTO and the suborbital hopper.

The technology requirements for these concepts have been identified and the development needs are rather modest and therefore consistent with the expected funding until the final decision on the Future Launcher's operational development, by 2007. In-flight experimentation for reusable rocket operation in a relevant flight domain is mandatory before this decision can be made. These activities together form the nucleus of the Future Launchers Technologies Programme (FLTP) to be started in 1999. esa

GOMOS: Envisat's Contribution to Measuring Long-Term Trends in Ozone and Other Trace Gases

G. Ratier, G. Levrini, A. Popescu & T. Paulsen
ESA Directorate for Application Programmes, ESTEC, Noordwijk, The Netherlands

C. Readings & J. Langen
ESA Directorate for Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Atmospheric chemistry is one of the key mission targets for the Envisat satellite, being prepared for launch in 2000. With the recent delivery of the GOMOS instrument (manufactured by Matra Marconi Space in Toulouse) to the Prime Contractor for integration into the satellite flight model, a major programme milestone has been achieved. Given the outstanding performance of the instrument that has been demonstrated in testing, GOMOS can be expected to deliver high-quality observations of ozone and other trace gases from space.

GOMOS on Envisat

General background

GOMOS (Global Ozone Monitoring by Occultation of Stars) is an atmospheric-chemistry instrument that forms part of the payload of Envisat. It operates in the ultraviolet and visible and exploits a stellar occultation concept (Fig. 1) to observe ozone and other trace species, plus temperature and water vapour. The main role of GOMOS will be the observation of ozone in the stratosphere and the monitoring of trends.

Atmospheric ozone is the main absorber of ultraviolet radiation from the Sun. Without ozone, life as we know it would not exist. Any substantial reduction in ozone would lead to damage to crops and human health. The radiation absorbed by ozone is responsible for skin-cancer in humans. Furthermore, the absorption of sunlight by ozone in the stratosphere is a source of heat, so that any reduction in levels would impact on our climate.

The level of ozone in the stratosphere represents a balance between ozone production and destruction. In the mid-upper stratosphere, ozone is formed by the dissociation of molecular oxygen by ultraviolet sunlight, followed by a reaction between the atomic oxygen and molecular oxygen. It is removed by a variety of catalytic cycles involving the oxides of hydrogen, nitrogen, bromine and chlorine.

Most of the cycles involving the oxides of hydrogen and nitrogen arise naturally, though there is some concern about aircraft emissions. This may be contrasted with the situation for stratospheric chlorine and bromine, where only small amounts arise from natural sources; in this case most is of anthropogenic origin, e.g. refrigerators, fire-extinguishers and agricultural fumigants.

Over the Antarctic, ozone depletion occurs in the lower stratosphere where the catalytic cycles – referred to above – cannot operate because there is too little atomic oxygen present. The situation is similar in the Arctic, although there reductions in ozone are masked to a certain extent by atmospheric motions. Reductions in ozone levels are also observed at mid-latitudes, but the mechanisms responsible are not clear.

In addition to the 'gas-phase chemistry' (above), it is now known that 'heterogeneous chemistry', involving aerosols and cloud particles, plays a key role in stratospheric ozone depletion. This type of reaction occurs in polar regions on polar stratospheric clouds (PSCs) and throughout the lower stratosphere on sulphate aerosols. Also important is transport since, because of the finite lifetime of ozone in the stratosphere, its distribution is determined by a combination of transport and chemistry.

Scientific issues

In many of the areas listed above, there are important questions that still need to be answered. GOMOS should bring significant contributions in many of these areas.

Stratospheric ozone content has been declining worldwide since the 1970s. Apart from the spectacular Antarctic ozone hole, there has been a very worrying decline at

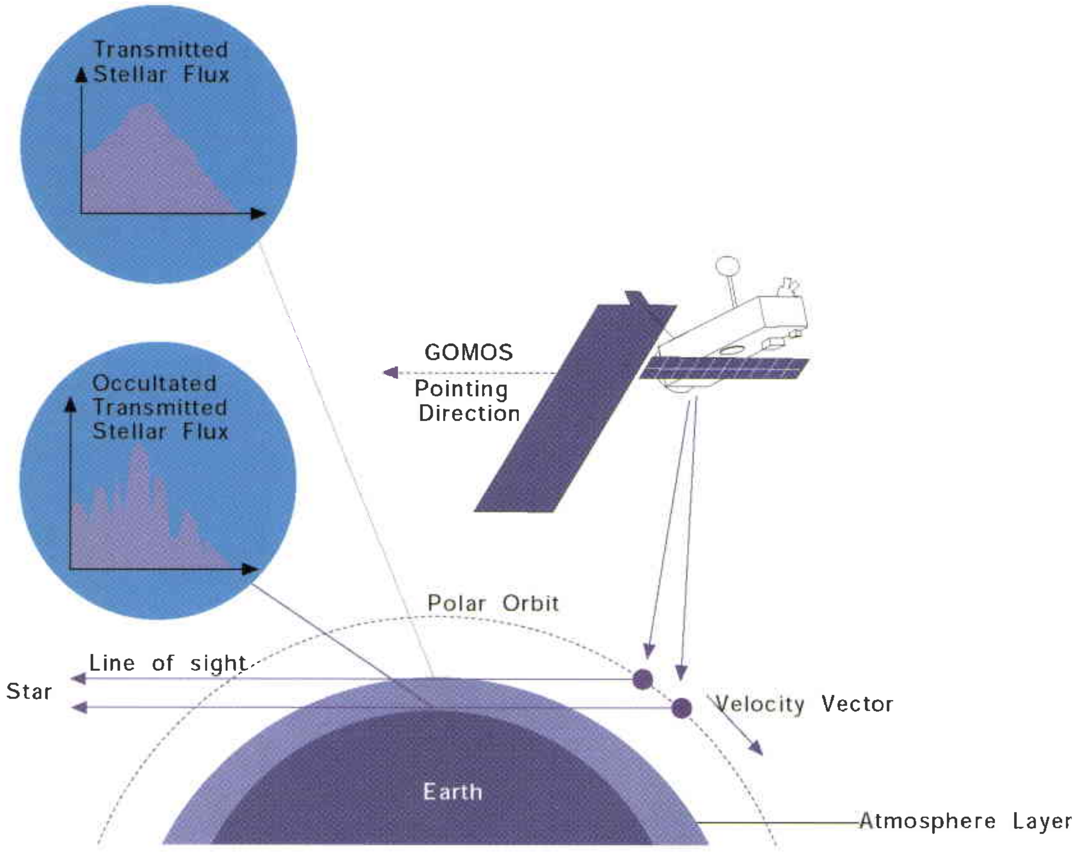


Figure 1. GOMOS measurement principle

northern mid-latitudes, above Europe and other heavily populated areas. Here total ozone is currently declining by between 4 and 8% per decade. Although measurements suggest that most of this decline ozone occurs in the lower stratosphere, in agreement with current hypotheses, the observations of trends in ozone profiles lack sufficient accuracy to make definitive statements. Worse, current models of stratospheric chemistry do not predict the magnitude of the observed decline in levels of ozone.

It is now clear that conditions favourable to ozone loss are also found most years within the Arctic vortex but, unlike its southern counterpart, this vortex is highly variable and very mobile. Further study of the Arctic is necessary to investigate whether this is a consequence of natural variability, or whether it is indicative of a trend towards colder winters, in which case Arctic ozone depletion will become more severe. It is also essential to clarify the mechanisms underlying the decreases in ozone in the Arctic and at mid-latitudes. The role of heterogeneous chemistry is not clear, nor is that of ozone chemistry in the mesosphere.

Stratospheric circulation is characterised by ascent in equatorial regions, poleward transport and descent at high latitudes. Extra-tropical pumping, as well as planetary waves, imposes upward equatorial motion and the global injection of tropospheric air into the stratosphere. The main mechanism involved is deep convection with cumulo-nimbus clouds extending to the tropopause. However, the minimum in the water-vapour mixing-ratio profile (hygropause) is not encountered at the tropopause, but a few kilometres above it. The reason for this difference is not fully understood.

Another important mechanism is the meridianal transport of air, depleted in ozone, from high latitudes in the form of polar filaments formed at the edge of the polar vortex. The contribution of this mechanism to observed trends in ozone at middle latitudes is not clear. Neither is the role of turbulent layers associated with the breaking of gravity waves. These waves are generated in the troposphere above mountains, above convective clouds and in the jet stream. They are the main controller of mesospheric circulation and may also play a role in stratospheric circulation, but our knowledge is poor.

Water-vapour concentrations in the lower stratosphere appear to have increased between 1981 and 1994, but the level of increase is larger than expected. This must be resolved as water vapour is a potent greenhouse gas and so the amount present affects the Earth's radiation balance. A high-resolution global climatology of humidity in the upper atmosphere is required to clarify the impact of these changes in water vapour on climate.

Also of some concern are polar mesospheric or noctilucent clouds, which are cirrus-like clouds of small particles, confined to the altitude range of 82 to 85 km, where the atmospheric temperature is at a minimum (i.e. the mesopause). It is argued that the appearance of these clouds is strong evidence for global change, but again our knowledge of them is quite limited.

The scientific requirements

One of the key requirements associated with GOMOS's monitoring role is the long-term accuracy of its measurements over the four years of the Envisat mission. Another major requirement is good vertical resolution, which should be as small as 2 km. Finally, good daily geographical coverage at all latitudes is needed to allow a proper understanding of the dynamics of the processes.

GOMOS must be able to detect the spectral signatures of all the target molecules (Table 1). For ozone, a broad spectral range (250 – 675 nm) is required, but it is also necessary to measure the temperature locally as it has an impact on the ozone absorption. This particular problem is addressed by observing the A-band of oxygen (at 760 nm).

All of the other target species lie within the range 250 – 800 nm, with the exception of water vapour, for which it is necessary to extend the spectral range. Hence, it has been decided that GOMOS should cover the spectral range 250 – 952 nm. Gaps in coverage within this overall range have been limited to regions devoid of relevant spectral information. Furthermore, to ensure that ozone spectra are not corrupted by the spectra of other species, a spectral resolution of better than 1 nm is required. For oxygen and water vapour, the spectral signature varies on a scale smaller than 1 nm, calling for a resolution of better than 0.2 nm, but only over a limited part of the spectrum.

Finally, it is necessary to consider the signal-to-noise ratio. This has to be specified for a given integration time linked to vertical resolution. Simulations have shown that, in order to retrieve ozone densities to an accuracy of better than 1% over the relevant altitude range, a signal-to-noise value of 100 is required for each 0.3 nm spectral pixel in the ultraviolet/visible. In addition, account has to be taken of small-scale structures (or scintillation) in the temperature/density profile, which induce rapid variations in the intensity of signals observed by GOMOS.

The GOMOS instrument

The concept

The original GOMOS concept was proposed in the late 1980s by a team of European scientists led by Service d'Aéronomie (CNRS) and the Finnish Meteorological Institute. The instrument exploits star occultation (Fig. 1), which is inherently self-calibrating and well-suited to meeting the main scientific requirements.

From its polar orbit, GOMOS observes stars whose lines-of-sight are tangential to the Earth's limb. For each individual star, the spectrum measured outside the atmosphere is compared to the spectrum seen through the atmosphere as the star sinks below the horizon. The difference reveals the presence of ozone and other trace gases. Occultation has already been demonstrated in space using the Sun as light source, but geographic coverage was limited. The specific advantage of GOMOS, related to the large number of observable stars, is that it combines the advantages of high radiometric accuracy with good Earth coverage.

Table 1. Main GOMOS products and potential applications

Product	Potential Application
O_3, NO_2, NO_3, H_2O, O_2, air (horizontal column densities)	Higher order GOMOS products Monitoring of trends
Aerosol extinction coefficients	Aerosol research Atmospheric-chemistry research
O_3, NO_2, NO_3, H_2O, O_2, air (vertical density profiles)	Atmospheric-chemistry research Monitoring of trends
Temperature and density profiles Turbulence product: High-resolution T and density	Atmospheric research and GOMOS Atmospheric-dynamics research

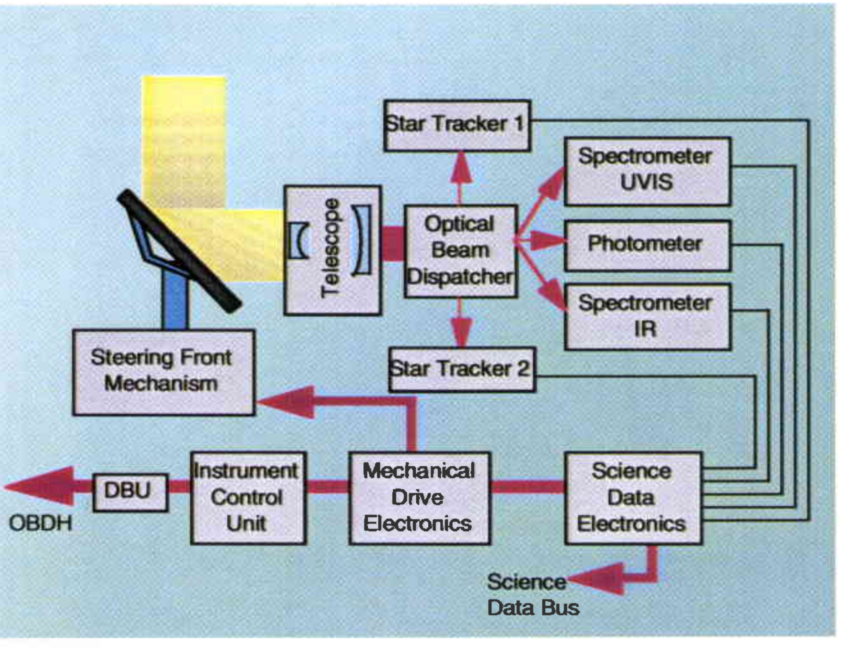


Figure 2. GOMOS functional block diagram

The design

A functionality of GOMOS is shown in Figure 2. The instrument is based on a 20 cm x 30 cm Cassegrain telescope, which simultaneously feeds, through an optical beam dispatcher placed at its focal plane, an ultraviolet/visible medium-resolution spectrometer (for signal measurements in the Huggins and Chappuis bands: 250 – 675 nm), a near-infrared high-resolution spectrometer (for O_2 and H_2O, around 760 and 930 nm, respectively). These are complemented by two fast photometers, operating in the 470 – 520 nm and 650 – 750 nm spectral bands, with a 1 kHz sampling rate, for observing scintillation.

By using a large steerable flat mirror (30 cm x 40 cm) in front of the telescope (Fig. 3), GOMOS is able to acquire and track stars down to magnitude 5 over a very large angular range (100 deg in azimuth). A complex star-tracking system – using two redundant star trackers – allows the star to be tracked within 20 µrad during the 50 sec of a typical scan. The star trackers are able to operate under both day and night conditions, i.e. over both the bright and the dark limb.

GOMOS will provide data at a constant rate of 222 kbit/s during nominal operation. The instrument weighs 163 kg and its power consumption is 146 W. Its main performance characteristics are summarised in Table 2.

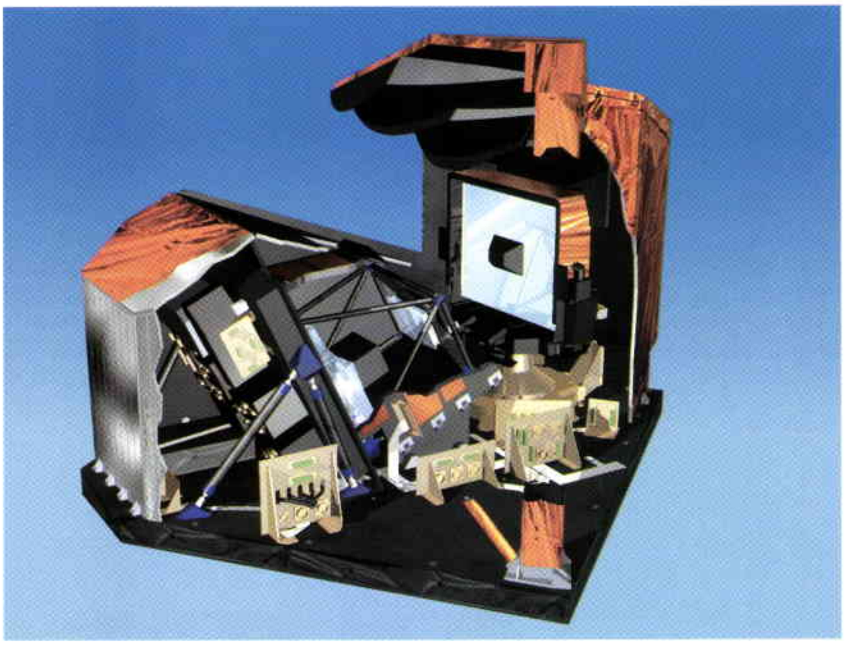


Figure 3. Cut-away drawing of GOMOS

Table 2. GOMOS instrument performances and major technical challenges

Requirements	Typical GOMOS Performance	Design Driver for
Number of occultations per orbit (45 on average)	~820 000 occultations during 4 year mission	Lifetime of pointing mechanism
Wide angular coverage	-10 to +90 deg. w.r.t flight direction	Large field of view of pointing mechanism
Altitude resolution/accuracy	1.7 km / 30 m pointing stability better than 20E-6 rad	High angular pointing accuracy (pointing servo electronics)
Spectral range of UVIS spectrometer	250 – 675 nm	High-transmission optics, high detector sensitivity in the UV
Spectral resolution accuracy	0.89 nm in UVIS; 0.12 nm in IR1/IR2	Detector size, grating and pointing
Photometer frame rate	1 kHz in the spectral range: 470 – 520 nm / 650 – 700 nm	Fast, high-sensitivity detectors

To realise such a performant instrument, specific technical developments have been necessary. State-of-the-art technology has been achieved in particular for the CCD manufacture (EEV) and for the design of the steering mechanism by Matra Marconi Space in Bristol (Fig. 4). The entire instrument has been developed by a consortium led by Matra Marconi Space in Toulouse, under Dornier's supervision. The flight model was delivered to the Envisat mission prime in October 1998, for integration into the flight-model satellite at Matra Marconi Space in Bristol.

The operation of GOMOS

The main mode of operation is the 'occultation' mode. Following a sequence of star observations uplinked to the satellite by the Envisat flight-operations control centre, GOMOS will acquire and track stars as they set through the atmosphere. The sensors are operated in such a way that the star and the surrounding background light are recorded simultaneously. The detector is fully programmable in order to ensure optimum alignment over the instrument's lifetime and the best possible signal-to-noise ratios.

In addition to this occultation mode, the GOMOS instrument's design also supports three other observing modes for in-orbit monitoring of performance and the re-calibration of the instrument's performance parameters.

GOMOS mission planning

GOMOS mission planning has been optimised to maximise the instrument's scientific return. The mission objectives can be grouped under two general headings (Table 3):

- 'Long-Term Objectives', which are specific to the atmospheric-chemistry objectives of GOMOS.
- 'Campaign Objectives', which are needed to validate GOMOS products and to compare them with the other two chemistry instruments on Envisat.

Depending on the specific mission objectives, with attached priority factors, the stars to be observed are selected from the star catalogue. The sequencing of observations is done according to the instrument's time-line capabilities. The observing schedule will be encoded as a macro-command for uploading to the satellite.

Various simulations have been performed to determine the merit functions of the different observing strategies. Figure 5 gives an example of a set of stars selected to observe stratospheric ozone over a period of 3 days near the spring equinox.

The mission-planning software is designed to include scenarios for long-term observations (over days or weeks) as well as for 'targeted' short-duration observations such as those related to a volcanic eruption.

GOMOS payload data segment

All data received on the ground are systematically processed and the following products are routinely generated within the ESA Payload Data Segment (PDS): Level-0, Level-1b (transmittance), and Level-2 (profiles

Figure 4. GOMOS telescope assembly during integration at Matra Marconi Space, in Toulouse (F)

Table 3. GOMOS science objectives

Long-Term Objectives	Stratospheric ozone monitoring
	Stratospheric chemistry: upper stratosphere 35 – 50 km
	Stratospheric chemistry: lower and middle stratosphere 15 – 35 km
	Large-scale dynamics at mid and high latitudes: polar vortex, planetary waves
	Dynamics of the equatorial lower stratosphere: dehydration
	Small-scale dynamics: gravity waves, turbulence
	Mesospheric ozone monitoring
	Noctilucent clouds
Campaign Objectives	Tangent occultation
	Validation of GOMOS products
	MIPAS and SCIAMACHY validation
	Arctic campaign
	Special events: solar proton event
	Special events: volcanic eruption
	Antarctic winter troposphere
	Stellar spectra

of ozone and other species). These products are generated in near real time (i.e. within 3 h of sensing) and then regenerated off-line using updated auxiliary data (precise orbits instead of predicted orbits, meteorological analysis fields instead of meteorological predictions, etc.).

With the exception of the quality of the auxiliary data, the algorithms used in the 'near real time' and 'off-line' processing are identical. All ESA processing centres (the Kiruna and ESRIN stations) for the near-real-time products and the German processing and archiving centre (supported by the Finnish Meteorological Institute) for the off-line products, will use the same processing algorithm, so that the user will get consistent products irrespective of the processing centre.

The ESA Level-1b and Level-2 algorithms have been defined following the Envisat Expert Support Laboratory (ESL) approach, whereby a scientific team provides support to an industrial contractor (ACRI, Sophia Antipolis, F). This scientific team includes members of the Service d'Aéronomie (Paris, F), the Finnish Meteorological Institute (Helsinki, SF) and the Institut d'Aéronomie Spatiale (Brussels, B). These algorithms have been prototyped by the ESL and then implemented, within the Payload Data Segment consortium led by Alcatel Space, by SSF Finland.

Data analysis and scientific products

Approach

The role of the GOMOS ground-segment algorithms is to convert the readings of the instrument into scientific products. Complex simulation and analysis codes have been generated for the purpose:

- A system simulator deriving the digital output of the instrument from the spectral intensity of stellar light received by GOMOS's telescope.
- A data-processing chain that performs a stepwise conversion of the ADC counts to vertical profiles of atmospheric constituents. This processor forms the central element of the GOMOS ground segment, as it will process the acquired data and generate the scientific products.

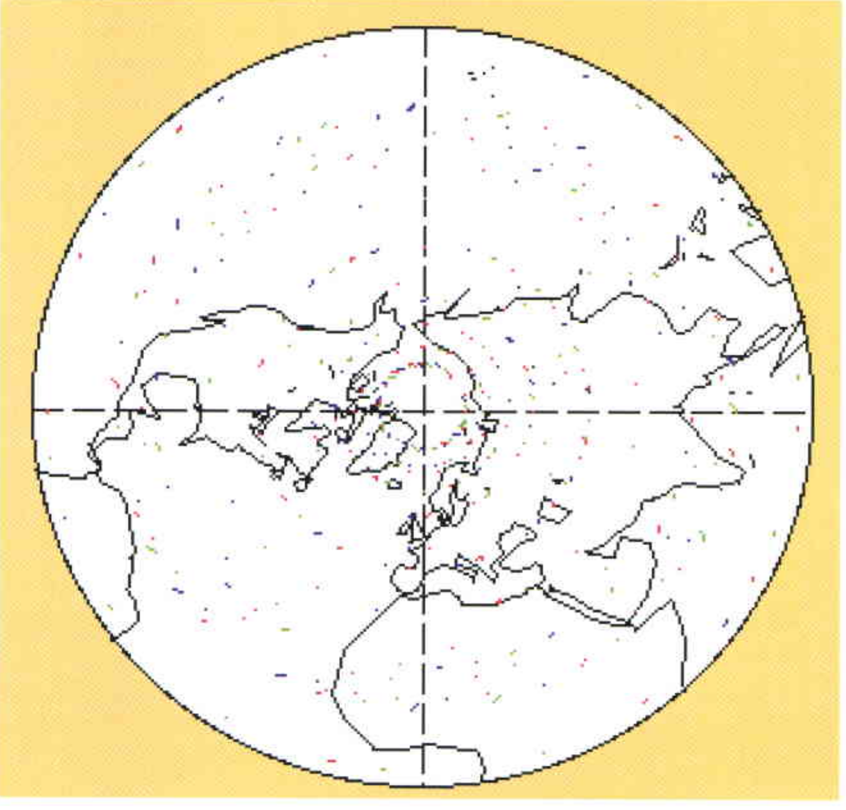


Figure 5. Locations of ozone measurements in the Northern Hemisphere after three consecutive days (around 21 March) with a specific star selection

- A calibration facility using in-flight data to update the calibration database of the data processor.

With these tools, ESA will support the data analysis up to the level of geophysical products related to a single occultation, thus covering the part that requires intimate knowledge of the instrument and of remote-sensing inversion techniques.

Scientific products and algorithms

The generation of scientific products, after low-level data handling, is sub-divided into two basic processes, namely the calibration into physical quantities (Level-1b) and the transformation into atmospheric composition parameters (Level-2).

Level-1b

The objective of the Level-1B processing is to estimate the set of horizontal transmissions using the spectra measured by the instrument during the occultation. The main processing steps will be:

- *Geo-location* providing the location of the tangent point above which the measurements are performed.
- *Wavelength resampling* to a common wavelength grid with correction for instrumental or platform pointing instabilities.
- *Correction of instrumental effects*.
- *Calculation of the transmission spectrum.* After estimation and subtraction of the atmospheric background signal, the atmospheric transmission will be calculated as the ratio of the occulted stellar spectrum to an average of several stellar spectra observed above the atmosphere ('reference spectra').

The main Level-1b scientific data handed over to Level-2 processing will therefore be the transmission spectrum, the photometer data and the geo-location for every atmospheric acquisition. The background spectra will also be made available, providing supplementary atmospheric information under bright-limb conditions.

Level-2

In the Level-2 processing, the transmission spectra will be converted into parameters representative of the state of the atmosphere. This implies taking into account three different processes:

1. Absorption by gaseous atmospheric constituents, most prominently by ozone (O_3), but also by nitrogen dioxide (NO_2), nitrogen trioxide (NO_3), oxygen (O_2), water vapour (H_2O), chlorine dioxide (OClO) and others.
2. Extinction of the stellar light by scattering from molecules (Rayleigh scattering) and from aerosol and high cloud (Mie scattering). Rayleigh scattering is well understood, but aerosol represents a considerable complication for GOMOS data analysis since its characteristic spectrum depends on droplet size distribution and chemical composition, both of which are *a priori* unknowns.
3. Refraction, i.e. bending of the light ray due to the vertical gradient in air density, and scintillation in the signal.

The analysis of the transmission spectra starts with correcting for the refractive and scintillation effects. In the next step, a 'spectral inversion' is performed whereby each of the transmission spectra is converted to a set of horizontal column densities of atmospheric constituents, i.e. the concentrations integrated along the ray's path. Finally, these horizontal column densities are converted to atmospheric concentration profiles in the 'vertical inversion', which can be visualised as 'onion peeling': once the contributions to the horizontal column of all atmospheric layers above the current one are known, they can be subtracted, and the remaining part divided by the path length through the current layer.

The time delay between the two photometer signals (red and blue) allows one to retrieve the refractivity, air density and temperature of the atmosphere. According to current simulations, these parameters could be provided with a vertical resolution of 200 m, representing a unique capability in terms of spaceborne remote-sensing experiments.

The main Level-2 data products are the horizontal column densities and concentrations of ozone, nitrogen dioxide, nitrogen trioxide, air, oxygen and water vapour, as well as the vertical profile of aerosol extinction and the high-resolution temperature profile.

GOMOS data are believed to be useful above 15 – 20 km altitude. An important feature is the high variability in precision caused by differences in the brightnesses and temperatures of the large ensemble of targeted stars. This is illustrated in Figure 6: in the lower stratosphere, the accuracy of ozone concentration is determined by the visual magnitude of the star, whilst at higher altitudes the star's temperature is more important as hot stars produce significant emission in the UV part of the spectrum.

Validation

Consistency checks on the algorithms and the

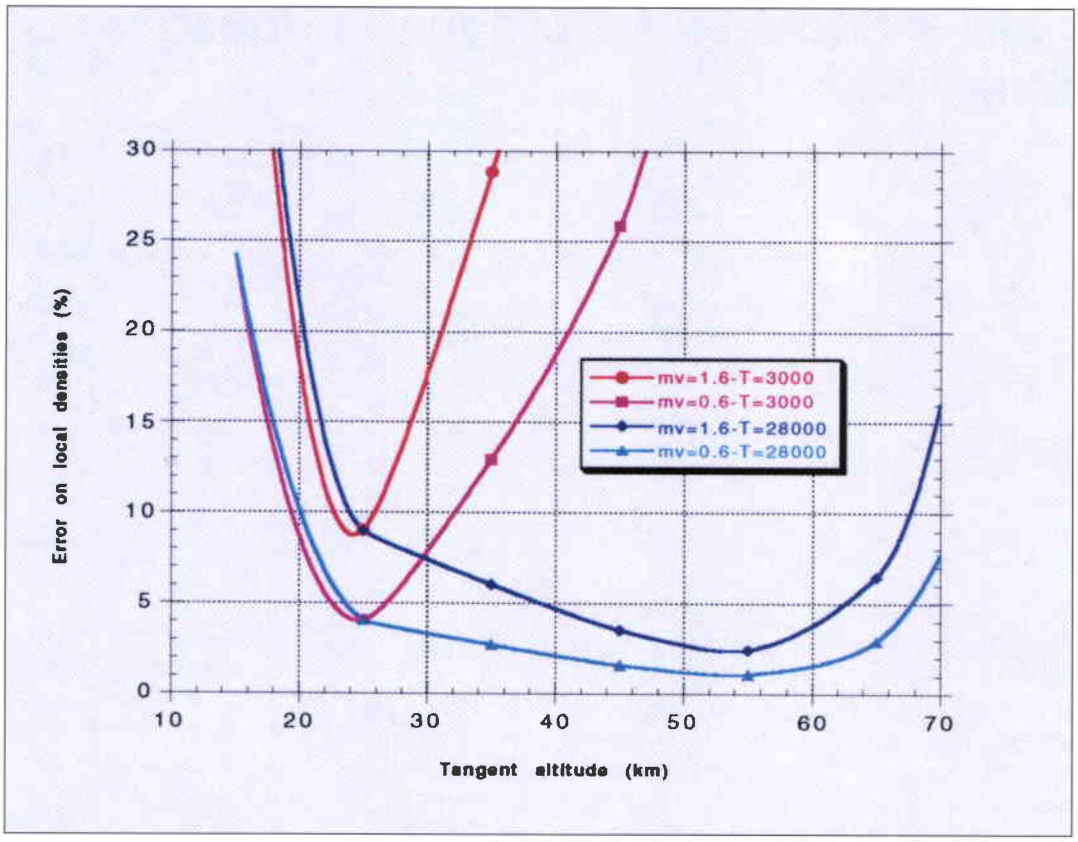


Figure 6. Expected accuracy of the ozone profile as a function of altitude for several star visual magnitudes and temperatures

precision estimates for the data products have been performed using the simulation tools mentioned above. During the Envisat commissioning phase, a geophysical validation campaign will be carried out. This will allow the Level-2 data from GOMOS and its companion instruments MIPAS and SCIAMACHY to be correlated with a large portfolio of independent observations by remote-sensing and in-situ experiments operating on other satellites, on aircraft, on balloon gondolas and on the ground. The air volumes and observation times of these validation instruments are unlikely to coincide precisely with those of the Envisat instruments; atmospheric models will be used to bridge the gap between the different measurements.

Conclusion

The decision to fly GOMOS on Envisat provides the opportunity not only to further our understanding of the chemistry of the Earth's atmosphere, but also to demonstrate the potential of the stellar occultation technique for ozone monitoring. In the latter context, it should provide very accurate global observations, well-distributed geographically, correcting what today is a serious observational deficiency. Current instruments either provide very accurate observations but with limited geographical coverage, or good geographical coverage but with limited accuracy. GOMOS should strike an excellent compromise between these two extremes.

On Envisat, GOMOS will serve a very useful role by providing observations that complement those from the other two chemistry instruments – a point well illustrated by the recent response to the Envisat Announcement of Opportunity, which revealed that many scientists were planning to exploit the synergy of these three instruments. Obviously, GOMOS will serve an additional role by providing a reference standard for monitoring the performance of the other two chemistry instruments.

Finally, looking to the longer term, it is anticipated that the star occultation technique will be capable of routinely monitoring ozone properly on a global basis. An operational concept derived from GOMOS is currently being evaluated.

'Sea & Space' – A European Educational Exercise

J. Lichtenegger
Remote-Sensing Exploitation Division, ESA Directorate for Applications Programmes, ESRIN, Frascati, Italy

S. Ansari
Informatics Department, ESA Directorate of Administration, ESRIN, Frascati, Italy

As part of the 1998 European Week for Scientific and Technological Culture organised by the European Commission, several organisations – ESA, the European Southern Observatory (ESO), the European Association for Astronomical Education, with the support of Eumetsat, the German National Research Centre for Information Technology and the Norwegian Space Centre – took the initiative of bringing space-oriented topics to the classroom in European schools. The project was appropriately called 'Sea & Space'.

Introduction

The 'Sea & Space' educational support initiative, directed primarily towards Europe's secondary-school teachers and students, was kicked off in January 1998. Run on the Internet with the help of innovative and interactive tools, it focuses on two globally significant topics: 'navigation' and 'remote sensing'. A range of activities have been offered to anyone who

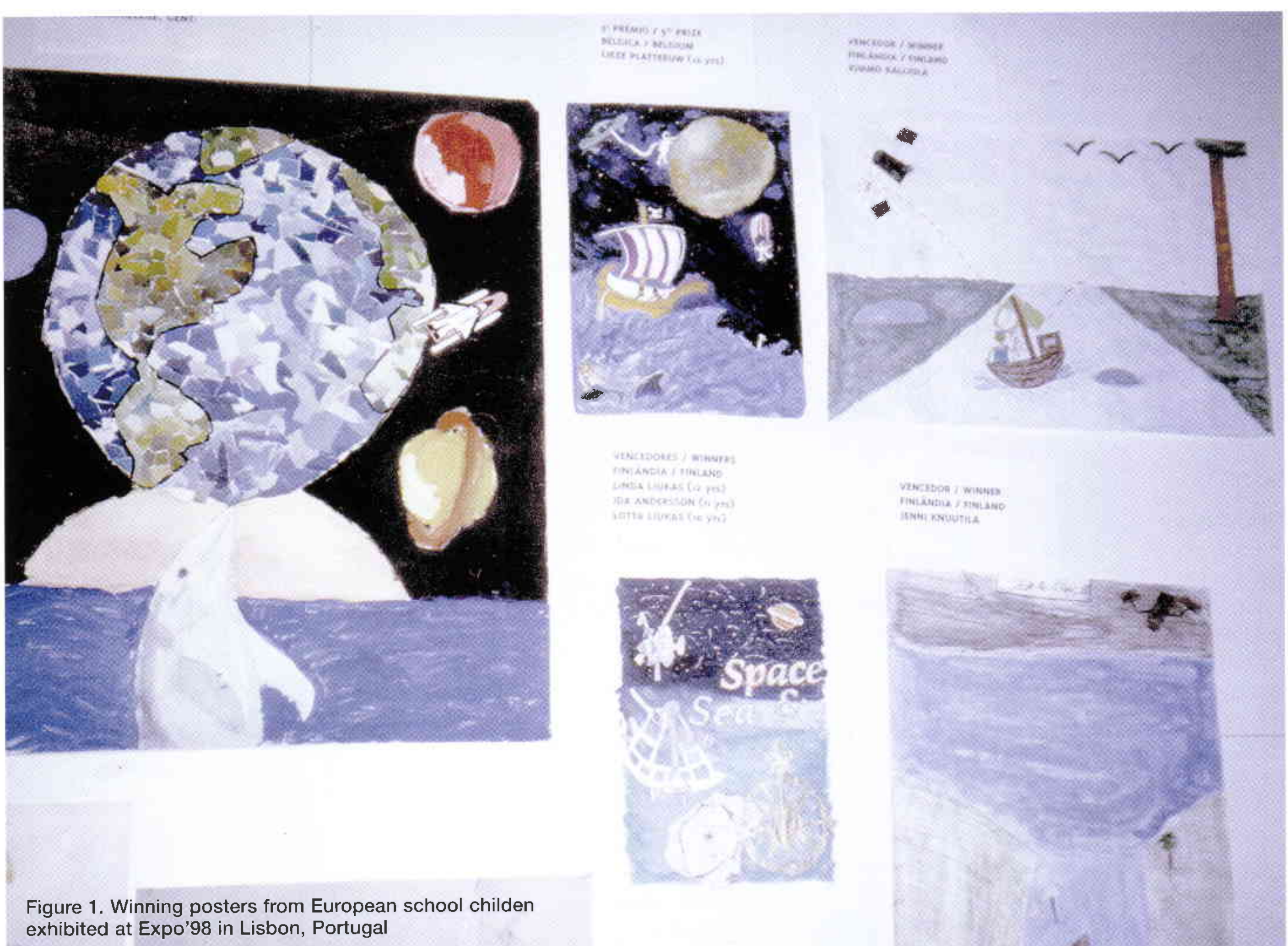


Figure 1. Winning posters from European school childen exhibited at Expo'98 in Lisbon, Portugal

wishes to participate, including:

- A national contest that was open to two categories of participants: one for children aged 10 to 13, who were invited to present a poster, and one for children aged 14 to 19, who were invited to produce a newspaper. In both cases the themes were to include navigation and Earth observation from space seen with artistic, experimental or scientific eyes.
- A web site has been created which carries information on navigation, the oceans and Earth observation from satellites. The web site also includes a tutorial, on-line exercises, and teaching material for downloading. It has encouraged visitors to the site to submit project proposals for which ESA has subsequently provided satellite remote-sensing data and expert advice.

The contest

Schools throughout Europe took up the challenge, issued via the Internet on 9 March 1998, with small teams of children being encouraged to draw and to paint posters, and to gather material for their newspapers. In late spring, national juries were nominated to make their choices of the best works, with respect to originality and creativity, scientific accuracy, clarity, organisation and presentation of ideas, and ability to discuss the subject matter from a multidisciplinary point-of-view.

The young artists responsible for the winning posters (Fig.1) – from Austria, Belgium, Bulgaria, France, Finland, Italy, Luxembourg, Portugal, Spain and the United Kingdom – each received a set of ESA/ESO videos, as well as T-shirts. The winning teams in the newspaper contest won a six-day trip to Expo'98 in Lisbon, where they would participate in a 'Super Contest', in which the first prize was a trip to South America, to visit Europe's launch base/ spaceport in Kourou, French Guiana, and ESO's Very Large Telescope at Paranal in Chile.

In September, fifteen teams, each consisting of an average of three students and a teacher from each participating country, travelled to Lisbon, where they presented their projects at a special event during the European Week for Scientific and Technological Culture. The presentations, in the Planetarium of the Marine Museum, ranged from the very professional, including one multimedia show, to simply drawn viewgraphs. In all cases, however, the content had been carefully studied and well prepared. Many of the presentations included individual experiments and their results, including an error-budget study for global positioning! It was very difficult indeed for the Jury to pick a winning team out of so many original ideas, but the eventual winner was Ireland – which as luck would have it was the entry that the participants themselves had chosen in their own secret ballot!

There were two other events at the Expo '98: the official hanging of the 32 winning posters of pupils by the students of the respective countries, and a video conference with the virtual-reality studio at GMD in Germany, and with Kourou in South America, moderated by ESO's Richard West and ESA's Wubbo Ockels, who answered the many questions from the students and engaged them in stimulating discussions. This novel conference could be followed on a gigantic screen in 'Sony Square' at Expo'98.

The Sea & Space Web pages (http://seaspace.esa.int:8000/)

As another element of the Sea & Space initiative, the following contents were offered to European schools on the World Wide Web (WWW) via the Internet:

- A chapter on 'Navigation' presenting the historical background to orientation and navigation on the sea, as well as the very latest navigational tools such as GPS, and encouraging children to conduct simple experiments for themselves, such as estimating the latitude and longitude of their schools.

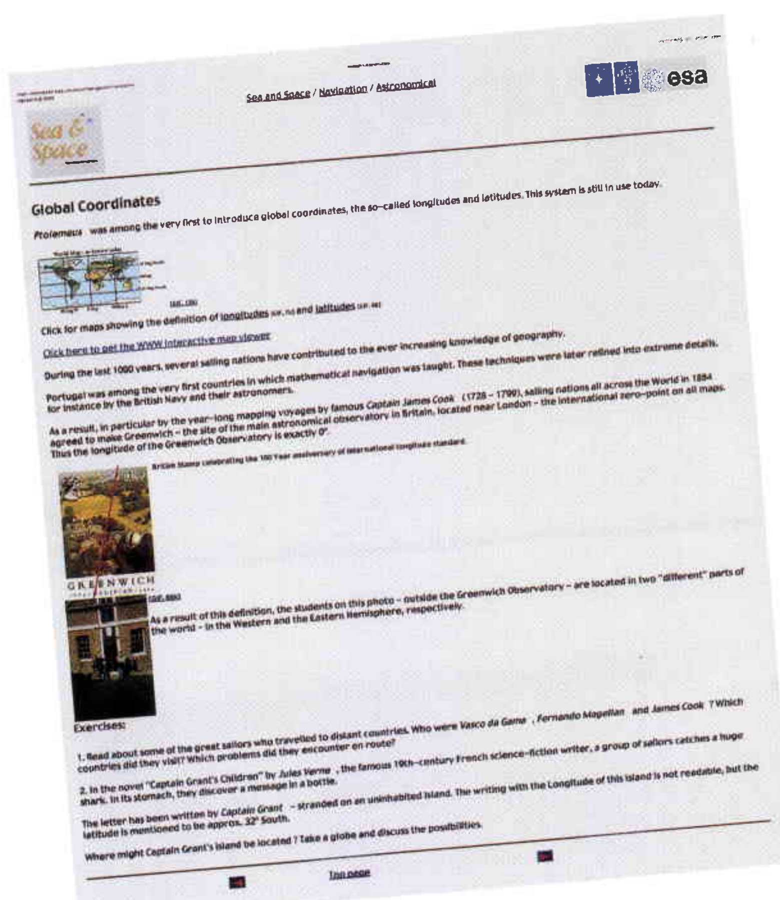


Figure 2. A Sea & Space web page on 'Navigation'. The page explains the global coordinate system and the significance of zero degrees longitude. The exercise is designed to encourage children to use maps and other means in their search for knowledge

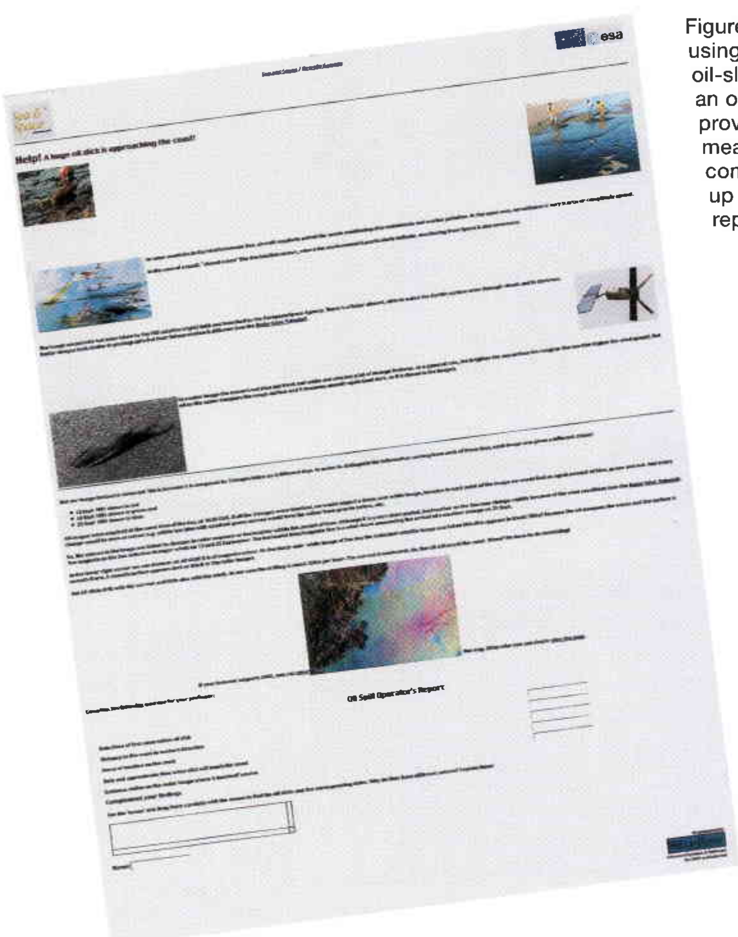


Figure 3. A Sea & Space web page on remote-sensing applications using satellite images. It introduces the use of radar satellite data for oil-slick monitoring in the Mediterranean Sea. It is a real case in which an oil slick was sighted long before it hit the coast. The exercise provides the interactive tools to make all of the necessary measurements (see Fig. 4) and more: the students have to compute/analyse their findings to achieve the final result. By signing up to the virtual classroom of Sea & Space, teachers can receive reports on their students' progress electronically

- A chapter on 'Water' in all its forms, from its presence in the oceans and in the air we breath, to its recent discovery in deep space.

- A chapter on 'Remote Sensing' (Fig.3), contributed totally by ESA, via which children and their teachers are introduced to the satellite images delivered by the Agency's ERS mission. It also includes a tutorial andexercises in how to exploit ERS imagery (fully interactive thanks to the use of Java Applet technology), and a series of viewgraphs that teachers can use to introduce the subject of remote sensing in the classroom.

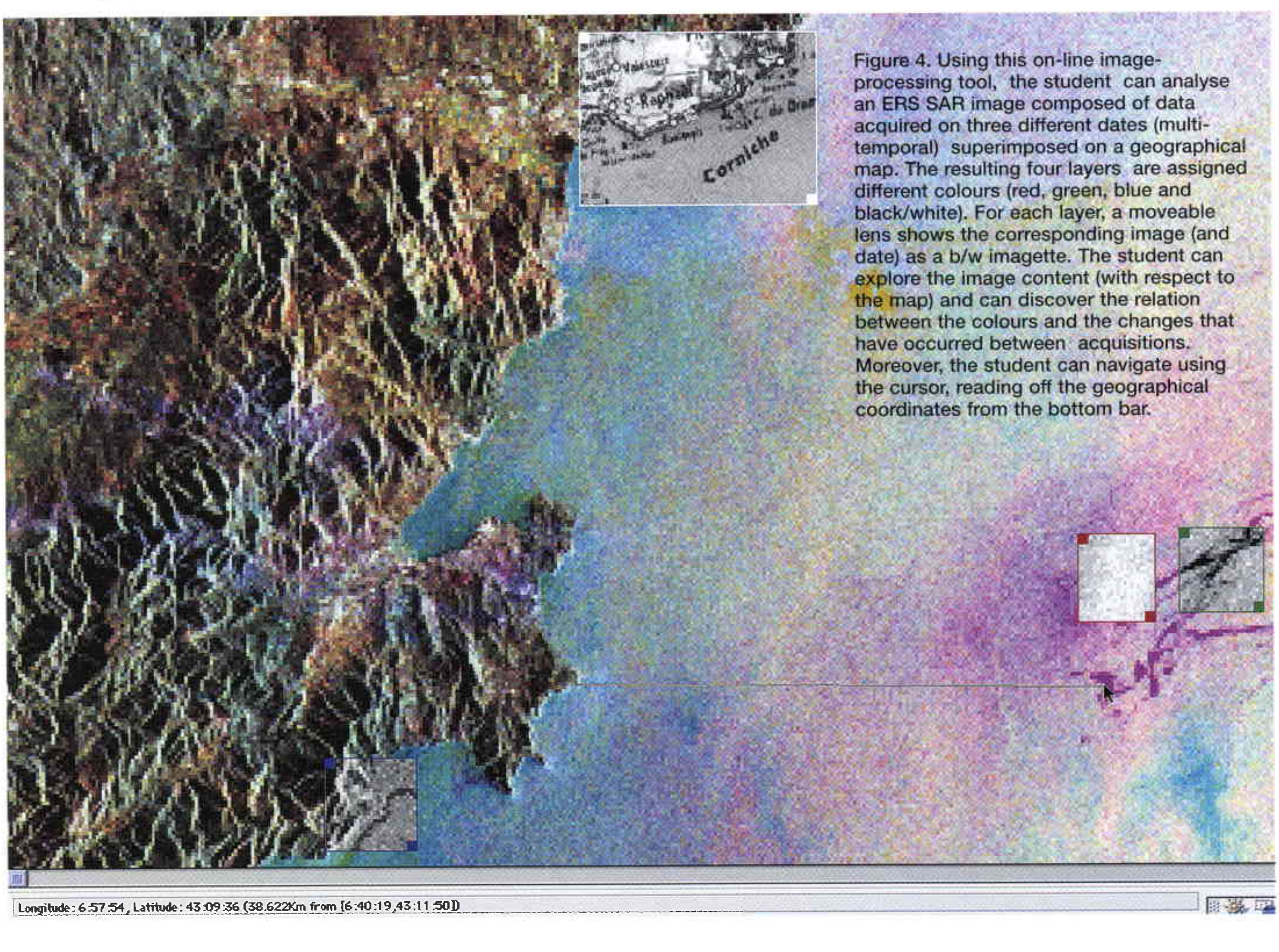


Figure 4. Using this on-line image-processing tool, the student can analyse an ERS SAR image composed of data acquired on three different dates (multi-temporal) superimposed on a geographical map. The resulting four layers are assigned different colours (red, green, blue and black/white). For each layer, a moveable lens shows the corresponding image (and date) as a b/w imagette. The student can explore the image content (with respect to the map) and can discover the relation between the colours and the changes that have occurred between acquisitions. Moreover, the student can navigate using the cursor, reading off the geographical coordinates from the bottom bar.

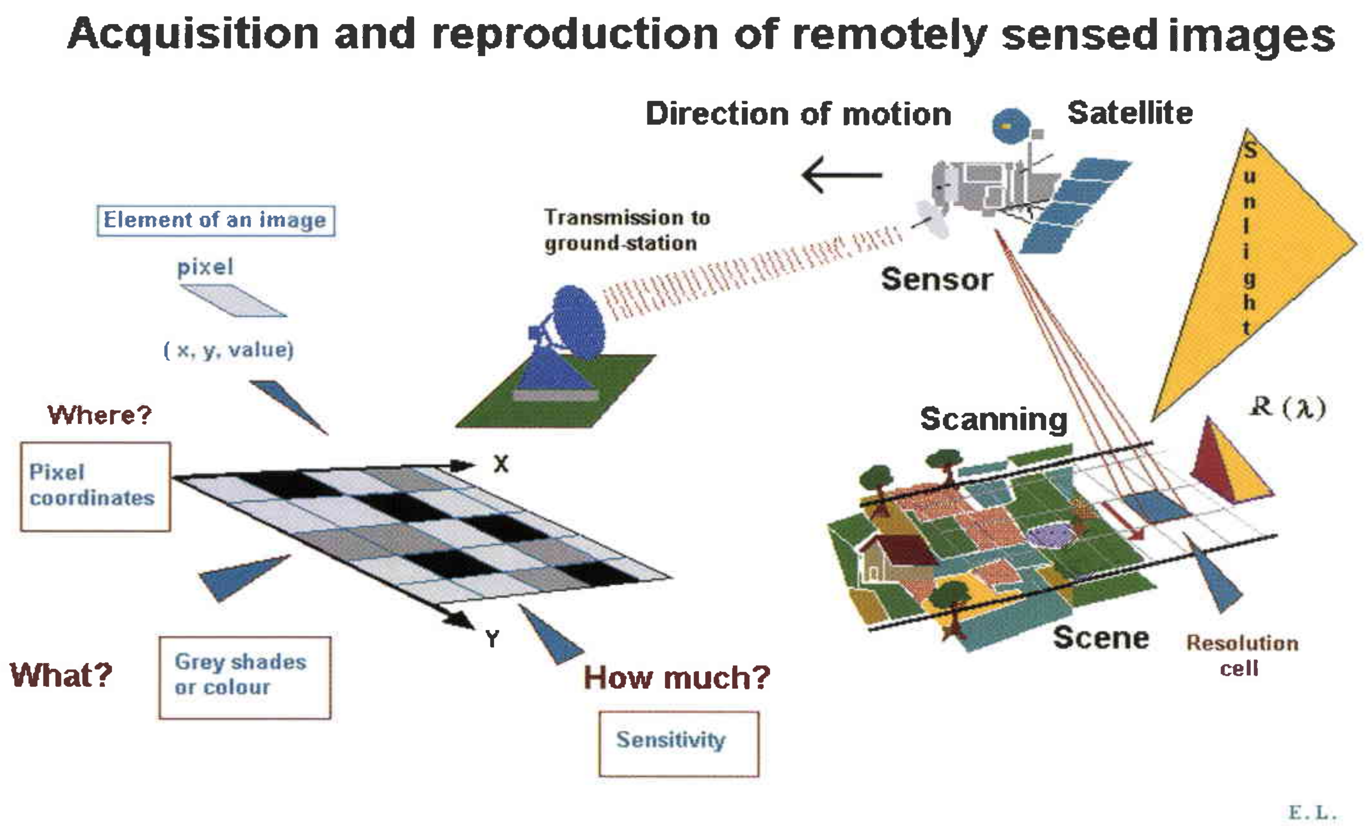


Figure 5. One of a series of viewgraphs for introducing and teaching remote sensing in secondary schools. The material can be used as it is for display during a lesson, or can be downloaded for further editing

Word of the new web site's existence gradually spread and within two months of its creation, from May onwards, the number of visits to the site began to grow markedly. The associated mailbox began to fill with proposals, some rather fantastic, but others carefully conceived and already well-defined. After many exchanges by e-mail, five projects were accepted and the corresponding satellite data were ordered for the five lucky schools and their projects:

- Geo Milev English Language School, in Burgas, Bulgaria, for: *'Pollution Monitoring of the Black Sea'*
- Gymnasium der Dominikanerinnen, in Hietzing, Vienna, Austria, for: *'Glacier Retreat in the Austrian Alps'*
- Gymnasium Groeberzell, in Germany, for: *'The Ammersee and Its Wetlands'*
- Samskola, in Saltsjöbadens, Sweden, for: *'A Town in the Sea Re-discovered from Space'*
- Amtsgymnasiet, in Sønderborg, Denmark, for: *'The Island of Als from Space (Coast-Archaeology/History)'*

All of them have received the data that they requested and are now hard at work with their teachers. By the end of the school year, or end-spring 1999 at the latest, the five teams will deliver their reports in the form of a web page, which ESA will host or link to its Sea & Space home page.

Conclusion

This novel educational event has truly demonstrated the potential and enthusiasm that exists today for using modern tools in Europe's classrooms. It has brought specialists from space-related organisations and children and their teachers in Europe's schools a lot closer together. It has given those children the chance to participate in a major European Union event that exploited technical know-how to communicate with a future generation that will take many of today's novelties for granted as being part of everyday life. The practical uses of the Internet are already making it a communications tool that no one wants to be without. Ten years from now the Global Positioning System (GPS) will be as common as laptop computers are today, and images of the Earth from space will be very much more accessible to a wider public as online services improve.

The initial phase of the Sea & Space initiative was planned to last until the end of June 1998, but the large amount of interest that it has generated has encouraged us to keep it open, providing as it does an ideal communications platform for education that combines four key elements: an Earth-observation image database, simple image-processing tools, a viable and inexpensive means of communication, and access to the advice of experts. esa

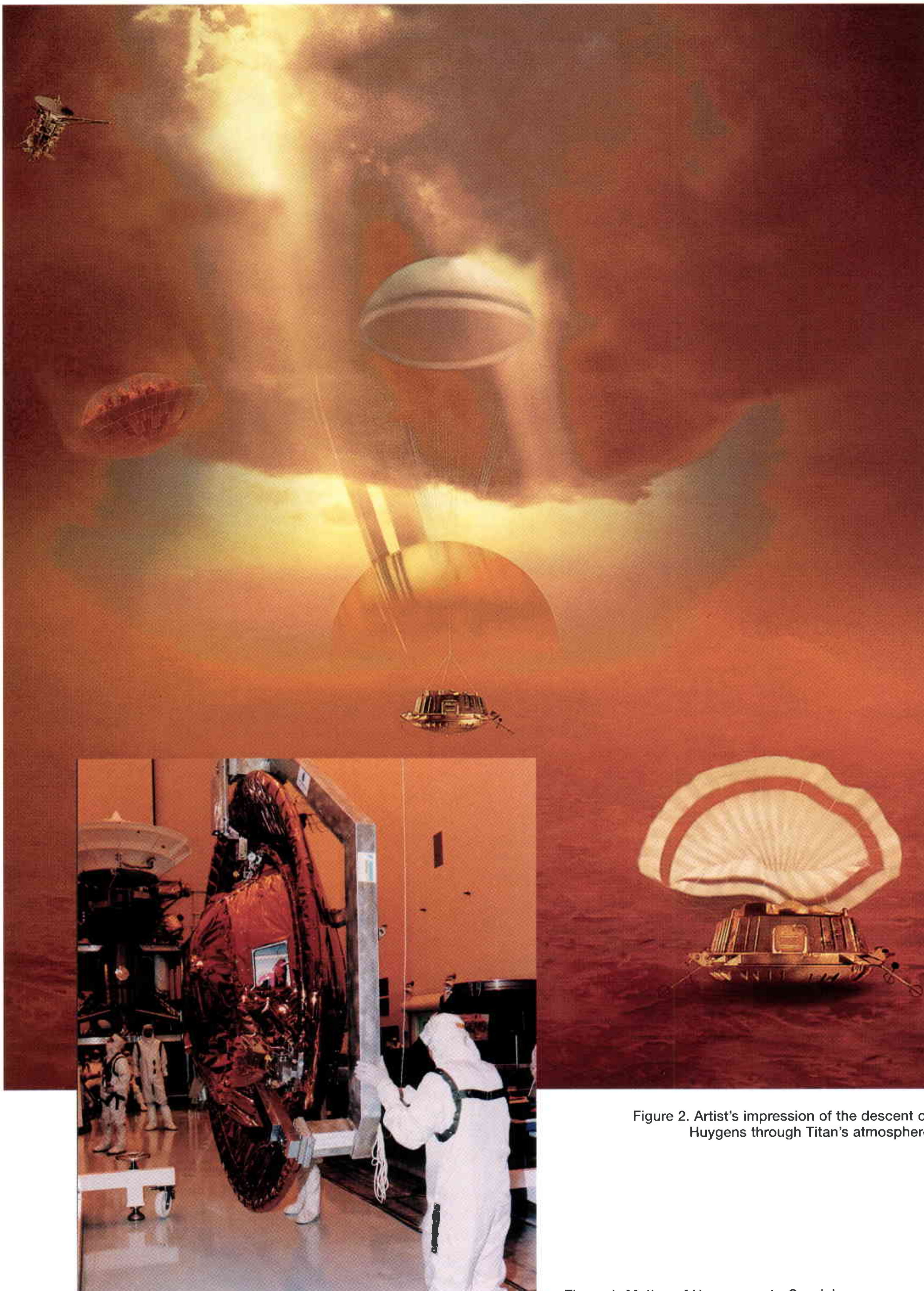


Figure 2. Artist's impression of the descent of Huygens through Titan's atmosphere

Figure 1. Mating of Huygens onto Cassini

A Second Life for the Huygens Engineering Model

S. Dodsworth, C. Sollazzo, M. Denis & R. Coda
Mission Operations Department, ESA Directorate for Technical and Operational Support, ESOC, Darmstadt, Germany

The Huygens mission

The Huygens Probe is ESA's contribution to the joint ESA-NASA Cassini/Huygens interplanetary mission. The ESA Huygens Probe is being carried on NASA's Cassini spacecraft (Fig. 1) to Saturn, where it will be released for entry in the atmosphere of Titan, Saturn's largest moon.

The Huygens Engineering Model (HEM) is proving to be an invaluable asset for the Huygens flight operations activities. It will contribute significantly to the probability of successful execution of the mission, especially in the event that unforeseen changes must be made to the planned mission scenario prior to the Probe's release or that unexpected system behaviour is discovered during check-outs.

The unique opportunity of having direct access to a real spacecraft on the ground is keeping up the motivation and honing the expertise of the Huygens Flight Control Team, while also contributing positively to the public-relations needs for this and future ESA missions.

The Cassini/Huygens spacecraft was launched by a Titan-IV/Centaur rocket from Cape Canaveral on 15 October 1997, for a seven-year flight to Saturn and a four-year orbital tour of the planet, its rings, its moons, and its magnetosphere. Huygens will be released before Cassini makes its first Titan flyby, will then coast for 22 days, and will enter the Titan atmosphere on 27 November 2004. During the controlled descent phase (Fig. 2), on-board experiments will execute a complex sequence of measurements to study the chemical and physical properties of this atmosphere. The data collected will be transmitted to Cassini, stored on solid-state recorders and later transmitted back to Earth. In the meantime, Huygens will be activated every six months to thoroughly test all of the on-board systems and experiment equipment.

The European Space Operations Centre, ESOC, in Darmstadt, Germany is responsible for the Huygens Probe mission control.

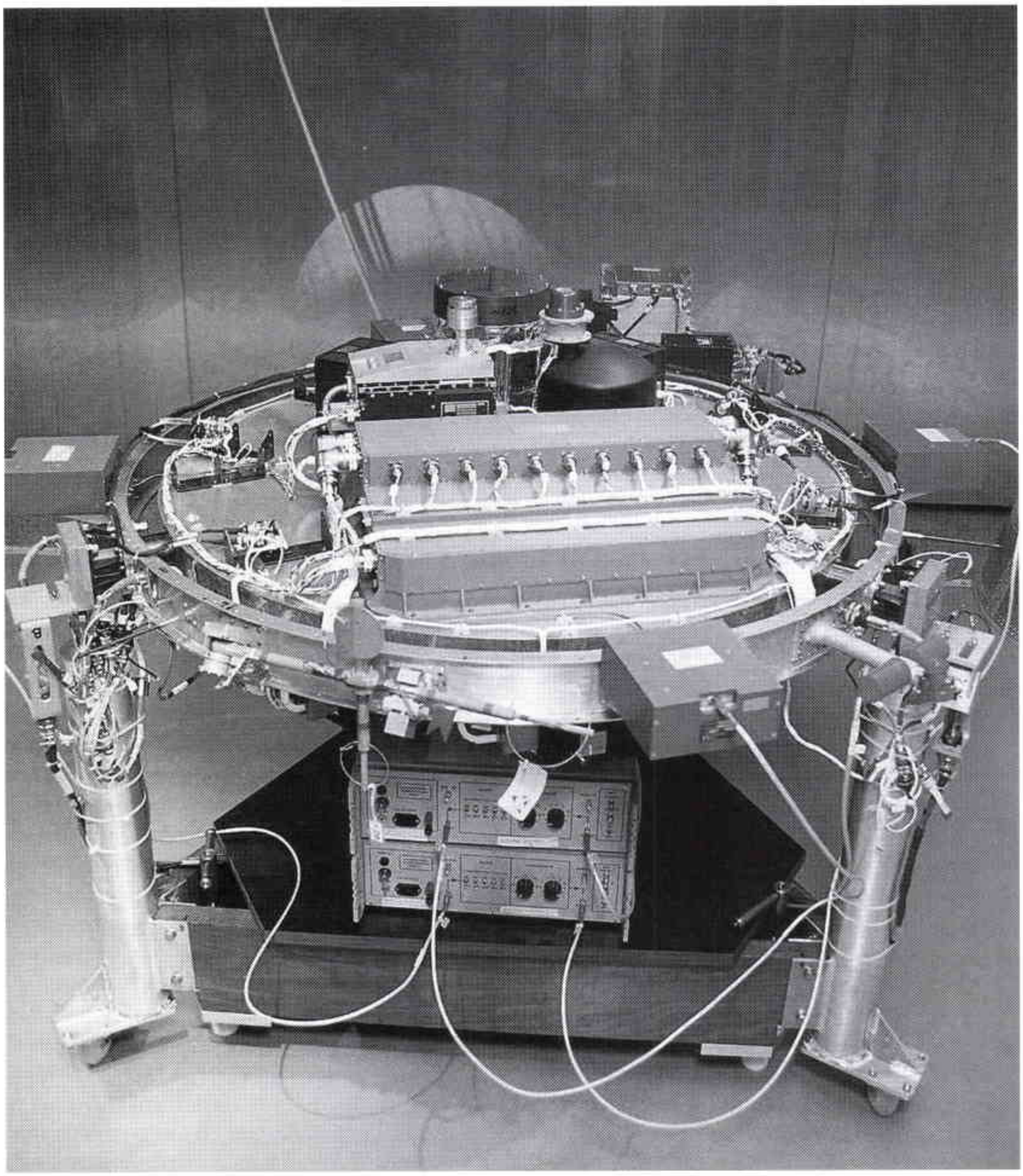
A role in operations for the Huygens Engineering Model

During the post-launch phases, the operations team has to be in a position to create and test the sequence of operations to be executed during a reactivation (or 'check-out', as it is called), and to react to failures of on-board systems. The team must also be able to analyse the behaviour of the system during the main mission phase, especially if anomalies occur. This requires suitable test and analysis tools and the relevant expertise to be available to the operations team. The limited access to Huygens, and the 'one-shot' nature of the mission make it imperative that any changes are completely validated before being implemented on the flying spacecraft.

The Huygens Engineering Model (HEM), refurbished by the inclusion of flight-spare units and hardware upgrades to make it representative of the Flight Model spacecraft, was selected as the most realistic and effective tool to support the operational and test activities and to rehearse in advance on the ground all of the operations critical to mission success. In addition, by using the Engineering Model, the operations team will be able to continuously refresh and enhance their knowledge of the Huygens systems and their operational behaviour, a key factor in maintaining expertise over the whole mission lifetime.

The HEM (Fig. 3), together with two sets of Electrical Ground Support Equipment (EGSE), was delivered to ESOC in early 1998, shortly before the second Huygens Probe reactivation. One set of EGSE and the HEM were installed in a room close to the Huygens Dedicated Control Room (DCR), and the operations team were trained in its use. The second set of EGSE was retained as spares. After validation of the set-up, the EGSE was modified to replace obsolete

Figure 3. The Huygens Engineering Model



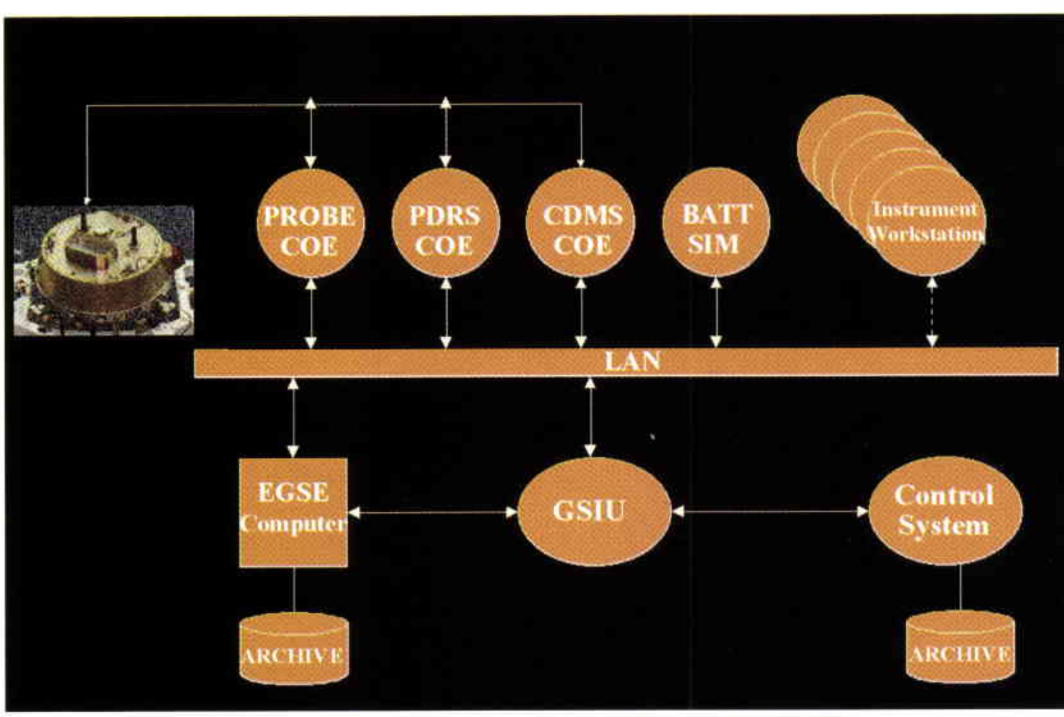


Figure 4. The Electrical Ground Support Equipment (EGSE) architecture

computer hardware with more modern equivalents, to ensure the continued maintainability of the system throughout its now extended lifetime. All that remained was to make the connection to the Huygens control system, which was done using the Ground Segment Interface Unit (GSIU), already developed to support testing of the Control Centre with the real Flight Model Huygens Probe prior to launch.

Architecture and integration within ESOC
Like the Flight Model, the Engineering Model is made up of two parts: the Probe itself, which contains the on-board experiments, and the Probe Support Avionics (PSA), which remains attached to Cassini. Whilst Huygens is mated to Cassini the PSA receives the signals from the Probe through an umbilical cable, and during the descent via the high-gain antenna on board Cassini. The data is then pre-processed and transferred directly into Cassini, and stored on board the spacecraft. The same paths are available to the EM Probe, and the RF signals are attenuated to provide the signal strength that would be seen in flight.

The EGSE is used to:
- provide the power and data interfaces to the HEM
- control and record operations
- record test results
- provide measurements not accessible to telemetry
- provide stimuli during tests
- continually monitor safety-critical parameters and terminate testing if necessary.

The interface between the HEM PSA and the EGSE includes the Cassini bus interface unit, which means that the data transfer across this interface is exactly the same as that being used on Cassini. The PSA check-out equipment provides for the conversion of data into a form convenient for passing across an Ethernet Local Area Network (LAN). Other check-out equipment allows direct interfaces to the Probe alone, or to the experiments. The GSIU provides the bridge between the EGSE LAN and the ESOC operational LAN (Fig. 4).

Operational use of the HEM
The HEM is one of a suite of support tools used by the operations team. The others are:
- a simulator, incorporating hardware and software emulators of the on-board processors, used for initial sequence testing, initial validation of software changes and team training
- a Software Development Environment for production and debugging of software modifications.

In combination, these tools provide an environment in which both changes to system software and check-out sequences can be exhaustively tested and finally validated.

Contribution to anomaly investigation
Already, the HEM has proved to be an invaluable tool in supporting system-level as well as payload investigations. Unexpected effects observed in flight during the first two check-outs could be reproduced on the ground, confirming the correct behaviour of Huygens. The HEM has also been used as a test bench for instrument software debugging.

During the first check-out eight days after launch in October 1997, the Huygens team observed a radio-frequency anomaly between the Probe and the Probe Support Avionics (PSA). The overall signal strength measured by the PSA was generally too low when compared to measurements made on the ground, and in addition the signal was unstable. It looked as though the Probe was not as good in flight as on the ground, and that if the signal were to continue to deteriorate during the seven-year flight, the Probe might not able to communicate with Cassini during its descent towards Titan. The second check-out in March 1998 was even more discouraging in that the signal strength was even lower. By then, Cassini/ Huygens was close to Venus and half the distance from the Sun as at the time of the first check-out.

Still confident in Huygens' performance, teams at ESOC, ESTEC, DASA and Aerospatiale cooperated in trying to identify the possible sources of the problem. A strong correlation with the position of the Sun in the field of view of the Cassini High Gain Antenna (Fig. 5) indicated that the anomaly was most likely caused by an outside influence, namely radiation from the hot environment of the inner Solar System, rather than any hardware failure or deterioration. They reasoned that the 4 m antenna on top of Cassini could be collecting solar radio noise and directing it to the same component receiving signals from the Probe itself via the umbilical, thereby interfering with communication between Cassini and Huygens.

A special test was set up and executed at ESOC on the HEM. The results seemed to prove that this was actually the mechanism driving the behaviour observed in flight. Increasing levels of noise were injected into the receiver's 'Mission Port' (simulating noise coming from the HGA), using the EGSE Link Simulator. A marked decrease in the signal strength measured by the PSA was observed at each step.

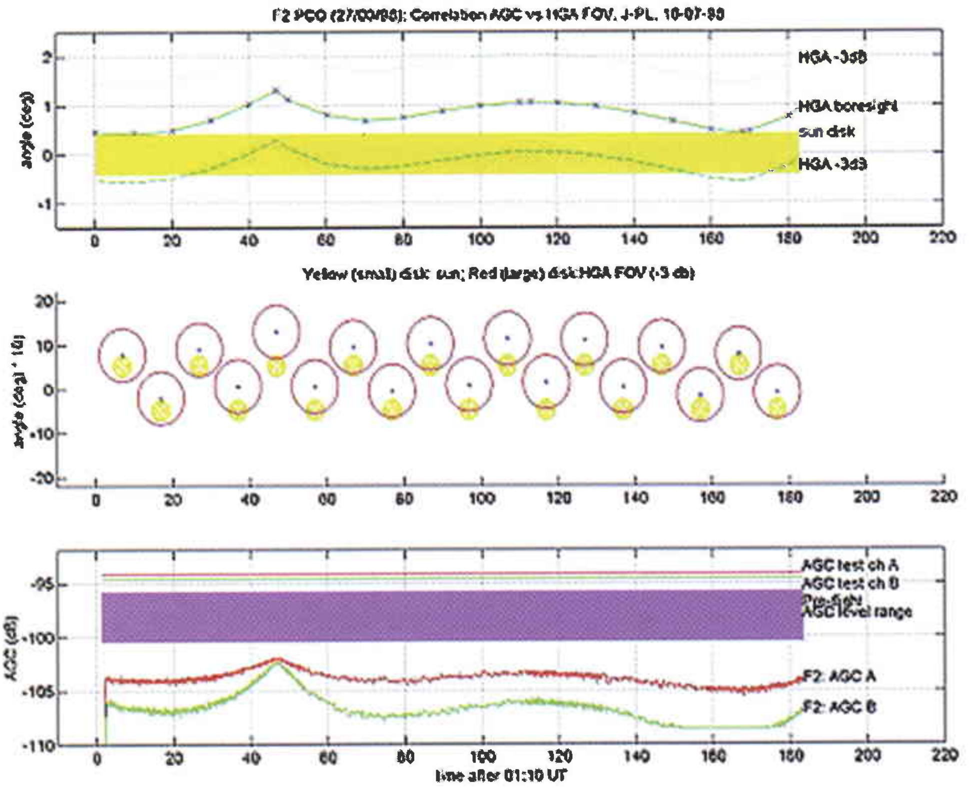


Figure 5. Correlation between the Sun-pointing ot the High Gain Antenna (HGA) and Huygens' receiver AGC signal-strength variation. Top and centre panels: Variation of the Sun cone angle with respect to the HGA boresight. Bottom panel: Strength of the receiver AGC signal recorded during the 2nd in-flight checkout (F2 AGC A; F2 AGC B), compared to the signal range measured on ground before flight. The signal strength measured during the off-Sun Huygens receiver calibration test (AGC test CH A; AGC test Ch B) is also shown

To achieve final confirmation of the theory for the in-flight Probe, Cassini had to be pointed away from the Sun by 12° to provide a clean radio-frequency environment. A sequence of telecommands then switched the Probe on for 30 minutes on 28 May 1998 to observe the radio-frequency signal strength. The results were extremely positive. Not only was the signal very stable, but it had recovered its nominal value, and was, in fact, even better than that which had been observed on the ground, as indicated in Figure 5.

The HEM had been used as the test bench to reproduce the anomaly and plan this special in-flight test before actually executing it in space.

Support to scientists
In June 1998, the scientists for the Descent Imager and Spectral Radiometer (DISR) – one of the six experiments on board, which will capture images of Titan during Huygens' descent toward its surface – were at ESOC to use the Engineering Model to test their equipment.

After analysing data both from ground tests and from the first and second check-outs, the scientists became aware that they will need to optimise their instrument's memory management in order to make their instrument more robust. During their week at ESOC, the scientists took hundreds of pictures using the DISR on the HEM to test different software configurations.

The ESOC team is already in the process of co-ordinating a new set of tests on the HEM to support investigations with another Probe instrument, the Doppler Wind Experiment, which interfaces directly with the Probe radio subsystem.

Focus of interest
While priority is always given to engineering and operational requirements, the Huygens Engineering Model is a natural point of attraction for all visitors to and staff at ESOC, who are used to seeing spacecraft only as collections of telemetry data presented on computer monitors.

Acknowledgements
The authors would like to thank the Huygens Project Scientist, the Huygens Project, the Huygens Prime Contractor Aerospatiale, the DASA team, and all of the Centre's personnel who supported the installation of the Huygens Engineering Model at ESOC.


IT'S 30 YEARS SINCE
THIS SPACE BECAME
TOO SMALL FOR US.

SOHO's Recovery – An Unprecedented Success Story

F.C. Vandenbussche
Scientific Projects Department, ESA Directorate for Scientific Programmes, ESTEC, Noordwijk, The Netherlands

The SOHO mission is a major element of the joint ESA/NASA International Solar Terrestrial Programme (ISTP). ESA was responsible for the spacecraft's procurement, integration and testing. NASA provided the launcher, launch services and ground-segment system and is responsible for in-flight operations following the launch on 2 December 1995. The SOHO mission operations are therefore conducted under a NASA/Goddard Space Flight Center (GSFC) contract with Allied-Signal Technology Corporation (ATSC). Following the spacecraft's in-orbit checkout and the transit from low Earth orbit to its operational halo orbit around the Lagrangian point (L1) between the Earth and the Sun, the SOHO mission was declared fully operational in April 1996. SOHO then completed its two-year primary mission and entered an extended-mission phase in May 1998. On 25 June 1998, all contact with SOHO was lost.

Introduction

On 25 June 1998 (07:12 UT), the following e-mail was issued by the Operations Team at NASA/GSFC:

"After the planned momentum management, while still in thruster mode, the Attitude and Orbital Control Subsystem (AOCS) switched into ESR (Emergency Sun Re-acquisition mode) on 24 June at 23:16, due to a procedure problem. On 25 June at 02:35 a second ESR occurred during standard ESR recovery, triggered by roll rate; the reason is unclear. Some time later, at 04:38, a third ESR triggered by a fine Sun-pointing anomaly and all telemetry was lost. The Deep Space Network (DSN) used a 70-m station (Madrid) to search for the downlink. Weak signal from the spacecraft is at the moment being received intermittently, but stable communication has not been established yet".

The space scientist's and space engineer's worst nightmare was beginning to unfold – SOHO was lost in space!

Within just a few hours of this e-mail message being received, an investigation team composed of ESA and Matra Marconi Space experts (MMS was the SOHO Prime Contractor) was in place at ESTEC in Noordwijk and at MMS in Toulouse. This team – in constant communication with NASA/GSFC in Greenbelt (USA) – studied the situation very carefully in order to propose measures for recovering spacecraft telemetry and attitude. The first recovery procedure was established in Europe, transmitted to GSFC and sent to SOHO on 25 June at 22:07 UT. It very soon became evident, after discussions with Jet Propulsion Laboratory (JPL) in Pasadena (USA), that the weak signals that were being observed at the DSN station in Madrid were only spurious, and that SOHO was not sending any live signals.

Due to the critical situation with the spacecraft and in order to centralise decision-making, it was decided to transfer the investigation team to GSFC. The first members left from ESTEC on 26 June, and the full ESA and MMS team was in place at GSFC by 28 June.

Milestones in the investigative process

The subsequent investigations showed that the loss of contact with SOHO had been preceded by a routine calibration of the spacecraft's three roll-control gyroscopes ('gyros') and by a momentum-management manoeuvre. The spacecraft's roll axis should normally be pointed towards the Sun and the three gyros aligned to measure incremental changes in spacecraft roll attitude.

Calibrations are performed to determine the drift biases associated with each of the three roll-axis gyros when the spacecraft has no angular rotational motion about its roll axis when under star-tracker control. Once these bias values have been accurately determined, they are up-linked to the spacecraft's onboard computer to be subtracted from the gyro measurements when determining the actual motion of the spacecraft. The biases drift slowly over time and with temperature fluctuations, which means that gyro calibration must be repeated periodically.

The gyros are used primarily for Initial Sun Acquisition (ISA), for thruster-related activities such as momentum management and orbit station-keeping, and for Emergency Sun Reacquisition (ESR). Momentum management is accomplished using the spacecraft's Attitude Control Unit (ACU) computer, and is performed approximately every two months to maintain the reaction-wheel speeds within their operational limits. The reaction wheels provide the three-axis control torques needed to counteract internal and external disturbance torques imparted to the spacecraft, and thereby very precisely control its attitude, and also to slew the spacecraft for special roll off-pointing manoeuvres.

Momentum management is necessary because the reaction wheels increase in speed over time in order to maintain spacecraft attitude in the presence of the external disturbance torques. As the wheels accelerate to speeds that approach their operational limits, momentum management is performed to restore the reaction wheel speeds to adequate initial values.

In the momentum-management mode, the ACU computer commands the wheel speeds to new initial values and the spacecraft attitude disturbance that follows from the wheel deceleration/acceleration is counteracted by firing the thrusters.

Normally, the three roll gyros perform the following functions:

- Gyro A is connected to the Failure-Detection Electronics (FDE) for roll-rate sensing for ESR to allow spacecraft roll-rate control using thrusters
- Gyro B is connected to the FDE for excessive roll-rate (anomaly) detection
- Gyro C is connected to the ACU for roll attitude sensing during computer-based control modes using thrusters.

Conservative usage of SOHO's gyroscopes has always been implemented because gyros are recognised as being life-limited items. Problems encountered in other programmes using similar gyros led to the introduction of additional changes following launch to further preserve gyro lifetime. Consequently, Gyro A was deactivated (spun down) after every calibration manoeuvre to conserve its life. There is an automatic onboard function to reactivate Gyro A if the spacecraft autonomously enters its ESR mode. However, all gyros are intended to be fully active during momentum-management manoeuvres.

ESR-5 of 24 June 1998, 23:10 (UT)
The Failure-Detection Electronics of Gyro B was set to 'high gain' for wheel management and was left on 'high' instead of 'low' after completion of the task. The reason was a recent change to the spacecraft command procedure, made in May. During standard momentum management, an ESR was triggered as a consequence of high gain, i.e. the roll-rate threshold was 20 times too low. In ESR-5, the spacecraft reconfigured to B-side (redundant/backup system used when there is a problem with the A-side/main system) and went into ESR Sun-pointing mode as expected. Gyro A, nominally available in ESR, was not spinning because the onboard software gyro-setting function was disabled from the ground. As roll control in ESR is based on the availability of a spinning gyro (A), this would subsequently lead to ESR-6.

ESR-6 of 25 June 1998, 02:35 (UT)
During the recovery from ESR-5 in initial Sun-acquisition mode, the spacecraft spun-up due to a non-zero Gyro-A drift-compensation value in the roll controller, while Gyro A was not spinning. The roll-rate anomaly was detected by Gyro B and the spacecraft was put into ESR-6. Subsequently, the spacecraft went back into B-side configuration. Sun-pointing was achieved by the Failure-Detection Electronics as expected.

ESR-7 of 25 June 1998, 04:38 (UT)
During the recovery from ESR-6, Gyro A output was read as zero by the ground operator (as expected in ESR), but in fact this value was caused by Gyro A not spinning. Gyro B's output was found to be non-zero and judged faulty. It was therefore switched off by

The Emergency Sun Reacquisition (ESR) mode

ESR mode is a 'safe hold mode' or a 'safety net' configuration entered autonomously by the spacecraft in the event of anomalies. It is a hard-wired analogue control mode that is part of the Failure Detection Electronics (FDE). Unlike the other control modes, it is not under the control of the Attitude Control Unit (ACU) computer. Thrusters are used in ESR to control the spacecraft attitude.

Once the spacecraft has entered the ESR mode, a recovery sequence must be commanded and executed under ground operator control to proceed to the 'normal mode' from which science observations are made. The first step in this recovery sequence involves the use of the ISA mode, in which the ACU computer takes over the commanding of the thrusters to point the spacecraft towards the Sun using the onboard Sun acquisition sensor SAS-1.

the ground, eventually causing ESR-7. During the recovery from ESR-6, again via the Initial Sun-Acquisition mode, further uncontrolled spin-up of the spacecraft was due to:
- Gyro A not spinning
- gyro drift compensation
- Gyro B being unavailable to stop the spin up.

Spin-up continued with increasing 'coning' motion, producing increasing pitch/yaw off-pointing (Fig. 1) until the fine Sun-pointing anomaly detector triggered at a spin rate estimated at about 7 deg/s; the spacecraft then fell into ESR-7. The ESR-7 controller diverged at this spin rate, which greatly exceeded design values. This loss of attitude control ultimately resulted in loss of power, telemetry and thermal control.

Spacecraft status at loss of telemetry

Battery management

The battery-management status was not as it should have been. Two batteries were fully charged at the time of telemetry loss, but only one of them was connected to the main power bus, with the current limited to 14.5 A. This was not enough to power the essential loads such as transponder, data-handling, etc., for which two batteries should normally be connected to the bus, giving a 50 A capability. In addition, the spurious switch-offs of three out of four battery-discharge regulators between January 1997 and May 1998 had gone undetected.

Analysis of power-subsystem behaviour

Following ESR-7, the power subsystem behaved as expected, until the loss of telemetry. A correlation of the diverging Sun-acquisition sensor angles (pitch and yaw), showed a good match with the solar-array regulation and battery-discharge/charge modes. Due to the limited current from the batteries (with only one of the four regulators active), a bus under-voltage occurred and triggered a random electrical load shedding, thereby reducing the bus load by around 10 A. When turning back towards the Sun, the automatic regulation system started to recharge the battery that had just been discharged, until the solar-array shadowing caused by spacecraft depointing again put it into battery discharge shortly before the loss of telemetry.

Analysis of RF subsystem behaviour

The RF subsystem reconfigured as expected during ESRs 5, 6 and 7. Telemetry is (by design) available on only one low gain antenna during an ESR. After ESR-7, there was loss of telemetry at 04:43 (UT) and possibly the loss of carrier at 04:52 (UT).

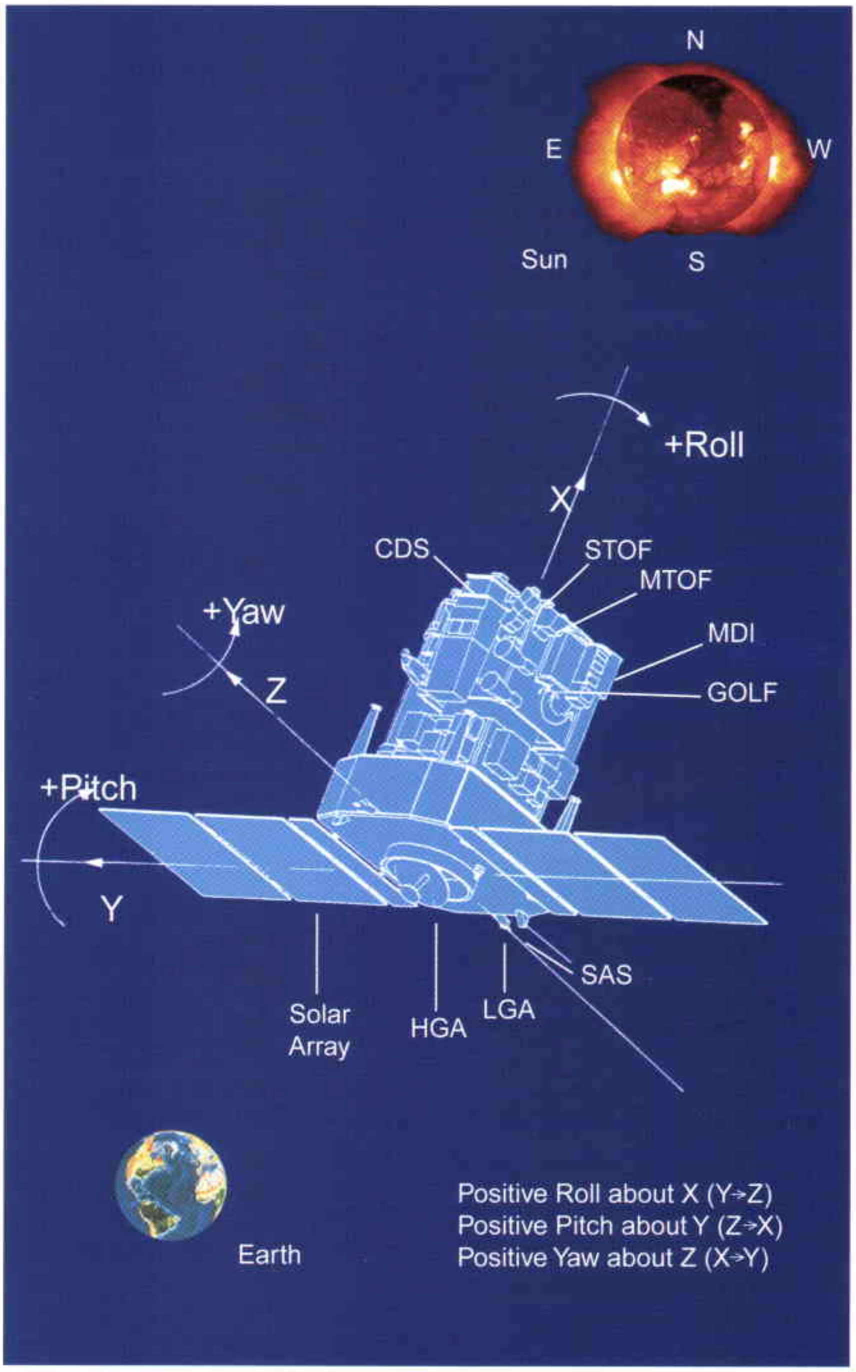


Figure 1. Rotational axes and sign conventions for SOHO manoeuvres

Analysis of data-handling subsystem behaviour

The data-handling subsystem reconfigured as expected during ESRs 5, 6 and 7.

Dynamic behaviour

Early in July, it was possible to run the dynamic mathematical model at MMS in Bristol (UK) which concurred very well with the last few minutes of telemetry. SOHO was, based on spacecraft dynamic considerations, expected to transit from an X-axis spin into a spin around its Z-axis, which would eventually be pointing coarsely towards the Sun. It was not known whether the ± Z-axis would be pointing at the Sun. The predicted time for transition ranged from 1 day to several weeks, while the spin-rate prediction varied from 4 to 8 deg/s.

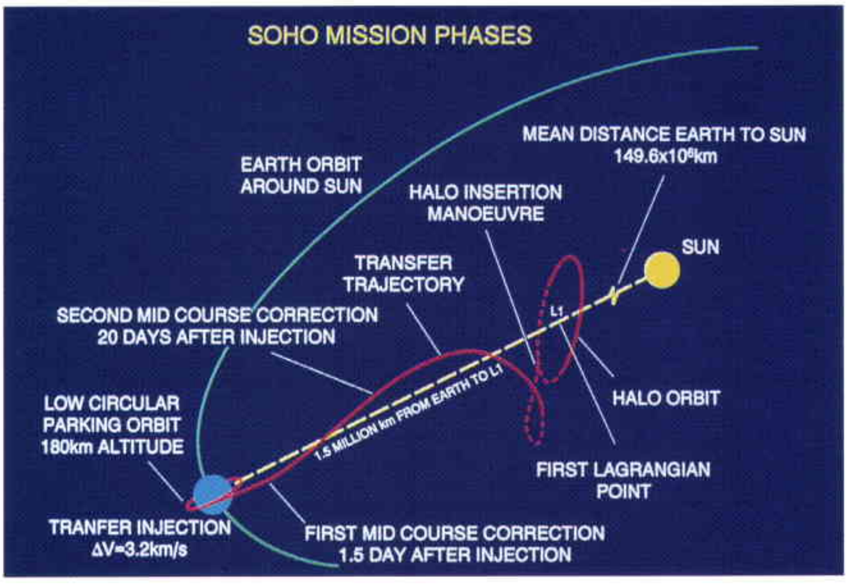


Figure 2. SOHO transfer trajectory and L1 halo orbit

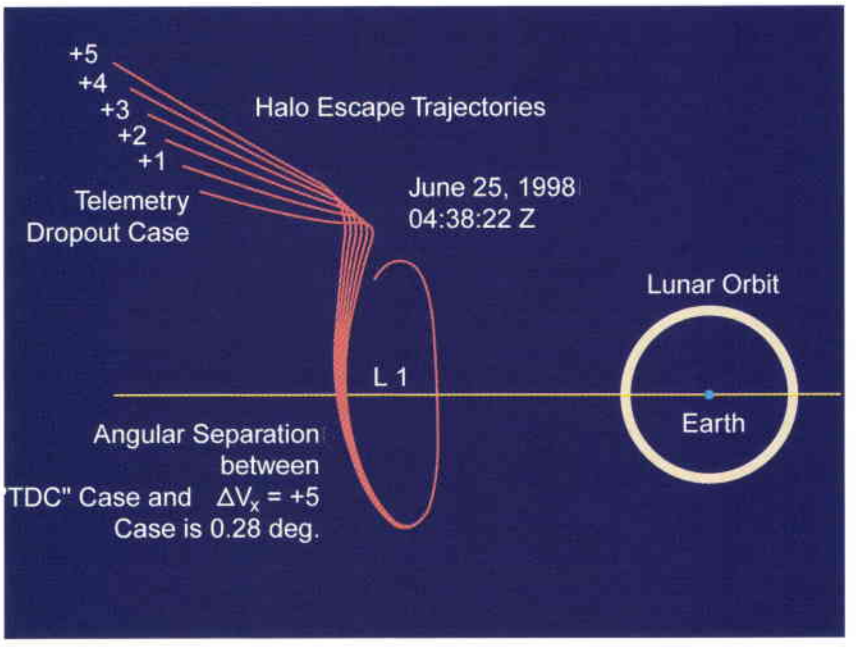


Figure 3. Computed potential halo escape trajectories, for delta-V's of 1 to 5 cm/sec

The Investigation Board
The SOHO Mission Interruption Joint ESA/NASA Investigation Board was established by the ESA Director of Scientific Programmes and the NASA Associate Administrator of the Office of Space Science to gather information and determine the facts, as well as to identify the actual or probable cause(s) of the SOHO mission interruption.

The primary purpose of this Board's investigation and subsequent management action was to identify and effect necessary changes and pursue corrective actions to prevent the recurrence of similar problems in the future and thereby improve the effectiveness of ESA/NASA operations.

The Board met at GSFC in early July 1998 and published its preliminary report on 10 July. The final report was published on 31 August. Recommendations were reviewed on 2 and 3 December 1998 during the Re-certification Review.

Thermal predictions
Thermal simulations were run at MMS in Toulouse (F) and spacecraft temperature predictions were established for the + and - Z-axes being pointed towards the Sun, and for intermediate cases with angles of ± 45° to the Sun. These thermal predictions showed that certain equipment items and instruments on the side of the spacecraft in shadow would be experiencing extremely cold temperatures, e.g. -62°C for the high-power amplifiers. The thermal model was subsequently also installed at GSFC for the on-going analyses.

The orbit predictions
SOHO's nominal trajectory is a halo orbit around the L1 Lagrangian point (Fig. 2), approximately 1.5 million kilometres from Earth. Halo orbits around L1 are inherently unstable and station-keeping (propulsive) manoeuvres must occasionally be used to stabilise them. If this reference trajectory is propagated from the point where SOHO's telemetry was lost and no additional delta-V is applied, it diverges only very slowly, retaining orbital halo characteristics up to mid-November 1998. Thereafter, the divergence would accelerate and eventually result in the spacecraft's escape into a solar orbit.

Several hypothetical trajectories based on post-loss delta-Vs were studied for delta-V's ranging from +1 to +5 cm/s (Fig. 3). The inertial orientation of the Z-axis would be moving by about 1deg/day due to the global orbital motion of the spacecraft around the Sun near the L1 point. This implied that after roughly 90 days, the Z-axis would be perpendicular to the Sun, such that the solar arrays would face the Sun for half of the spin period. This meant that if SOHO was to be recovered, it had to be achieved when the Z-axis would be coarsely perpendicular to the Sun and before the end of November. Fortunately, the two conditions were compatible.

Spacecraft recovery *(Table 1, Fig. 4)*
On 23 July, based on a proposition from researchers at the US National Astronomy and Ionosphere Center (NAIC), the 305-m diameter dish of the Arecibo radio telescope in Puerto Rico (Fig. 5) was used to transmit an S-band signal (at 2.38 GHz and with a power of about 580 kW) towards SOHO whilst using the 70-m dish of NASA's Deep Space Network in Goldstone (USA) as a receiver, thereby locating the spacecraft's echo and tracking it for more than one hour. The radar echoes from SOHO confirmed its predicted location, and a spin rate of 1 rpm.

Table 1. Main Events in the Recovery Activities

Day	Date	Time	Days from ESR	Event(s)
176		04:38	-	Emergency Sun Reacquisition (ESR-7)
176	25 June	04:43	-	Interruption of mission
204	23 July	10:00	28	Confirmation of orbital position and spacecraft spin rate by Arecibo and DSN radar
215	3 Aug.	22:51	39	Reception of spacecraft carrier signal by DSN
220	8 Aug.	23:14	44	Reception of spacecraft telemetry
224	12 Aug.	23:39	48	Begin thawing of hydrazine tank
240	28 Aug.	23:02	64	End thawing of hydrazine tank
242	30 Aug.		66	Begin thawing of hydrazine lines
259	16 Sept.	05:45	83	Start of attitude recovery
259	16 Sept.	18:29	83	ESR-8
259	16 Sept.	18:33	83	SOHO lock to Sun
266	21 Sept.	16:58	90	SOHO in RMW
268	25 Sept.	17:30	92	Orbit correction (first segment)
268	25 Sept.	19:52	92	SOHO in Normal Mode
278	5 Oct.	18:21	102	Start of instrument recommissioning
	5 Nov.		133	Completion of instrument recommissioning

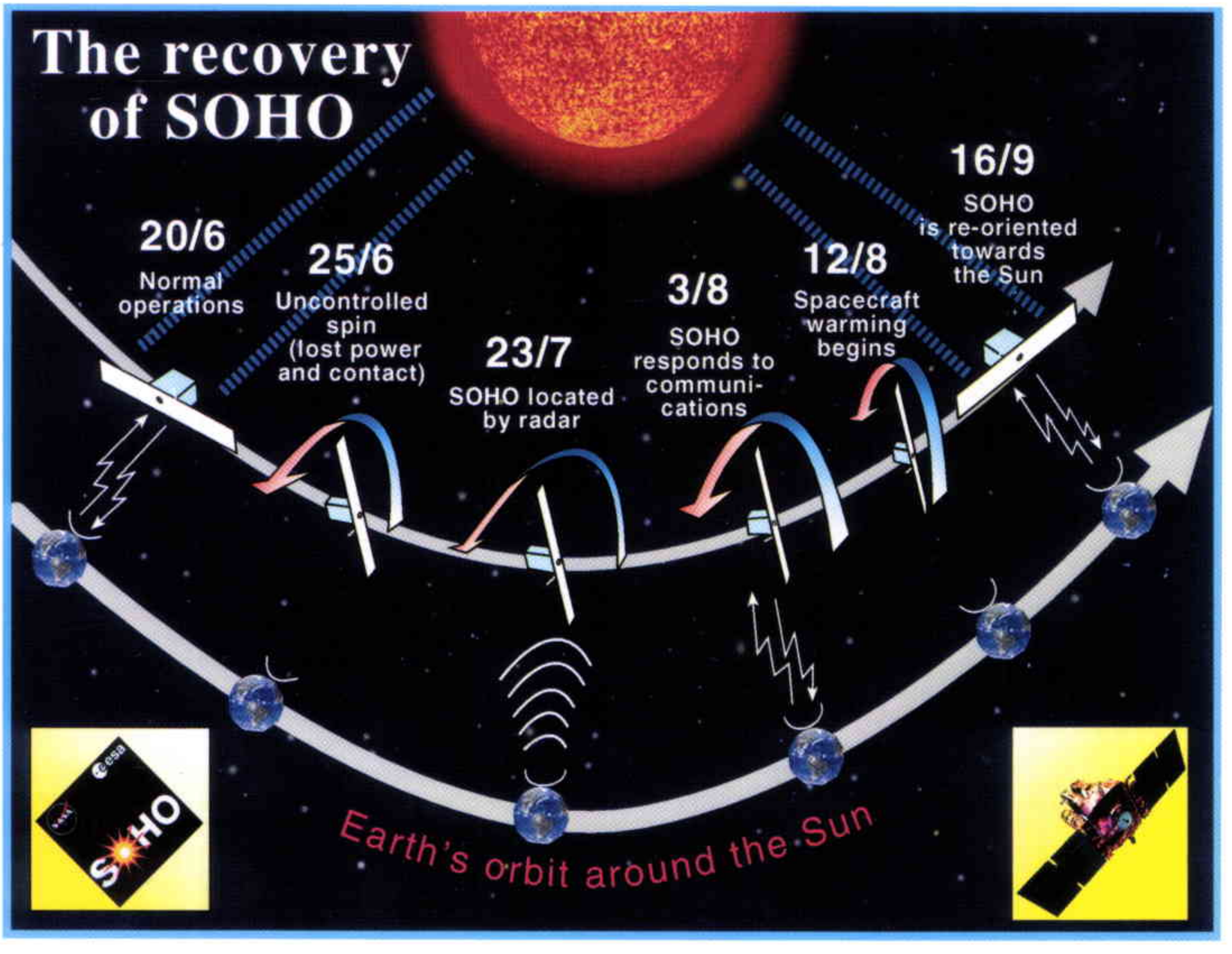


Figure 4. Some of the key events in SOHO's recovery

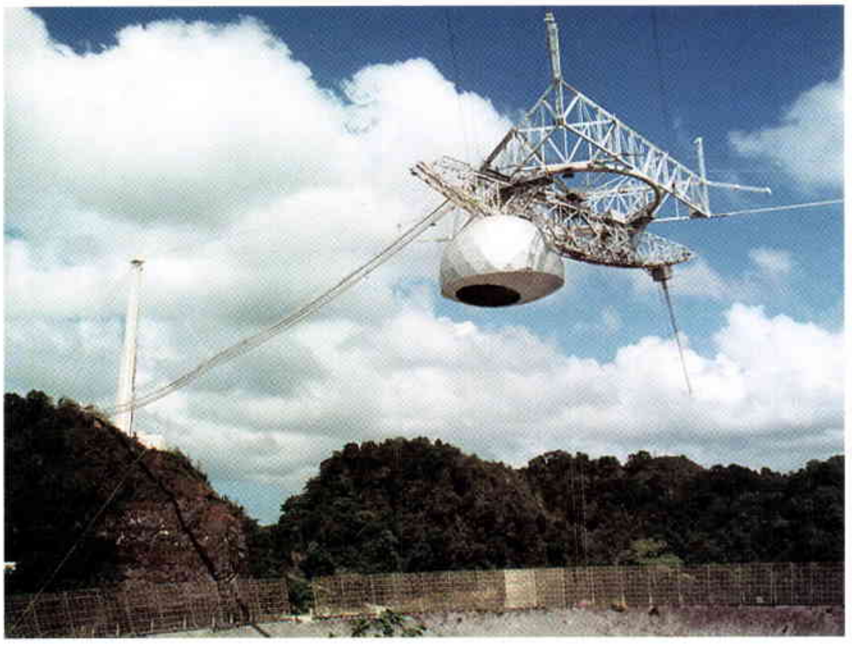


Figure 5. The Arecibo radio telescope in Puerto Rico

Carrier recovery
From the moment that contact with the spacecraft was lost, the Flight Operations Team at GSFC continued up-linking commands, via the DSN, for at least 12 hours per day (normal pass) plus all available supplementary time. The ESA ground stations in Perth (Australia), Vilspa (Spain) and Redu (Belgium) supported the search for a down-link signal. Special equipment was set up at the ground stations to search for spikes in the down-link spectrum and view it in real time at the SOHO operations facilities.

On 3 August, contact was re-established with SOHO after six weeks of silence. Spikes in the down-link were detected by the spectrum analyser installed at Goldstone and by ESA 's Perth station, at 2244.945 MHz and with a ground Automatic Gain Control (AGC) of –135 dBm. The spikes were lasting between 2 to 10 s as expected. A commanding sequence was successfully executed through receiver-2, which was connected to the –Z facing low-gain antenna. Attempts during the following days to command the spacecraft via its +Z facing low-gain antenna were unsuccessful, indicating that it was SOHO's –Z-axis that was pointed towards Earth. Analysis of the frequency of the spikes being detected allowed SOHO's rotation period to be more accurately established; it was 52.8 sec.

From carrier detection to telemetry reception
The next objective, after contact had been re-established on 3 August, was to acquire and decode the telemetry. Unfortunately, despite taking special measures at the ground stations in order to be able to receive bursts of telemetry, it proved impossible to decode any such telemetry, which would have told us the status of the spacecraft. It was decided to use the on-board batteries, by first recharging them for several hours and then switching on the telemetry using that stored energy.

Several attempts to charge even one of the batteries and connect it to the power bus were unsuccessful. Investigations by battery experts in Europe showed that below 20 V there would not be enough power to maintain the Battery Charge Regulator (BCR) in an 'on' position. Therefore, to charge just one battery it was necessary to keep sending the 'BCR on' command repeatedly. On 8 August, after 10 h of in-loop commanding, telemetry was successfully switched on and battery-2 was connected to the bus. Seven frames of telemetry were then received at the GSFC Control Room via the normal network. To avoid discharging the battery, the Battery Discharge Regulator (BDR) was opened at the end of the test, switching off the power and hence the transmitter.

At this time, it was established that the following items of equipment were working correctly: the Central Data Management Unit (CDMU), including the decoder, transponder-2, High Power Amplifier-2 (HPA-2), the Service Module Remote terminal Unit-2 (SRTU-2), and the AOCS Remote Terminal Unit (ARTU).

Now the main challenge was to keep the +28 V bus alive by ensuring that the battery remained charged. The next day, 9 August, the telemetry was switched on again and a command issued to also switch on the Payload Remote Terminal Unit (PRTU). This enabled temperature readings to be acquired for each instrument.

Battery charging
A new power budget was established based on the power consumptions of the onboard equipment needed for the recovery operations being planned, as well as the charge/discharge ratio of the batteries. Since the solar arrays were only illuminated for part of the time (the angle to the Sun at this time was approximately 45°), the batteries were being charged for only 45% of the time. The newly established power budget showed that the batteries would charge over several cycles if the total power consumption remained below 67 W. However, telemetry required 105 W for a minimum configuration, and would therefore quickly drain the batteries. Recovery of the spacecraft would therefore require periods of battery charging alternated with other activities. After lively debate among the recovery-team members, the 'end' of battery charging was first set at between 45 and 46.5 V and was later readjusted to between 40 and 41 V.

Attitude determination
During the same period, the telemetry data on the Sun Acquisition Sensors (SAS) had been collected. The availability of this data confirmed that the Failure Detection Electronics (FDE) were working fine as far as SAS data processing was concerned. The analysis of the SAS data confirmed a spin period for SOHO of 52.6 s, that the spacecraft's +Z-axis was facing the Sun and that the angle between the spacecraft rotation axis and the Sun was about 36.7°.

Thawing of the hydrazine tank
Another challenge was the thawing of the onboard hydrazine tank and the associated pipes and thrusters. From the first temperature readings from the telemetry and the thermal analyses performed, it was estimated that at least 48 kg of the estimated 200 kg of hydrazine in the tank was frozen. Thrusters 1, 3, 4, 7 and 8 and their associated pipes were also frozen, due to temperatures colder than –21°C (minimum thermistor reading obtained). These elements are on the –Z-axis of the spacecraft and therefore not illuminated by the Sun. The +Z-facing side of the spacecraft showed more favourable temperatures, around 0°C.

The tank thawing operation was started on 12 August, after a cycle of battery charging, but the first signs of a temperature increase were not observed until 25 August. The tank heating was performed with the two batteries on the bus and, after telemetry switch-off, by providing power only to the tank heaters (all other equipment was switched off except for short temperature and battery-voltage telemetry checks every 4 h). The tank thawing process had to be interrupted three times to recharge the batteries. The total power consumption during the heating operation was about 87 W (with telemetry off).

Thawing of the tank was completed on 30 August, after 275 h of heating (more than 11 days, without taking into account the battery charging periods). This was longer than the expected 7 days owing to higher than estimated heat losses during the interruptions to charge the batteries, and probably also the larger mass of frozen hydrazine. A very careful balance between the time devoted to battery charging and the power available for thawing the complete propulsion subsystem had to be maintained.

Thawing of the hydrazine lines
Once the tank had been thawed, the thawing of the pipes and thrusters was started on 3 September. Following a long discharge cycle, it was not possible to recharge the batteries whilst simultaneously maintaining the temperature of the propulsion subsystem – the latter was becoming colder and the batteries were discharging. Priority had to be given to recharging the batteries as well as the maintenance of the 28 V bus, which was crucial for communication with the spacecraft. It therefore became evident that the complete thawing of the propulsion subsystem was a major challenge.

Fortunately, it was possible to patch the onboard data-handling software in order to use the available solar-array power more efficiently, switching the heaters on only when power was available from the solar arrays. Also, by fine-tuning the battery-charging/thawing cycle, an optimum duty cycle of 2 h of charging and 5 h of heating was established.

Thawing of the propulsion subsystem was believed to be not yet complete when spacecraft attitude recovery activities were started on 16 September – thrusters 7B and 8B, and their associated pipes, were still frozen. This had prompted the investigation of alternative attitude-recovery strategies without these thrusters.

Possible recovery scenarios
Four possible alternatives were identified:

1. Full ESR recovery – a two-step approach based on the assumption that the full B-side of the propulsion system would be available for recovery. The first step would be stepwise spin-down of the existing Z-axis rotation to about 1deg/s. Full recovery would then be initiated once the Sun was close to the centre of SAS-1's field of view. During this ESR recovery, all eight branch-B thrusters would be used with SAS-1 for pitch and yaw control, and with one of the gyros for roll control.

2. ESR without roll control – this approach took into account the possibility that there might be insufficient power for the above scenario; ESR recovery without roll control would be pursued, using the Z-axis de-spin, four thrusters of branch-B only, and SAS-1.

3. Dual-spin recovery – this scenario, proposed by NASA, was based on the idea of stabilising a spinning spacecraft around its axis of minimum moment of inertia. However, this posed nutation problems, and would not achieve a closed-loop coarse Sun-pointing attitude like in ESR.

4. ISA recovery – similar in concept to ESR recovery, this approach uses the A-side with ISA mode, in case the B-side (ESR mode) would not be available. An important

difference is that the ISA mode makes use of the SAS-1 sensor only, leading to less than hemispheric coverage (ESR uses three SASs, and thus has omni-directional coverage), this would make the timing of the ISA triggering more critical.

The final choice was alternative 2 — ESR without roll control.

Attitude recovery
After a three-week-long period of meticulous preparation and an aborted attempt on 9 September, attitude recovery was established on 16 September as follows:
- After a full battery charge, the propulsion subsystem received a 6 h heating boost in order to test the thrusters needed for recovery. (It was established that all 8 branch-B thrusters were available.)
- A design calibration was carried out, followed by a 2.37 deg/s de-spin (in three steps). In less than an hour, data evaluation confirmed that the thrusters were working as expected and that the target spacecraft spin rate had been achieved.
- A second three-step de-spin manoeuvre brought the spacecraft rotation rate down to 0.86 deg/s. After a careful check on the success of the manoeuvre and a 'go' for all subsystems, ESR-8 was triggered to point the spacecraft towards the Sun without roll control. The roll rate was then corrected using thrusters 5 and 6 in open-loop from the ground.

On 22 September, there was an attempt to make the transition from ESR to ISA (Initial Sun Acquisition), then to FSA (Fine Sun Acquisition) and on to RMW (Roll Mode with Wheels). However, this was not successful for several reasons and ESR-9 was triggered. Later the same day, while recovering from ESR-9, a command timing problem triggered a reconfiguration of the data-handling system and a spacecraft emergency was declared on 23 September, lasting until normal-mode recovery.

After a busy week of recommissioning activities for the various spacecraft subsystems and an orbit-correction manoeuvre, SOHO was finally brought back to normal operating mode on 25 September, at 19:52:58 UT. Remarkably, the only equipment failures at spacecraft level were in two of the three gyros. All other subsystems were working as well as they had before contact was lost.

Instrument re-commissioning
From thermal models, confirmed by housekeeping data received on 9 August, it was established that the instruments had been through an ordeal of extreme temperatures, from approximately +100°C to less than –120°C. Understandably, the twelve instrument teams were anxiously awaiting the moment when they could switch on and check out their instruments.

Instrument re-commissioning started on 5 October with the SUMER instrument, followed by VIRGO on 6 October, GOLF on 7 October, COSTEP and ERNE on 9 October, UVCS on 10 October, MDI on 12 October, LASCO and EIT on 13 October, CDS on 17 October, SWAN on 18 October, and CELIAS on 24 October. The re-commissioning exercise proceeded very smoothly proving that, even after more than three months of forced inactivity, the experiment operations teams were collaborating and working as effectively as they had before the SOHO mishap. All twelve instruments also performed as well as they had before the unfortunate loss of contact, and

Figure 6. Some of the members of the SOHO Recovery Team, at NASA/GSFC on 17 September 1998

some even better, despite the extremes of heat and cold to which they had been subjected.

Epilogue

As luck would have it, SOHO's tribulations for 1998 were not yet over. On 21 December, the last onboard gyro failed during the preparation of a routine orbit-correction and wheel-management manoeuvre. The spacecraft was again put into ESR mode, using two-axis attitude control for pitch and yaw and controlling the roll axis in open-loop from the ground. By early in January 1999, it was possible to control the yaw manually from the ground. The use of thrusters to maintain SOHO's attitude had a significant impact in that a weekly orbit correction was now needed, consuming an average of 7 kg of hydrazine.

Following SOHO's initial recovery with only one gyro operational, a gyroless mode of operation was already being contemplated. In early January, therefore, it was decided to accelerate the development of gyroless operation. This called for modification of the onboard Attitude and Orbit Control Subsystem (AOCS) software and, in particular, the controller that had used the gyro. A software patch was prepared and tested in Europe before being delivered to GSFC for uploading on 29 January. Recovery from ESR was started on 30 January and wheel-management and orbit-correction capabilities were achieved on 1 February, making SOHO the first three-axis-stabilised ESA spacecraft to be operated without a gyro.

Acknowledgement

The more than 160 members of the SOHO Investigation/Recovery Team (Fig. 6) – drawn from the ESA, Matra Marconi Space, NASA and AlliedSignal Flight Operations Team – are to be congratulated for a job well done. They had achieved their mandate – to re-establish communications with SOHO and to return it, as far as possible, to full routine operation – under very demanding technical and schedule constraints.

WWW

The SOHO Web page with daily images, operation plans, targets, and image gallery is available at:
sohowww.estec.esa.nl (European site) and
sohowww.nascom.nasa.gov (US site)
The latest EIT images can also be found on the Web at:
unbra. nascom.nasa.gov/eit/eit_full_res.html

The Re-certification Review

The SOHO Mission Interruption Joint ESA/NASA Investigation Board strongly recommended that the two Agencies immediately proceed with a comprehensive review of SOHO operations, addressing issues in the ground procedures, procedure implementation, management structure and process, and ground systems. This review process should be completed and process improvements initiated prior to the resumption of SOHO normal operations.

The Re-certification Review took place at GSFC on 2/3 December 1998. The conclusions and recommendations of the Review were as follows:

- The Board acknowledges the outstanding achievements of the SOHO Recovery Team
- The spacecraft is operating in a Sun-pointing mode with all instruments on and collecting high-quality science data
- Roll gyro redundancy has been lost, which increases the risk associated with recovery from future spacecraft anomalies
- The Board endorses the implementation of several measures to increase ground-system effectiveness in order to reduce risk to operations
- Recommendations include a strengthened management structure and processes with increased staffing and includes a phased approach to transition to normal operations
- Implementation of the response to these recommendations will contribute significantly to the mitigation of risk in future operations and ensure the obligations of both Agencies.

SOHO Mission Interruption Joint ESA/NASA Investigation Board – Extract from Final Report

Contact with the Solar Heliospheric Observatory (SOHO) spacecraft was lost in the early morning hours of 25 June 1998 (EDT), during a planned period of calibrations, manoeuvres, and spacecraft reconfigurations. Prior to this, the SOHO Operations Team had concluded two years of extremely successful science operations. A joint European Space Agency (ESA)/National Aero-nautics and Space Administration (NASA) engineering team has been planning and executing recovery efforts since loss of contact, with some success to date.

ESA and NASA management established the SOHO Mission Interruption Joint Investigation Board to determine the actual or probable cause(s) of the SOHO spacecraft mishap.

The Board has concluded that there were no anomalies on board the SOHO spacecraft, but that a number of ground errors led to the major loss of attitude experienced by the spacecraft.

The Board finds that the loss of the SOHO spacecraft was a direct result of operational errors, a failure to adequately monitor spacecraft status, and an erroneous decision which disabled part of the onboard autonomous failure detection. Further, following the occurrence of the emergency situation, the Board finds that insufficient time was taken by the Operations Team to fully assess the spacecraft status prior to initiating recovery operations. The Board discovered that a number of factors contributed to the circumstances that allowed the direct causes to occur.

The Board strongly recommends that the two Agencies proceed immediately with a comprehensive review of SOHO operations addressing issues in the ground procedures, procedure implementation, management structure and process, and ground systems. This review process should be completed and process improvements initiated prior to the resumption of SOHO normal operations.

Use of WWW Technology for Mission Control Systems

S. Haag, J. Gallego & M. Jones
Mission Control Systems Division, ESA Directorate for Technical and Operational Support, ESOC, Darmstadt, Germany

The remarkable increase in the popularity of the Internet, fed by rapid expansion of its supporting technology, has led to new ways of doing business, as well as revolutionising the entertainment industry. In particular, people are beginning to use the Internet for many daily tasks, such as on-line shopping, on-line banking, booking travel, etc.

Until recently the world of mission control was a closed one, carried out from control rooms equipped with expensive custom-built systems. Providing access to mission data from outside this hermetic environment was difficult and expensive. The Internet and its technologies – especially those associated with World Wide Web (WWW) browsers – are beginning to change all that.

What is a mission control system?

Descriptions of mission control systems are often obscured in layers of jargon and tedious, irrelevant detail that conceal the relative simplicity of their principles. We will try here to give a simple explanation of a mission control system's basic functions, and then make an analogy with systems more familiar to the layman to help reinforce this.

In essence, a Mission Control System (MCS) is responsible for monitoring the health of a spacecraft and for controlling it. It may also monitor and control elements of the supporting ground equipment. It comprises a computer system connected to one or more ground stations, which are responsible for communication with the spacecraft. Via the ground stations, the MCS receives telemetry data from the spacecraft, which it uses to monitor the spacecraft's health. The MCS controls the spacecraft by sending it telecommands, which are in effect instructions to the spacecraft. An MCS thus operates on the same principles as a process control system, in which the process is monitored via readouts of sensors and controlled via commands to the process. The telemetry data will contain so-called 'housekeeping' parameters; typically these are regularly sampled on board to acquire information about the spacecraft's subsystems. These parameters can contain analogue values, such as battery charges and currents, temperatures of particular components, or binary values, such as an on/off indication for an on-board experiment.

The practice during the Launch and Early Orbit Phase of a mission has been to operate mission control from control rooms at ESOC, either the Main Control Room (MCR) or Dedicated Control Rooms (DCRs). These control rooms are equipped with work stations supporting the various displays. It is important to note that in this traditional approach, spacecraft operations activities have always been localised in the MCR or the DCR at ESOC. This simplifies security (i.e. authentication and authorisation of users of the control system).

Analogies between MCS and other systems

From the point of view of the interactive user, a mission control system has many features in common with commercial Information Technology (IT) systems, such as those for banking, stockbroking and e-commerce. Typically these systems have a certain number of 'screens' falling into two categories:

- Various views of the data the system deals with (e.g. for banking, the statement of recent transactions on an account; for stockbroking, the current price of a selection of shares). These screens correspond to the telemetry displays and telecommand history displays of mission control.
- Those which allow the user to give instructions to the system (e.g. for banking, to initiate a transfer from an account). These screens correspond to the interface for sending telecommands to a spacecraft (in ESOC terminology, the 'manual-stack').

On-line or Internet banking allows account holders to manage their accounts via the World Wide Web (WWW). They need a simple PC with Internet access and a suitable WWW browser. Typically they start the browser, key in the Internet address (Unified Resource Locator: URL) for their on-line banking service. The user will have to give security information (e.g. account number and password or Personal Identification Number: PIN) – this corresponds to the 'roles and privileges' facilities of an MCS. He/she will then get the on-line banking home page that will have hyperlinks in the form of desktop icons to the various services provided. Each such service will typically have a 'screen' associated with it. The user may then have to provide further security information (e.g. to carry out a cash transfer) and the screen may be a form. The analogy can be carried further. After making cash transfers the user can ask for a list of completed transfers, the analogue of a telecommand history. In some forms of e-commerce, the response to say a purchase request, will be provided in the form of an e-mail. In MCS terms, this is the analogue of a telecommand report, a feature of ESA's Packet Utilisation Standard (PUS).

The question is then, if such services can be provided to the public at large for such a security-sensitive service as banking, can a similar service be provided to the space data or operations community by mission control systems? This article sets out to demonstrate that the answer is definitely yes. Because of the high cost of space missions, it is natural that in the past a closed, conservative approach has been taken to the implementation of control systems. However, the pressures to reduce costs and the increasing demands of users are changing this. Remote access to mission control systems is now really needed and we can cite three reasons:

1. During certain phases of a mission, support is needed from the spacecraft manufacturer or from payload providers. Traditionally, they have come to the mission control centre and used facilities there, but it would be cheaper for them to work from their home bases.

2. Payload providers need to access the data provided by their on-board experiments and to be able to control them. Typically this has been done via expensive special-to-project Payload Operations Control Centres (POCCs) or Science Operations Centres (SOCs), with dedicated communications links to the mission control centre. The idea of having remote access to payload control from the experimenter's home base has been around for a long time under the name of 'telescience'. As the number of low-cost missions which cannot afford expensive POCCs/SOCs grows, the pressure to provide genuine telescience increases.

3. There are great pressures to reduce the cost of operations. For routine operations, one way to do this is to automate them, thus reducing the amount of manual control needed. However, it is unlikely that all situations can be dealt with automatically and spacecraft specialists may still need to be called out. Traditionally the engineer would physically travel to the control centre. Remote access to mission control data via Internet technology could allow more responsive on-call support without the engineer having to leave home. Of course, automation technology is also required (not the subject of this article).

The technologies

Object orientation

Until the early 1990s, most software engineering (i.e. building of software) was based on the techniques of structural analysis, involving the analysis of data-processing problems by functional decomposition. In such analyses, data was treated separately from function.

Object-oriented methods originated in the Simula67 and Smalltalk programming languages, and the techniques of structured analysis, particularly data modelling. Although the approach dates back some 20 years, it has only recently become mature to the extent that it is the mainstream paradigm for the 1990s. Object-oriented methods differ from structured methods by:
- starting development with the identification of the objects in the problem domain with which the software will deal
- building an object model (rather than a functional model)
- integrating functions and data into objects, instead of separating them between the data model and the functional model.

Object-oriented methods are supported by a number of object-oriented languages, of which C^{++} and Java are the most well-known.

For reasons for which we do not have space here, object-oriented methods have proved to have many advantages over the earlier structural ones. In particular, software with rich functionality is made easier to implement because of the ability to inherit code. This inheritance property also permits easier re-useability, which can be realised using object libraries (analogous to subroutine libraries in the older technology) and application frameworks, which are in effect reusable object-based architectures.

The object-oriented paradigm is now leading to a new discipline of component-based software engineering in association with technologies such as CORBA and DCOM (discussed later).

Client/server

There is no precise consensus in the IT Industry on the meaning of the term 'client/server', but the following 'definition' probably captures the most common understanding. In the client/server approach, an application is split into a server and a client process. The server process provides services and the client consumes them. A server can service many clients at once and regulates their access to resources. This also means that client/server systems are usually distributed. However, it is also possible to localise server and client(s) on one machine. Client/server computing is the most basic technology underlying the Internet.

There are different possibilities for distributing tasks between client and server, for example:
- All the processing is done on a server, while the client user work stations are just used as display terminals.
- Distributed Application Model: some of the processing is done on each client station, while the basic kernel processing is done on the server. This configuration is very flexible, since the task distribution between server and clients can be varied according to need.

CORBA

In most organisations today, heterogeneous computing environments, i.e. mixtures of different platforms, operating systems and languages, are a reality. Differences between platforms reinforce the need for multi-vendor solutions. CORBA (Common Object Request Broker Architecture) is a standard defined by the Object Management Group (OMG), an industry consortium, whose objective is to define a set of interfaces for interoperable software. CORBA is a specification of the framework that enables the integration of different components split over a network of work stations and written in different programming languages. It provides location transparency in that a client located on any work station can access objects located on a server, over a network. CORBA is based on two main concepts:
- An Interface Definition Language (IDL) to define object interfaces; these can be invoked from any language providing CORBA bindings (this includes C, C^{++} and some versions of Java; see below)
- The Object Request Broker, which is the object key. It lets objects transparently make requests to, and receive responses from other objects located locally or remotely.
- CORBA is the definition of a form of client/server middleware – in fact the best available to date.

Vendors provide products to support the CORBA standard. The work reported here has used the product ORBIX from Iona (Ireland). DCOM (Distributed Common Object Model) is an alternative standard in the area, supported principally by Microsoft.

Java

Java is an object-oriented programming language, similar to but simpler than C^{++}. Java code can be downloaded to Web browsers in the form of 'applets', which can then be executed on the client. The Java code executes within a so-called 'Java Virtual Machine' (VM) resident on the client work station. This gives platform independence, in that it permits the use of any client platform that can support the Java VM environment. The latest version of the Sun Java Development Kit (1.2), for example, also supports CORBA.

SCOS-2000

SCOS-2000 will be ESOC's latest and most

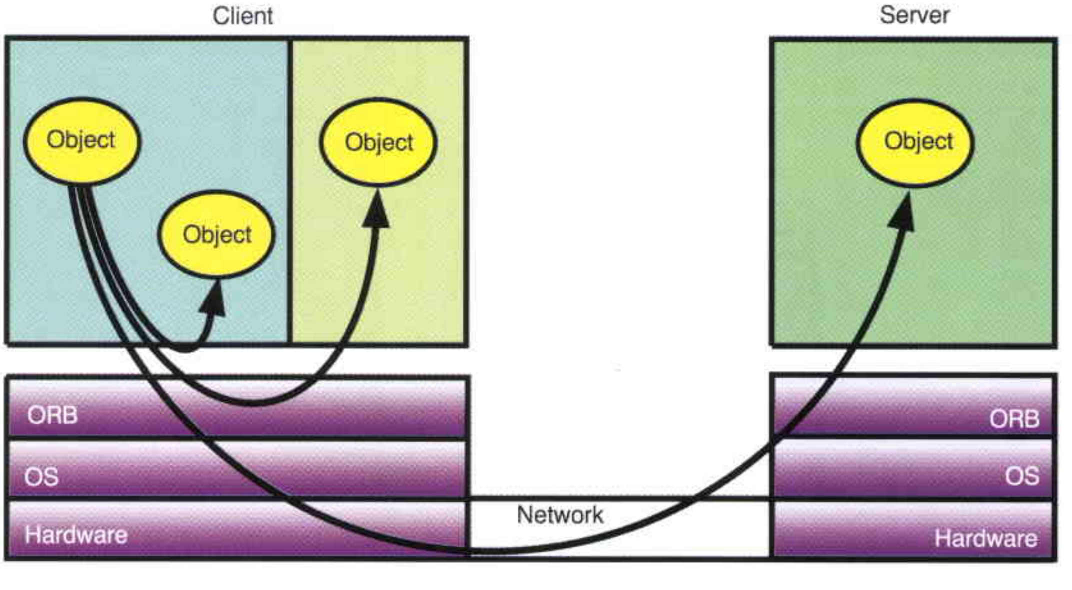


Figure 1. Location independence achieved using CORBA

modern mission control system. It is an upgrade of the SCOS-II system, described in earlier issues of the ESA Bulletin and successfully used for four missions to date. In SCOS-2000, the telecommand system is rewritten and made fully generic. The internal runtime database system is being replaced by a Commercial-off-the-Shelf (COTS) product for better performance and function. SCOS-II/SCOS-2000 runs under the Unix operating system (currently Solaris 2.6 on Sun platforms). Like SCOS-II, SCOS-2000 is a distributed system using client server and object oriented technology. In addition it uses CORBA technology.

SCOS-II/SCOS-2000 is an example of an application framework. The technologies used allow easy mission customisation, a point already proven with SCOS-2000 in low-cost implementations such as that for the Teamsat mission (reported upon extensively in ESA Bulletin No. 95) in 1997. SCOS-2000 will be completed in mid-1999 and an early release was demonstrated in December 1998.

As an open system SCOS-II/SCOS-2000 is an excellent choice of platform to provide a basis for remote access, and is thus the MCS kernel that the work reported here uses. Most of this work was carried out in the last 18 months or so using SCOS-II, but it will be applicable for SCOS-2000 and will be adapted as necessary.

Remote displays using X technology
X11 is the foundation for the standard graphical desktop environment for most Unix systems. The idea of X11 is to provide desktop access to any platform in a network from any other platform. In the Unix world, the X11 display system runs just like any other application on the desktop. The X11 server resides on the local desktop and handles all local X protocol communications. The protocol contains all messages for screen updates, mouse movements, window positions, etc. The X client application resides either on the local Unix work station or on the remote server. The two parts of the system – the X server and the X client – are in operation whether the programs are run locally or remotely (but it can also run on the local Unix work station). So an X11-based application automatically inherits the ability to be run remotely from a simple 'X-terminal'.

For SCOS-II this means that, for example, an application on the Soho spacecraft data retrieval system at Goddard Spaceflight Center can be started remotely from an X-terminal in Darmstadt, and Soho telemetry thereby viewed from Darmstadt. This facility has also been used with firewall security between the two networks. There are new facilities available in firewalls that permit one to connect sites with all the necessary security control, but the fact that the X-protocol itself has no security mechanism (no encoding of the data) means security is limited.

X is also a powerful tool for doing remote maintenance. It has been used for SCOS-II installations at sites remote from the SCOS-II maintenance team residing at Darmstadt.

Remote displays using CORBA
Siemens Austria has carried out a study entitled 'Exploitation of New Information Technology on Flight Control Systems', in which they implemented a remote Man/Machine Interface (MMI) to SCOS-II using CORBA technology.

The basic idea of the study is to use CORBA technology to run the display objects on a PC platform. This was facilitated by the fact that SCOS-II displays use a design pattern called the 'Model View Controller' (MVC), shown in Figure 2. A 'design pattern' in object-oriented methods is yet another form of reuse, and comprises a specialised object model for solving a particular problem. In the case of the MVC, the problem is that of separating a model of some system from its display (or 'view') and the interactions via the 'controller' with these two using, for example, mouse and keyboard. This separation allows easy building of new views. For a control system like SCOS-II, the model comprises a set of telemetry parameter objects. The view object within the context of telemetry displays is a presentation of a single model on a screen; whenever the model changes, the view object is informed and updates its displays. Via the clock control, the user may change the model (e.g. switch between live and retrieval processing modes).

This model-view controller approach can be reused within a CORBA implementation, as shown in Figure 3. The model and views are distributed over a heterogeneous client-server

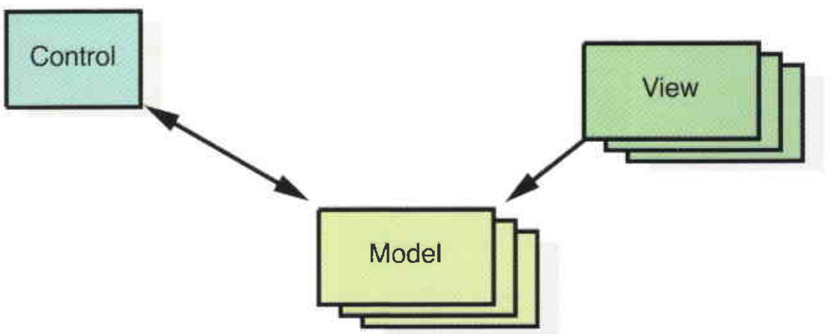


Figure 2. Local model and view
Model: comprises a set of telemetry parameters
View: presentation of the data on the screen

network. Views, which are acting as clients, are located on different work stations (e.g. PC/ Windows NT). Figure 3 shows two models, one for real-time data, the other for retrieval. The porting of the view to a PC is straightforward, since ILOG VIEWS, the commercial package supporting the Graphical User Interfaces (GUIs), is also available on that platform and allows support of Motif, Windows and Windows 95 MMI standards.

Remote displays using Web technology

The previous approach involved porting the view objects to the PC/NT client platform. An alternative approach is to implement an interface via a WWW browser. This has the advantage that no client software has to be set up on the PC/NT platform other than a Web browser. This involves implementing a Java applet that is downloaded to the client Web browser to execute the view.

A first step in the prototype was to implement a telemetry query facility, whereby the user can request static and dynamic information on one parameter at a time. Since it only deals with one parameter, there is no problem of performance. Figure 4 shows the resulting Web-based telemetry query display.

The second step was to implement an alphanumeric display facility, whereby users can select several parameters from the list and build their own alphanumeric display (Fig. 5). This demonstrates that Java provides excellent features to build an MMI, but it also shows that it requires a lot of resources on the user work station in order to update the screen when receiving the new values. At present a message is sent to the Java virtual machine every time any parameter is updated. To avoid this, parameter updates can be grouped together and sent in a batch to the user work station.

A simplified schematic of the setup is shown in Figure 6. A Web server has been implemented to which the PC client connects, e.g. via the Internet. The Web server in turn is connected to a SCOS-II system via a special interface which provides parameter values. In order to communicate with the SCOS-II system, a C++ interface server acting as a communication channel between the SCOS-II server and the Java application was built. This server is responsible for message exchange between the Java user application and the SCOS-II C++ server software. The Web server had to be

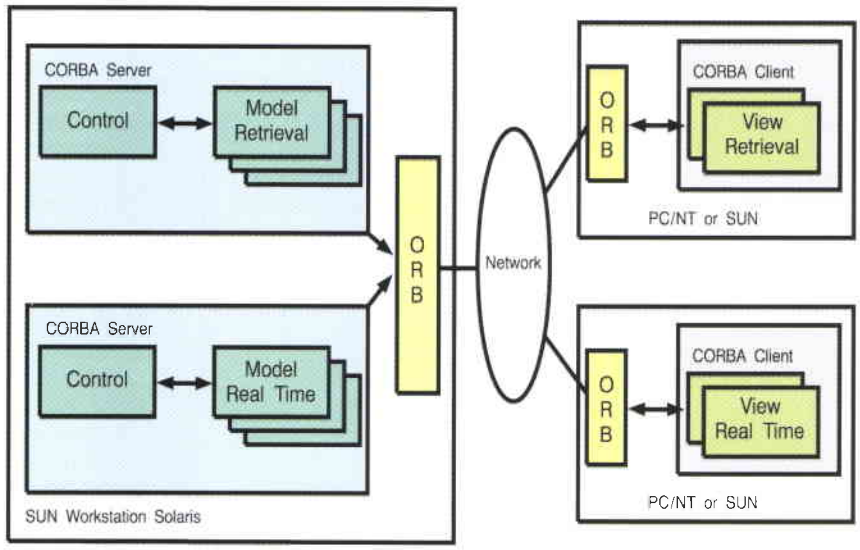


Figure 3. Distributed models and views

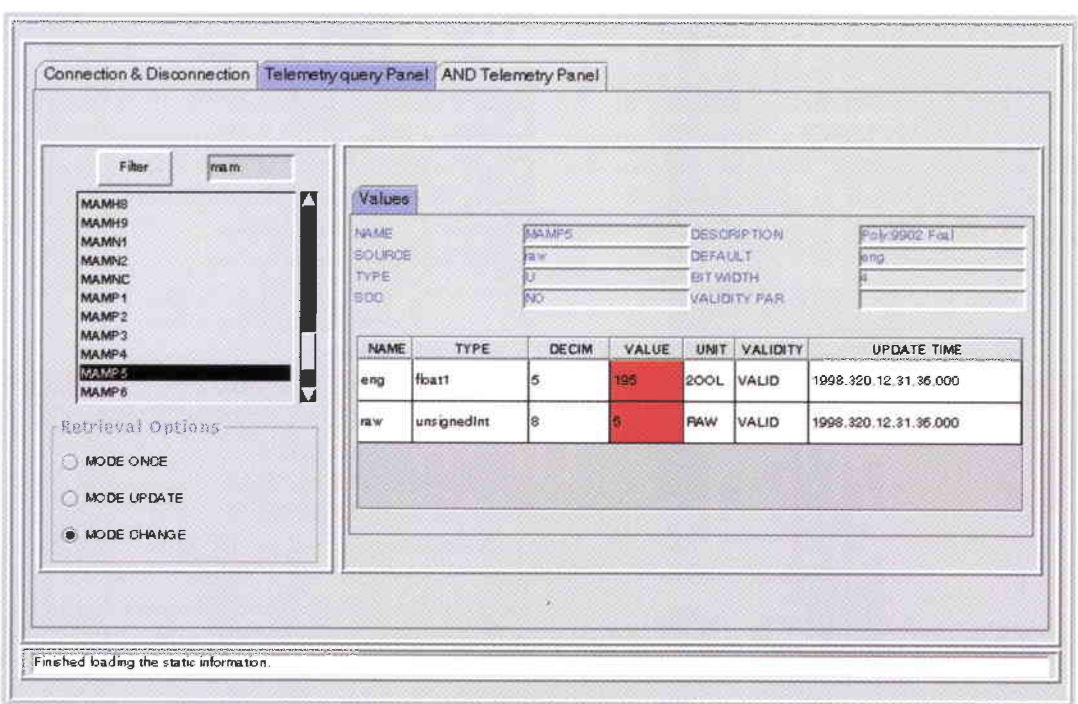


Figure 4. Telemetry query

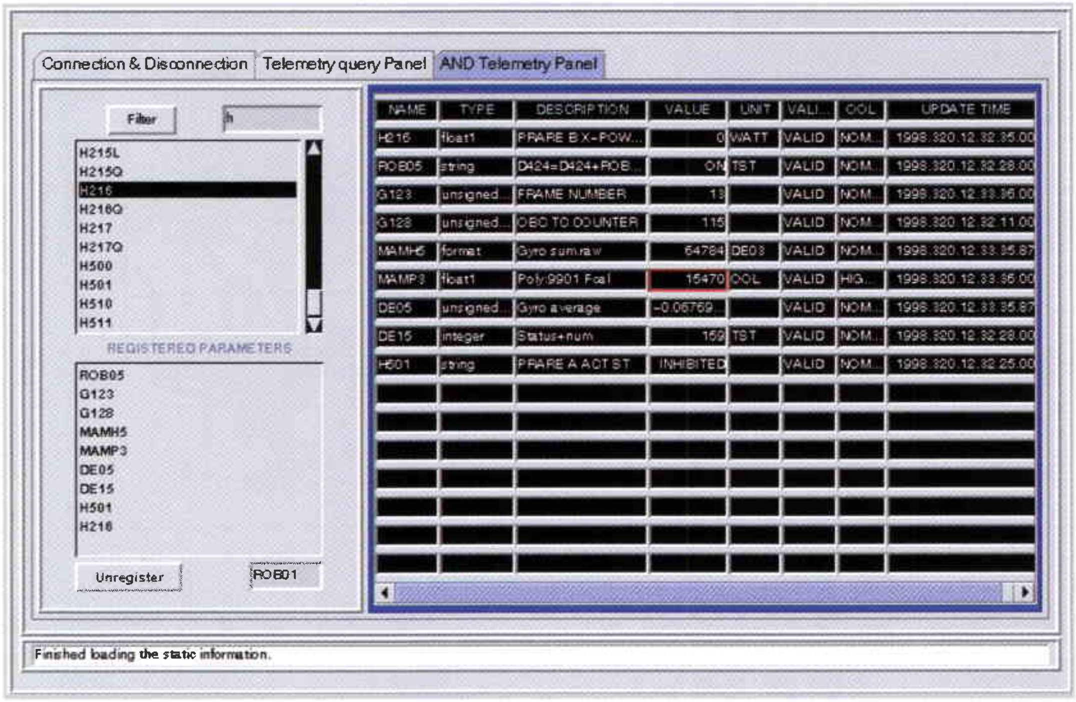


Figure 5. Alphanumeric display facility

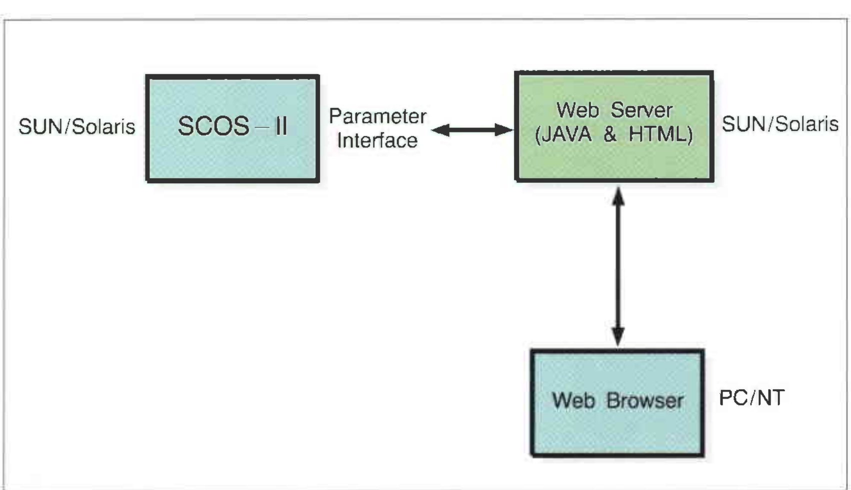
located on the same work station as the interface server as applets can only communicate with the Web server (due to security restrictions). This work was carried out by J. Gallego, a Young Graduate Trainee at ESOC.

Combining Web and CORBA technology

The work reported here is at the preparation stage and will be carried out within the framework of a study called Web Remote Monitoring, also by Siemens Austria.

The implementation of the parameter interface using CORBA opens SCOS-2000 to the external world. External components will be able to connect to SCOS-2000 using this interface in a standard manner, independent of the programming language (C^{++}, Java). As mentioned earlier, the newest version of Java is integrated with CORBA: this will ensure compatible evolution of these Java- and CORBA-compliant products in the future.

Figure 6. Java interface



If the SCOS-II system is installed behind a firewall system, the use of CORBA allows one to implement security-controlled access by external users (Java applets embedded in the HTML used for building Web pages) to the SCOS-II system, via a technique called 'HTML tunelling'.

While our current prototype, which uses Java, can only be used on a Local Area Network (LAN) and cannot pass a firewall, the merging of CORBA and Java and the installation of special CORBA security software on the firewall machine solves this problem. Figure 7 is a schematic of the proposed architecture.

Remote control

We have talked at length about remote monitoring, but what about remote control (i.e. commanding)? In principle, the techniques for remote monitoring could also be applied, e.g. to set up a remote manual stock. However, there are issues that have nothing to do with remote access technology. In particular, e.g. for an on-board experiment, remote commanding would only be useful if: (a) the MCS can ensure that the remote commands are going to the intended experiment and (b) the commands do not cause changes in resource consumption on board which affect either the spacecraft bus or the other experiments. For this reason, external command operation requests are normally submitted to a 'mission planning' process. It follows that the uses of remote control are likely to be strictly limited to very special cases, such as independent on-board experiments without resource constraints. The Web Remote Monitoring study will also examine remote control.

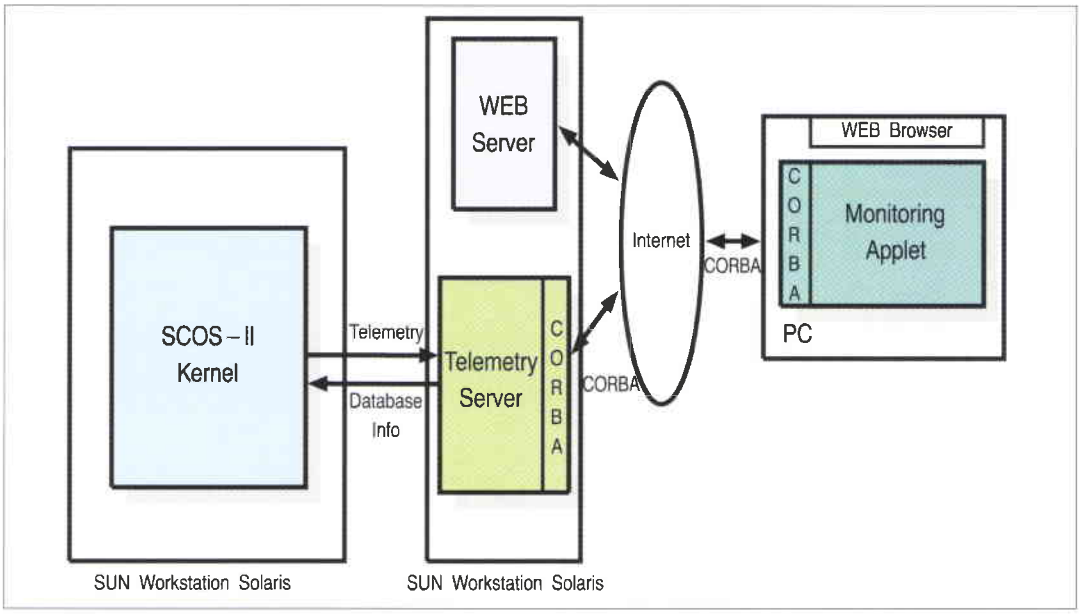


Figure 7. Using a Web technology architecture

Conclusions

This article has described several approaches to providing remote user interfaces to mission control systems:

- Using X11 technology: this works well in a Unix environment in which there are no security restrictions (e.g. a Local Area Network). It comes 'free-of-charge' with a Unix-based MCS and is also of great advantage for the maintenance of the system when, as is increasingly the case, it has to be installed at a remote site.

- Three possible approaches to making the system even more open, by allowing displays to run on PC clients using either CORBA or Web technology, or a combination of both. Broadly speaking, the approach wins on performance grounds and can handle security, but requires the user to install the display software on his client platform. The Web approach does not require any specific software installation other than a Java-enabled Web browser. Because of the overhead of the Java Virtual Machine, it has lower performance. An approach combining Java and CORBA is a good compromise in having the advantages of both browser access and good security.

The Web-based approaches are of particular interest for 'lights-out' operation, which requires: (i) high-level automation of the ground system, (ii) complemented by remote access to the system by engineers, either in their offices or 'on-call' at home. The work reported here goes a long way towards fulfilling the second part, since by these means 'on-call' engineers could provide out-of-hours assistance from home in the event of unforeseen contingencies. Technical feasibility is confirmed by the work done to date. However, the question of performance needs to be resolved by prototyping demanding displays, such as the alphanumeric and graphic displays so essential in the operations environment.

Do the results of these studies answer the question of which operating system to adapt for modern mission control systems, and in particular the vexed issue of Unix versus Windows NT? At this point, Unix and NT are currently the leading modern operating systems. However, without going into any examination of their comparative strengths and weaknesses, it is taken for granted that both systems are suitable for mission-critical applications such as mission control systems. Furthermore, it is not possible to predict how these systems will evolve over the next ten or so years.

The results of these studies clearly show that working in a heterogeneous environment (e.g. mixed Unix and NT platforms) is well understood and is no problem. Our view is that the correct policy is to reduce dependency on particular operating systems, and avoid getting tied into particular vendor's proprietary products. This can be achieved using the integration technologies presented here, and it is further helped by the fact that many popular COTS products are available for both Unix and NT.

Water Recovery in Space

C. Tamponnet & C.J. Savage
Thermal Control and Life Support Division, ESA Directorate for Technical and Operational Support, ESTEC, Noordwijk, The Netherlands

P. Amblard & J.C. Lasserre
Techno-Membranes, Montpellier, France

J.C. Personne
Université de Montpellier II, Montpellier, France

J.C. Germain
CORRYL, Courtaboeuf, France

In the absence of recycling, water represents over 90% of the life-support consumables for a manned spacecraft. In addition, over 90% of the waste water generated can be classified as moderately or slightly contaminated (e.g. shower water, condensate from the air-conditioning system, etc.). The ability to recover potable water from moderately contaminated waste water hence enables significant savings to be made in resupply costs. A development model of such a water-recovery system, based on membrane technology, has been produced and tested using 'real waste water' based on used shower water. Results indicate some 95% recovery of potable water meeting ESA standards, with total elimination of microbial contaminants such as bacteria, spores and viruses.

Introduction
'Life support' covers the theory and practice of sustaining life in environments or situations in which the human body is incapable of sustaining its own natural functions. There are essentially only three practical, non-exclusive ways to ensure the biological autonomy of man when isolated from his original biosphere: provide all required consumables at the start of the mission or resupply them, regenerate life-support materials during the mission, or utilise in-situ resources (in the case of manned missions on planets).

Historically, air, water and food were taken on board and the waste stored and returned to Earth. This was a completely open-loop life-support system used successfully for short-duration space missions. As space missions get longer, however, supply loads get heavier and soon prohibitive, effectively limiting the duration of such missions, however exciting and potentially important they may be. It becomes crucial then to close some vital loops to permit longer missions.

When we consider the three vital loops of a life-support system, i.e. air, water and food/solid waste, the most demanding in terms of mass constraints is the water loop. Indeed, water represents approximately 92% by mass of the total life-support consumables (see Table 1). Closing the water loop by recovering potable water from waste water will therefore already provide for 92% of human needs, i.e. 92% autonomy of man in space.

Background
Waste water can be roughly classified according to its degree of contamination. It is now generally accepted that highly contaminated water, such as urine, must be subjected to a process involving phase change before it will be regarded as suitable for re-use. Such phase-change systems have been studied for several years, notably in Russia and the USA, and include techniques such as AES (Air Evaporation System), TIMES (Thermo-electric Integrated Membrane Evaporation System) and VCD (Vapour Compression Distillation). Moderately or slightly contaminated water, such as hygiene (washing, showering) water, condensate recovered from the air-conditioning system, product water from the air-revitalisation (oxygen recovery) system and possibly also the product water from the urine processing system, can be treated in other ways which promise to be less complex, consume less power and provide a higher percentage recovery rate.

From Table 1 it can be seen that over 90% of the expected waste water can be classified as 'moderately contaminated'. If, in addition, the product water from the processing of the highly contaminated waste stream is regarded as 'moderately contaminated', the need, as a first priority, for an effective, reliable and efficient 'core water recycling system' for processing moderately contaminated water becomes evident.

Core water recycling system

Based on the conclusions of past studies financed by the Agency, a core water recycling system was designed, aimed at recovering potable water from hygiene water, typified by shower water. The system, shown schematically in Figure1, uses a combination of filtration and reverse-osmosis units in successive stages to eliminate solids, organic and inorganic molecules, including micro-organisms, from the product stream. The aim is to produce water meeting the ESA quality standards for potable water defined in ESA PSS-03-402.

To validate the technology, a development model has been designed, built and tested. This development model water-recovery unit (Fig. 1) is contained in a rack approximately 2 m wide, 2.1 m high and 0.6 m deep, and consists of four successive membrane units: one ultra-filtration (UF) unit based on a mineral membrane, and three successive reverse-osmosis (RO) units. It is sized to produce approximately 2 litres of drinking water per hour (Fig. 2). The role of the first (ultra-filtration) unit is to reduce the turbidity of water, i.e. to exclude particulate materials and high-molecular-weight macromolecules. Elimination of low-molecular-weight organic molecules as well as ionic compounds (salts) is the task of the three successive reverse-osmosis units. The test bed operates nearly automatically, controlled by software specifically designed for that purpose, the main exception being the periodic purges needed to maintain membrane performance, which are done manually.

The UF unit consists of a cartridge containing seven tubular 'Carbosep M1' ultra-filtration membranes (zirconium and titanium on a carbon support), connected in parallel. These membranes have a molecular weight cut-off of 150 x 10^3 dalton, and a total filter surface area of 0.16 m^2. The operating pressure is typically 2 – 4 bar.

The RO units consist of Filmtec SW30 (first unit) and Filmtec SW30HR (second and third units) membranes, made from polysulfone on polyester support, each about 6.4 cm in diameter and 36.5 cm in length. Each has a total membrane area of 0.9 m^2 and typically operates at a pressure of about 55 bar.

Table 1. Average human requirements per person per day

Consumables		**Waste**	
Type	Mass (in kg)	Type	Mass (in kg)
Gaseous state		**Gaseous state**	
Metabolic oxygen	0.83	Metabolic carbon dioxide	1.00
Sub-total (gaseous)	*0.83*	*Sub-total (gaseous)*	*1.00*
Liquid state		**Liquid state**	
Water for:		Water from:	
- food re-hydration	1.15	- metabolic perspiration and respiration	2.28
- food preparation	0.79		
- drinking	1.62	- urine	1.50
- dish washing	5.46	- faeces	0.09
- hand/face washing	1.82	- dish washing	5.46
- shower	5.45	- personal hygiene	7.27
- laundry	12.50	- laundry	12.50
- toilet flushing	0.50	- toilet flushing	0.50
Sub-total (liquid)	*29.29*	*Sub-total (liquid)*	*29.60*
Solid state		**Solid state**	
Solids for:		Solids from:	
- dry food	0.62	- sweat	0.02
- packaging, bags, paper	0.89	- urine	0.03
		- faeces	0.09
		- packaging	0.89
Sub-total (solid)	*1.51*	*Sub-total (solid)*	*1.03*
TOTAL	**31.63**	**TOTAL**	**31.63**

During operation, the incoming waste water is pre-filtered and stabilised by the addition of biocide (0.2% oxone solution). Sulphuric acid is then added, if necessary, to obtain a pH of 4. After processing through the ultra-filtration unit (UF1) and the first two reverse-osmosis units (RO1 and RO2), sodium hydroxide is added to the permeate to raise its pH to 7, before the final reverse-osmosis stage (RO3).

Test plan

The test campaign, illustrated in Table 2, was conducted in three stages:

(i) Test-bed commissioning, consisting essentially of system verification and preliminary testing at subsystem and system level.
(ii) Performance during a short-duration (24 h) test with reference water.
(iii) Performance during three long-duration (100 h) tests with real waste water.

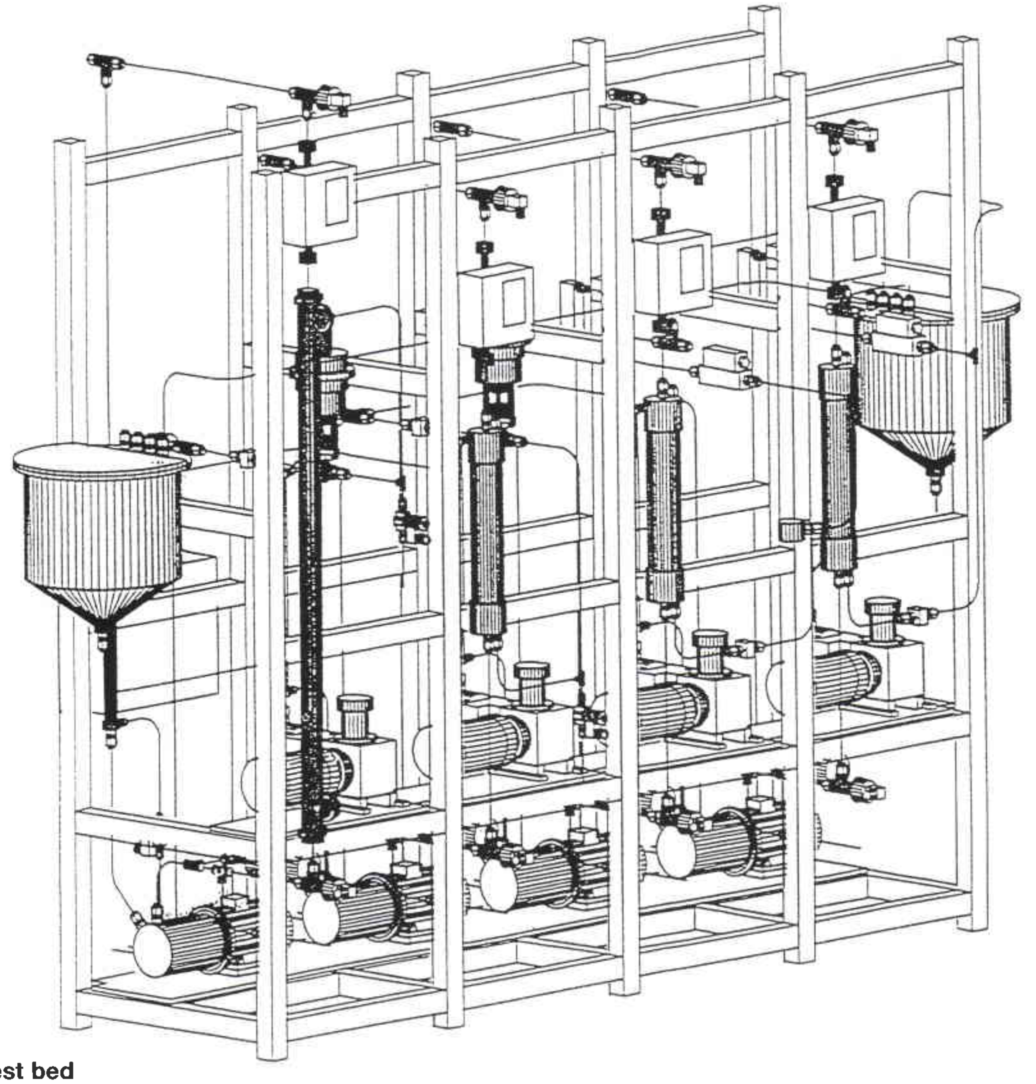
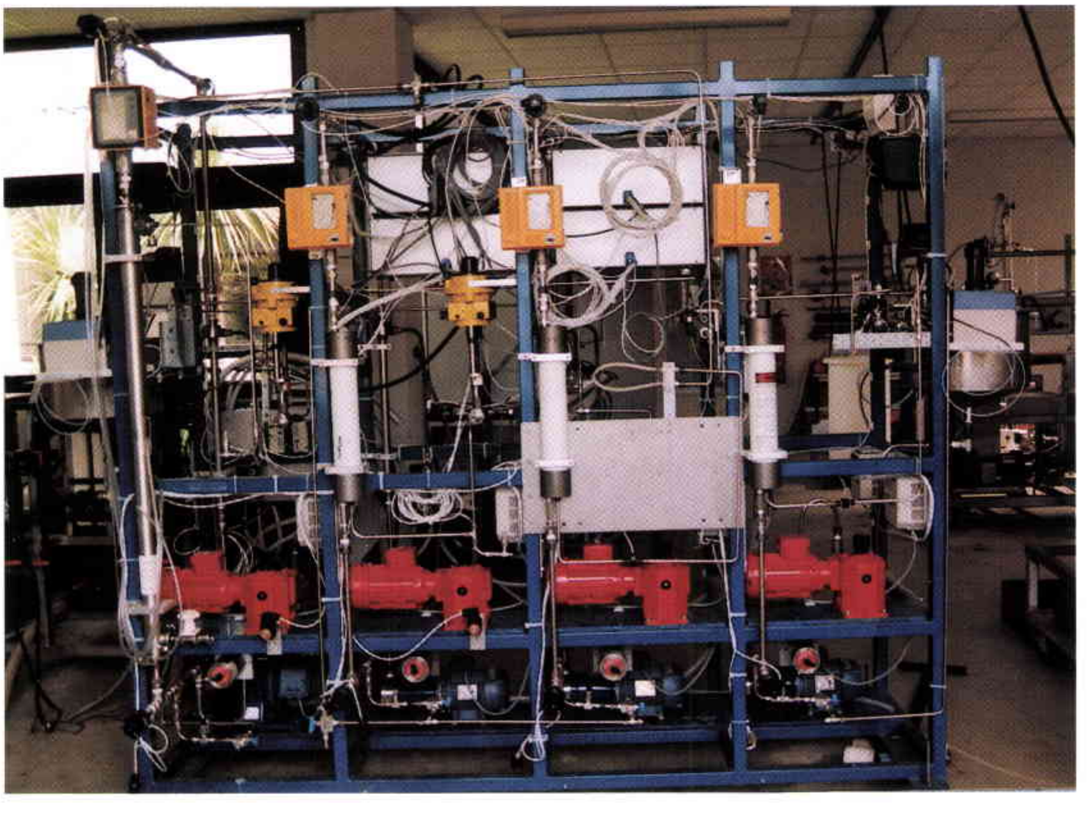


Figure 1. The water-recovery test bed



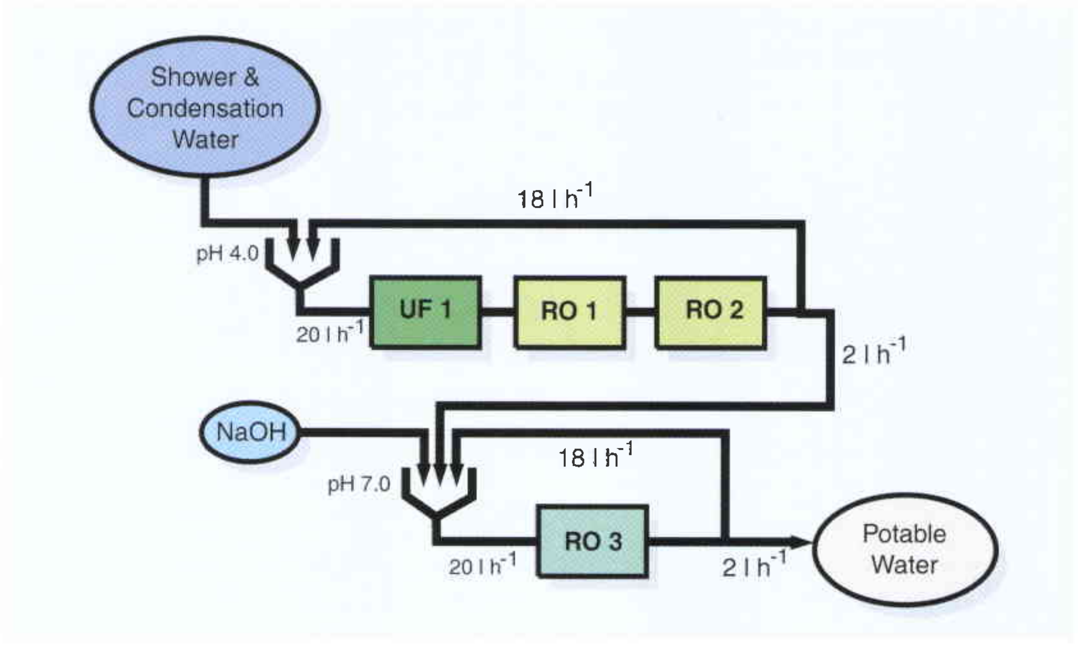


Figure 2. Water production cycle inside the recovery unit

Experimental tests were performed using real waste water based on:

- shower water (10 litres of commercial mineral water to which had been added 2.5 g of soap)
- condensation water (2 litres of demineralised water)
- bactericide (oxonia at 0.2% concentration by volume)
- sulphuric acid, as required to provide a pH of 4.0.

Achievement of a recovered water quality compliant with the ESA standards for potable water (ESA PSS-03-402) was considered as the major success/failure criterion, especially regarding the system's ability to prevent any microbial (bacterial or viral) risk. The second major criterion was the percentage of water recovered.

Test performance and results

During the testing, particular emphasis was placed on:

- quality of the recovered water
- elimination of any microbial contamination
- performance of the membranes
- performance in terms of the percentage of water recovered.

The recovered water complied with the ESA standards for drinking water (see Table 3), with one exception, namely the TOC (Total Organic Carbon) concentration. This was due to the addition of oxonia to the waste water.

The ability of the Water Recovery System to eliminate all microbial contamination was tested four times:

Table 2. Overall flow of the test campaign

VERIFICATION AND PRE-TEST	
CHOICE OF REGULATION PARAMETERS	
FUNCTIONAL TEST	- Verification at component level - Verification of automated mode
SYSTEM VERIFICATION	- Ultrafiltration membrane permeability - NaCl retention by RO membranes

PERFORMANCE TEST WITH REFERENCE WATER	
During test	- Data collection - Permeate & retentate sampling - Compounds & microbial analysis - Purging operations
After test	- Cleaning operations - Performance synthesis

PERFORMANCE TEST WITH REAL WASTE WATER	
	1st Run
During test	- Data collection - Permeate & retentate sampling - Compounds & microbial analysis - Purging operations
After test	- Cleaning operations - Performance synthesis
	2nd Run
During test	- Idem as 1st run - Microbial overload on day 4
After test	- Idem as 1st run
	3rd Run
During test	- Idem as 1st run - No oxonia added to waste water after day 2 - Microbial overload on day 4
After test	- Idem as 1st run

Table 3. Quality of recovered water compared to ESA standards

Parameters		Drinking Water ESA Standard	Hygiene Water ESA Standard	Recovered Water
pH		6.5-8.5	5-8.5	6.2-7.8
Conductivity	($mS.cm^{-1}$)	0.75	3	<0.01
Turbidity	(NTU)	2.5	10	<0.25
TOC	(ppm)	0.5	10	1.3-2.7
Oxidative power	(ppm)	-	-	230
F^-	(ppm)	1	10	<0.8
Cl^-	(ppm)	200	1000	<1.1
NO_3^-	(ppm)	25	50	<0.4
PO_4^{2-}	(ppm)	5	50	<0.2
SO_4^{2-}	(ppm)	250	TBD	<1.1
Na^+	(ppm)	150	750	<1.8
K^+	(ppm)	12	120	<0.1
NH_4^+	(ppm)	0.5	0.5	<0.1

(i) test of microbial retention by the UF unit alone during test-bed commissioning
(ii) monitoring of microbial elimination during the first long-duration test
(iii) simulation of a 'microbial accident' (serious microbial contamination) during the second long-duration test
(iv) simulation of two simultaneous microbial accidents (serious microbial contamination coupled with a failure in the bactericide [oxonia] delivery) during the third long-duration test.

Microbial contamination was induced by the addition to the waste water of the following micro-organisms:
- *Escherichia coli* ATCC 10536 bacteria at a final concentration of 5×10^6 $CFU.ml^{-1}$
- *Bacillus subtilis* ATCC 6633 spores at a final concentration of 1×10^6 $CFU.ml^{-1}$
- *Bacteriophage* MS2 virus at a final concentration of 2×10^9 $BFU.ml^{-1}$.

In the first three tests, the presence of oxonia alone was responsible for the complete elimination of the microbes (bacteria and viruses). In the fourth test, the presence of microbes was observed in the first tank before the ultra-filtration unit, but none was found after that unit.

In all cases, neither bacteria nor viruses were detected after the ultra-filtration unit, assuring the complete decontamination of waste water and protection for the down-stream reverse-osmosis membranes against bacterial contamination and bio-film development.

The performance of the membranes was according to specification and remained constant throughout the tests. Table 4 shows the membrane performance from test run number 3, but these results are typical and varied very little from run to run. The water-recovery yield was always above 95%.

These 100 h tests demonstrated the correct functioning of a water-recovery system based on membranes. It also validated the control software allowing an automated mode of functioning. The purging procedure during testing and the cleaning procedure between tests, performed manually during this test campaign, were also validated. In order to support extended testing, the next logical step in development, to explore performance over periods of months rather than days, the control software needs to be upgraded to enable purging and cleaning to be carried out automatically.

Conclusions

The ability of current membrane techniques to recover potable water from moderately-contaminated waste water has been demonstrated. The associated control system and purging/cleaning procedures have also been verified. The design has proven to be very robust in the face of simulated 'microbial accidents'. Although the design appears to protect the membranes efficiently against risks from, for example, bio-degradation or bio-film development, continuous testing has so far been limited to only a few days. The next logical step, prior to testing in space conditions, is to explore the long-term (months rather than days) performance of the system. esa

Table 4. Membrane performance during long-duration test number 3

Membrane Type	Flux		Salt Retention
UF1	85.0	$l.h^{-1}.m^{-2}.bar^{-1}$	-
RO1 (SW30)	8.8	$l.h^{-1}.m^{-2}$	99.4%
RO2 (SW30HR)	12.2	$l.h^{-1}.m^{-2}$	99.6%
RO3 (SW30HR)	13.0	$l.h^{-1}.m^{-2}$	99.5%

L'Acte en Conseil

G. Lafferranderie
Conseiller juridique, ESA, Paris

Une nouvelle appellation est apparue en 1993 dans le monde des instruments juridiques de l'ESA: l'Acte en Conseil. Pour quelles raisons, qu'appelle-t-on un Acte en Conseil dans le système juridique de l'ESA? Quels sont ses objectifs, comment se présente-t-il? Toutes questions intéressantes pour celui qui se penche sur les textes juridiques concernant les programmes et activités de l'ESA mais qui peuvent l'être également pour d'autres, en démontrant notamment l'ingéniosité dont le juriste doit faire preuve pour offrir rapidement des solutions dans le cadre – politique et juridique – de textes existants à adapter.

Première constatation: cette appellation est récente même si certains[1] ont cru pouvoir se référer à l'Acte adopté par les signataires européens de l'Accord intergouvernemental sur la Station spatiale internationale (IGA) signé à Washington en septembre 1988. Dans ce cas il ne s'agissait que de la mise en place d'un Comité chargé de suivre pour les Gouvernements européens signataires de l'IGA l'application de celui-ci. Les représentants des gouvernements européens signataires et le Conseil de l'ESA (puisque l'Agence elle-même avait un rôle) ont alors par un instrument juridique qu'on a dénommé 'Acte' institué ce Comité, arrêté sa composition et son mandat (ESA/C/MIN/87, Annexe III). L'Acte en Conseil dont nous parlons ici n'a rien à voir avec ce dernier. C'est une appellation que vous ne trouverez pas dans la Convention de l'Agence (y compris ses Annexes) ni dans les règlements, etc. La Convention parle de Déclaration et de règlement d'exécution pour les programmes facultatifs et il fallait trouver un nom distinctif.

Les traits principaux

L'Acte en Conseil ne concerne que des *programmes facultatifs* gouvernés par les instruments juridiques identifiés dans l'Annexe III de la Convention: Résolution du Conseil dite 'habilitante', Déclaration des Etats participants et règlement d'exécution du programme[2].

Jusqu'à présent trois Actes en Conseil existent :

- l'Acte en Conseil relatif à la conduite en commun des programmes Plate-forme polaire et POEM (adopté le 16 décembre 1993 ESA/C/CXI/Act-EO)
- l'Acte en Conseil relatif aux programmes spatiaux habités et la contribution de l'Europe à la coopération à la Station spatiale internationale (ESA/C/CXI/Act-ISSP(Final) adopté le 15 février 1994), et
- l'Acte en Conseil sur les mesures relatives à l'achèvement du programme Ariane-5 développement (ESA/C/CXXVII/Act(Final) adopté le 18 décembre 1996) concernant les programmes Ariane-5 développement, Ariane-5 évolution, Infrastructure Ariane-5 et Arta Ariane-5.

La caractéristique de l'Acte en Conseil est donc bien de concerner des programmes facultatifs existants selon leurs propres règles; un Acte en Conseil seul ne peut créer un programme facultatif[3].

L'Acte en Conseil est *exceptionnel* car il répond de manière collective à une situation de crise et énonce les engagements à remplir dans une période de relative courte durée. La crise est bien sûr financière et demande le rassemblement de ressources de diverses origines et des méthodes de gestion adaptées.

Il est adopté *en Conseil* (il pourrait l'être dans le cadre du Conseil directeur de programme en charge des programmes en question), ce pour renforcer la notion de solidarité. Le Conseil, l'instance suprême, est témoin en quelques sorte de cet engagement; il donne sa caution politique. Il faut relever que le premier, l'Acte en Conseil sur les programmes Plate-forme polaire et POEM-1 a d'abord délibéré dans le Bureau qui, selon la Convention, est placé auprès du Président du Conseil pour l'assister et qui permet des délibérations confidentielles entre les 'chefs de délégation'.

L'Acte en Conseil, dans ce cas, a permis l'entrée en vigueur simultanée de deux Déclarations. Il s'ensuit que l'Acte en Conseil est adopté par les Etats participant à chacune des Déclarations concernées et non pas par le Conseil lui-même, ce qui se reflète dans le préambule qui liste ensuite les autres documents juridiques, Déclarations, etc.

Un Acte en Conseil lie entre eux deux ou plusieurs programmes facultatifs et assure une passerelle entre les Déclarations correspondantes qui conservent leur valeur et ne sont pas amendées par l'Acte en Conseil.

L'Acte en Conseil doit être alors vu comme un document à valeur *politique*, l'affirmation d'une solidarité entre plusieurs Etats participants et un instrument juridique permettant de mettre en place une gestion commune en respectant les dispositions de chaque Déclaration concernée (enveloppe financière, échelle de contributions, considérations sur le retour géographique).

Les Etats participants auraient pu se lancer dans la révision des Déclarations ou établir une nouvelle Déclaration, exercice qui contenait ses périls: rediscuter les participations, agréer de nouveaux contenus de programmes; il était plus raisonnable d'essayer de construire sur l'existant que de le démolir, le consolider en réorientant l'édifice.

Au plan juridique, cela peut paraître curieux, mais l 'Acte en Conseil n'est ni une Déclaration ni une Résolution. Ses dispositions peuvent conduire à amender les règlements d'exécution. Peu importe l'appellation: ce qui importe c'est l'objectif et la place dans l'ensemble juridique relatif à plusieurs programmes facultatifs.

Déclarations, Acte en Conseil et règlement d'exécution doivent être considérés comme un tout, un ensemble où chacun a sa propre partition à jouer.

Examinons les textes

On citera notamment le préambule de l'Acte en Conseil ISSP du 15 février 1994 :

"Soulignant que le présent Acte poursuit les objectifs suivants: (i) réaffirmer l'engagement politique de l'Europe de jouer pleinement son rôle de Partenaire au programme de Station spatiale internationale; (ii) permettre, par la mise en vigueur des Déclarations amendées sur les programmes MSTP et Columbus, la poursuite ordonnée et la nécessaire réorientation des activités de l'Agence consacrées à la définition détaillée et à la préparation de la technologie pour ce qui est appelé à devenir la pièce maîtresse de la contribution européenne à la Station, les contributions complémentaires à la phase initiale du programme et le concept opérationnel et d'utilisation – compatible avec les besoins des utilisateurs et leur satisfaction par les programmes correspondants de l'Agence – applicable à l'ensemble formé par ces contributions européennes; (iii) associer les deux programmes de façon à constituer un programme global du 31 mars 1994 au 31 décembre 1995; et (iv) faire la liste des étapes nécessaires pour préparer la décision du Conseil au niveau ministériel sur un programme global à partir du 1er janvier 1996."

Sur la place des Déclarations et la gestion unifiée des programmes, on se référera à l'Acte en Conseil EO du 16 décembre 1993:

"Considérant la nécessité de conduire de façon cohérente ces deux programmes (PF-POEM-1) qui partagent le même objectif,"

"Considérant que la cohérence mentionnée ci-dessus suppose de prendre des mesures spécifiques de nature à unifier la conduite de ces deux programmes".

Les budgets annuels des deux programmes sont établis et votés simultanément et constituent un seul budget global divisé en deux sous-emplois budgétaires dont chacun est financé en fonction de son propre barème de contributions.

Une politique industrielle unifiée est mise en oeuvre...; tout dépassement de coût exposé pendant l'exécution de ces deux éléments est assimilé à un dépassement de coût cumulé unique réputé imputé aux deux sous-emplois budgétaires proportionnellement aux valeurs des deux enveloppes financières.

Aucun Etat ne peut se retirer de l'un ou l'autre de ces éléments, excepté lorsque ce montant total est supérieur au dépassement de coût cumulé visé à l'article III.4 de l'Annexe III de la Convention.

Ce même esprit se retrouve dans l'Acte en Conseil relatif à l'achèvement du programme Ariane-:

"Soulignant que le présent Acte en Conseil a pour objet de prendre, moyennant l'ensemble des mesures applicables aux programmes Ariane-5 et aux différents acteurs en cause, des dispositions permettant d'achever le programme de développement Ariane-5".

Cet Acte en Conseil rassemble des engagements pris :
– par les Etats participant au programme de développement Ariane-5,

- par les Etats participant aux programmes Ariane-5 complémentaire,
- et par les Etats participant à la Déclaration sur la phase de production (qui n'est pas, rappelons-le, un programme facultatif de l'Agence au sens de l'article V.1.b. de la Convention).

Il faut aussi mentionner en annexe l'échange de lettres avec Arianespace, ce qui ajoute un autre acteur d'autant plus qu'Arianespace parle au nom de l'industrie, ce qui fait l'originalité de cet Acte en Conseil.

Ces diverses citations confirment le caractère politique exceptionnel, l'objectif d'unification de programmes approuvés et de solidarité.

Conclusion

L'Acte en Conseil est et demeure un instrument exceptionnel pour faire face à une solution de crise, sans mettre à bas l'existant déjà négocié. Divers événements, défaut de souscription, évolution dans les contenus techniques, rendent nécessaire et vital un regroupement rapide des ressources dans une gestion harmonisée. L'Acte en Conseil est une mesure ad hoc, temporaire, destiné à préparer l'avenir, dans un souci de solidarité européenne. Je crois que c'est là le maître mot de l'Acte en Conseil, la solidarité européenne sur un objectif commun dans un souci de la meilleure utilisation des ressources disponibles. Le juriste d'alors et les délégations ont su trouver une réponse qui a fonctionné. Etait-ce la seule? Vaut-elle pour l'avenir, pour d'autres cas?

[1] K. Madders, *A new force at a new frontier*, éd. Cambridge Univ. Press, 1997. Toutefois à la note 45, page 218 de l'ouvrage, il est dit ceci: 'But its use as a tool for coherence has its origin in the crisis which befell especially ESA's manned space programmes in 1991 and 1992...'

[2] G. Lafferranderie, Considérations sur la procédure d'engagement des programmes facultatifs, *Bulletin ESA* n°51, août 1987, p. 53. Voir aussi 'La Convention de l'ESA à l'oeuvre', *Colloque ECSL, Florence*, éd. M. Nijhoff Publ., 1994.

[3] Un *programme facultatif* est un programme entrepris dans le cadre de l'Agence, conforme à sa mission et auquel participent les Etats membres intéressés. Ceux-ci définissent dans une Déclaration leurs engagements, le contenu du programme, son enveloppe financière. Il y a donc une Déclaration par programme esa

Risk Management at ESA

C. Preyssl & R. Atkins
Product Assurance and Safety Department, ESA Directorate for Technical and Operational Support, ESTEC, Noordwijk, The Netherlands

T. Deak
Scientific Projects Department, ESA Directorate for Scientific Programmes, ESTEC, Noordwijk, The Netherlands

Exposure to risk is unavoidable, but one of the most frequently recurring findings of investigations of catastrophic events in recent years has been the observation that insufficient attention was placed on systematic risk assessment and management. In fact this was one of the notable conclusions from the investigation of the Challenger explosion. Projects have to assess and manage these risks in a systematic and pragmatic cost-effective way.

Introduction

The prime management standard of the European Cooperation for Space Standardization (ECSS) initiative*, ECSS-M-00, places risk management in a key position among the standards defining management practices. The details of the risk-management process, are defined in the standard ECSS-M-00-03, 'Risk Management'. ESA was one of the main contributors to the definition of the ECSS risk-management process and the results of all ESA initiatives have been amalgamated into an approach to integrated risk management.

From 30 March to 2 April 1998, ESA held an international workshop on risk management with the twofold objective of confirming the existence of suitable and practical solutions for systematic risk management on projects, and exchanging experiences on this subject. The encouraging results from the presentations and discussions have been used to define a set of recommendations for the further implementation of risk management within ESA projects.

ECSS and the risk-management process

Definitions

Risk can be seen as a 'project resource' in addition to the conventional resources such as cost, schedule and technical performance, which includes safety and dependability. Risk management is a proactive process, aiming at the optimisation of these resources in the course of a programme.

Risks are introduced by potential problem situations in a project that have undesirable consequences in terms of cost, schedule, and technical performance. A risk scenario is the sequence of events leading from the initial cause to the undesirable consequence. The cause can be a single event, or an occurrence, which triggers a dormant problem.

The magnitude of a risk is measured in terms of its probability of occurrence and the severity of its consequences. Scores can be attributed to represent each probability and severity. The probability score is then a measure of the likelihood of occurrence of the risk scenario, and the severity score is a measure of the amount of damage or penalty to be expected. Information on the risks is often displayed in a risk diagram. In addition, a risk scale can be introduced to categorise risks and classify them as acceptable or unacceptable. Figures 1 and 2 show examples of a risk diagram and a risk scale, which can be used to communicate information on risk scenarios.

Risk reduction is achieved by lowering the magnitude of a risk, by lowering its probability and/or severity with the help of preventive and mitigation measures. Preventive measures aim to eliminate the cause of a problem situation, whilst mitigation measures aim to prevent the propagation of the cause to the consequence, or reduce the severity or the probability of the consequence.

A risk is deemed acceptable when its magnitude is less than a given threshold.

Overview of the risk-management process

The steps inherent in the risk-management process are:

Step 1: Definition of Risk-Management Policy
Step 2: Identification and Assessment of Risks
Step 3: Decision on Acceptability and Reduction of Risks

* In 1996 the ESA-PSS specification system was superseded by a new series of standards developed by the European Co-operation for Space Standardization (ECSS). On a space project they are made applicable through contracts with industry.

Step 4: Monitoring, Communicating and Acceptance of Risks

Risk management must begin at the outset of a project, and the various steps in the process must be iterated throughout the project life cycle, as illustrated in Figure 3.

Step 1: Definition of Risk-Management Policy
The risk-management process cycle starts with the definition of a project risk-management policy. The set of tradable resources on the project is established and the project goals and constraints associated with these resources are identified. Furthermore, a risk-categorisation

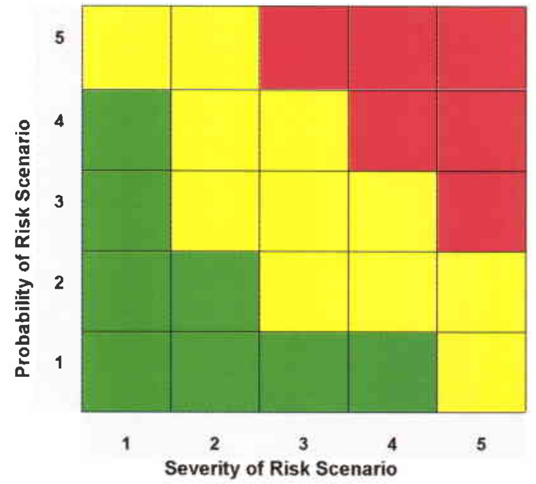


Figure 1. Risk diagram

Magnitude of Risk Severity X Probability Score	Risk Index	Magnitude & Acceptability of Risk of Risk Scenario
	> 20	**Maximum => unacceptable:** maximum disruption of project plan, maximum threat to project success, implement new process or change baseline plan
	15 – 20	**High => unacceptable:** maximum disruption of project plan, large threat to project success, implement new process or change baseline plan
	10 – 15	**Medium => acceptable:** some disruption of project plan, some threat to project success, aggressively manage, consider alternative process
	5- 10	**Low => acceptable:** little disruption of project plan, little threat to project success, some management actions necessary
	< 5	**Minimum => acceptable:** no disruption of project plan, no threat to project success, current approach is sufficient

Figure 2. Risk scale

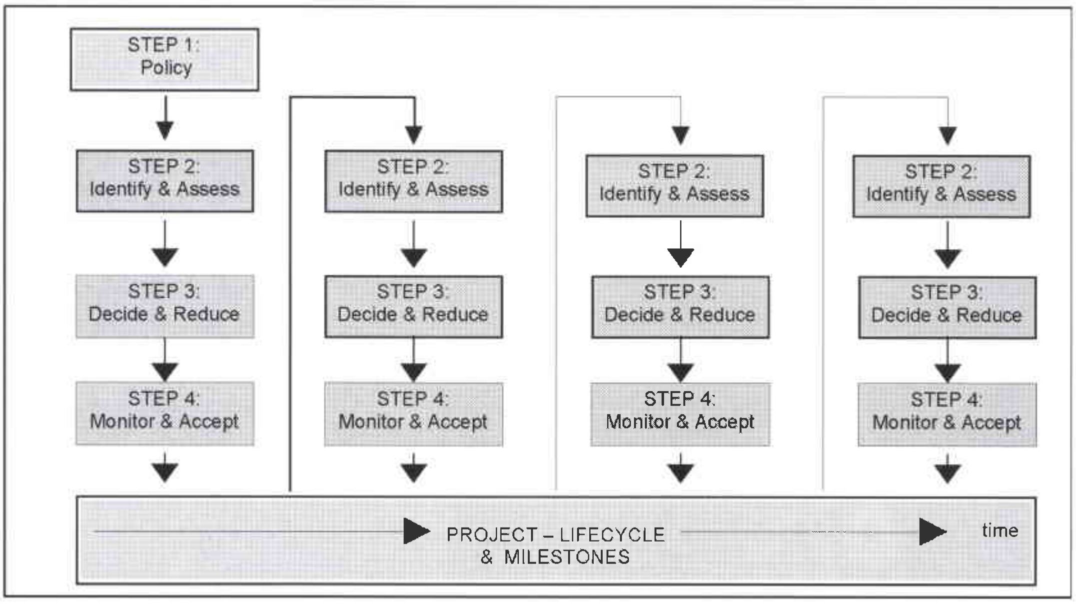


Figure 3. Risk-management process cycle

Figure 4. Consequence severity categories

Consequence Severity of Risk Scenario	Severity Score	Impact on Performance	Impact on Schedule	Impact on Cost
	5	**Maximum:** Unacceptable, no alternatives exist	**Maximum:** Can't achieve major project milestone	**Maximum:** Cost increase > 15%
	4	**High:** Major reduction, but workarounds available	**High:** Project milestone slip $\geq$ 1 month, or project critical path impacted	**High:** Cost increase > 10%
	3	**Medium:** Moderate reduction, but workarounds available	**Medium:** Project team milestone slip $\leq$ 1 month	**Medium:** Cost increase > 5%
	2	**Low:** Moderate reduction, Some approach Retained	**Low:** Additional activities required, able To meet need dates	**Low:** Cost increase < 5%
	1	**Minimum:** Minimal or no impact	**Minimum:** Minimal or No impact	**Minimum:** Minimal or no impact

scheme based on consequence severity and probability categories is established.

Figure 4 shows an example of a scheme for scoring the impacts on the tradable resources of cost, schedule and technical performance, whilst Figure 5 shows an example for scoring the probabilities of risk scenarios in a qualitative way.

Risk acceptance criteria are established to classify the various risks as acceptable or unacceptable for the project.

Step 2: Identification and Assessment of Risks
The second step in the risk-management process deals with the identification of all risk scenarios including their causes, which lead to the undesired consequences specified in the risk policy. The scope of the identification can cover various project risk domains such as:
- management
- programmatics and politics
- requirements
- technology and design
- engineering and integration
- manufacturing and qualification
- operations
- safety and dependability.

The probabilities and severities of the different risk scenarios are identified in order to determine the magnitudes of the risks and to rank them accordingly. Information sources include expert judgement, previous experience, data from other projects, and analyses.

Step 3: Decision on Acceptability and Reduction of Risks
The third step in the risk-management process leads to decisions as to whether the individual risks are acceptable, or whether attempts should be made to reduce them, according to the risk policy. In the latter case, appropriate risk-reduction strategies are determined within the optimisation of tradable resources. Then the optimum risk-reduction strategy is implemented to resolve the risks and its effectiveness verified.

Step 4: Monitoring, Communicating and Acceptance of Risks
The last step in the risk-management cycle comprises the control of all acceptable, resolved and unresolved risks and risk-reduction actions by systematic monitoring and tracking. This involves periodic reassessment

Figure 5. Probability categories

Probability of Risk Scenario	Probability Score	Chance of occurrence per mission/project
	5	**Maximum:** certain or almost certain to occur, will occur at least once, the chance is 1 to 1
	4	**High:** will occur frequently, The chance is between 1 to 1 and 1 to 10
	3	**Medium:** will occur sometimes, The chance is between 1 to 10 and 1 to 100
	2	**Low:** will seldom occur, The chance is between 1 to 100 and 1 to 1000
	1	**Minimum:** will almost never occur, The chance is less than 1 to 1000

ESA Workshop on Risk Management

Objectives of the Workshop
The roots of risk management in ESA are to be found in the pioneering work performed by the Agency's Product Assurance and Safety Department. Starting with safety risk assessment, the Department has developed tools and procedures for assessing space-project risks. The Workshop held at ESTEC (NL) from 3 March to 2 April 1998, was convened to share these developments with experts in the field, especially those from other industries, and to confirm that they are indeed serving as a sound foundation for practical systematic risk management on ESA projects.

ESA, national space agencies and industry are under pressure to cut costs, to deliver faster and to increase the performance and sophistication of space systems. The inevitable implication therefore is that the risks on programmes will increase. It is for this reason that ESA selected "How do you cope with faster, cheaper, better ... and more risky" as the motto for the Workshop. Systematic risk assessment and management provides an important means both of coping with these increasing pressures and evaluating the limits of acceptability of the "faster, cheaper, better" approach.

Overview of sessions
About 140 participants from all over the world attended the meeting, with more than 10% coming from the USA and Japan, and 20% were ESA staff.

The first day of the Workshop took the form of a risk-management seminar, which gave participants the opportunity to familiarise themselves with risk-management principles and to view risk management from different perspectives. These introductory lectures were given by C. Preyssl (ESA), J. Fragola (SAIC, USA), M. Frank (SFA, USA), G. Hall (MHA, UK) and T. Bedford (TU-Delft, NL).

On the second day, the Workshop proper began with a plenary session in which the various approaches to risk management at ESA, NASA, and the space and non-space industries were presented and compared. Keynote addresses and speeches on these topics were given. A. Soons (ESA) stressed the importance of systematic risk management and ESA's commitment to it for its projects. P. Rutledge (NASA) explained the risk management process at NASA, and drew attention to the relevant pages on the NASA Web Site:

http://pdi.msfc.nasa.gov:8018/srqa/delivery/public/html/index.htm.

J.Chachuat's (Matra-Marconi Space) presentation summarised his experience in the implementation of risk management and highlighted the main barriers to its successful implementation in projects and gave some "golden rules". P. Kafka (GRS), representing the non-space sector, explained the risk-management policy in the nuclear technology field and the trend from deterministic to probabilistic risk assessment.

The afternoon plenary session dealt with risk-management approaches on projects, where technical and programmatic issues become integrated, including the risk-management programme for the Space Shuttle. More information on United Space Alliance's approach to risk management can be found at:

http://usa1.unitedspacealliance.com/usahou/orgs/10-12/.

Other presentations dealt with risk management on the International Space Station project, the standardisation work on risk management by the European Cooperation for Space Standardization (ECSS), past and present ESA activities on risk management and the applications of risk management to Dutch Rail projects and software-intensive systems.

On the third day, there were five sessions dealing with approaches, methods and applications of technical and programmatic risk considerations in the space and non-space sectors. The presentations and demonstrations stimulated a critical review of the state-of-the-art and achieved considerable cross-fertilisation between the various industries represented.

Present experience with risk management was the topic of the morning session on the last day. The conclusions and recommendations derived from all sessions were presented during the closing afternoon session, after a round-table discussion. One of the main recommendations to ESA was to continue and intensify the active support of systematic risk management within the Agency as an organisation and in its projects by including, for example, risk-management requirements in new projects.

Figure 6. Risk trends

= Risk has not changed
< Risk has decreased
> Risk has increased

Magnitude of Risk Severity X Probability Score	Risk Index	Risk Scenarios		
		Performance	Schedule	Cost
	> 20 unacceptable risk			
	15 – 20 unacceptable risk			
	10 – 15 acceptable risk	S1=		S2>
	5- 10 acceptable risk	S2<		
	< 5 acceptable risk		S2= S1=	S1=

and review of the risks and the updating of the assessment results after iteration of the risk-management steps. New risks or changes to existing risks are identified, as well as areas where a more detailed risk analysis has to be performed or better data is required in order to reduce uncertainties. It is verified whether the risk reduction and control activities are having the intended effects, and the risk trend over the project's evolution is illustrated by identifying how the risk magnitudes have changed over the project's lifetime.

The risks and the risk trend are communicated to the project's team members. Finally, the residual risks are subjected to formal risk acceptance by the appropriate level of management.

An illustrative example of risk evolution during a project is shown in Figure 6.

Implementation of risk management
The responsibility for the implementation of risk management rests with the project's management. The risk-management process, however, requires a team effort, involving all project-team members, and it supports all project decision making. Project management has to ensure that all of the necessary data and resources are available to successfully implement integrated risk management during all project phases. Project management must also establish the project risk policy, ensure the adoption of a risk-management culture on the project, and use the risk information gathered for its project decision making.

The individual project team members support the implementation of risk management in different ways. Product-assurance team members can facilitate the process by providing know-how. The other team members provide risk data for the various project domains, communicate relevant risk information to management, and implement the actions resulting from the risk management approach.

Conclusions and outlook
Systematic risk management is necessary to cope with the considerable risks of space projects and the ever-increasing pressure on resources. Efforts to achieve a breakthrough in the introduction of formal risk management at ESA have therefore been stepped up. The ESA Workshop, held as part of this implementation strategy, helped to raise awareness of the risk-management issues and to identify suitable practical solutions for systematic risk management in the space domain. The Agency has already started to build on the Workshop findings and recommendations, strengthening its commitment to risk management as an integral part of its activities. Further studies are in progress, more project applications are being carried out, risk management is being addressed in the context of the emerging ECSS standards, and training initiatives are under development. esa

L'initiative PME à l'Agence spatiale européenne

F. Doblas & N. Bougharouat
Bureau de la Politique industrielle, Section des Relations industrielles, ESA, Paris

L'initiative PME de l'ESA a été établie avec le double objectif de faire bénéficier le système ESA et les industriels du spatial des avantages que les PME innovantes peuvent leur apporter, et de faire bénéficier à leur tour les PME des possibilités offertes, autant par l'ESA que par une collaboration accrue avec les entreprises spatiales, tout en apportant une attention particulière à ne pas accroître la fragmentation actuelle de l'industrie de fournisseurs d'équipements spatiaux européens.

Pourquoi une 'initiative PME' à l'ESA? La volonté d'encourager la participation des PME (Petites et Moyennes Entreprises) est un élément nouveau dans le contexte de la politique industrielle de l'Agence spatiale européenne. La question est apparue lors de la préparation de la Réunion ministérielle de mars 1997. Le Conseil au niveau ministériel a demandé au Directeur général de donner une place spéciale aux PME dans les activités de l'Agence et un accès équilibré aux activités technologiques:

(a) en leur garantissant la participation dans la définition du plan des actions technologiques de l'Agence

(b) en adaptant à leur taille les règles de cofinancement

(c) en leur offrant le support technique des experts et des laboratoires de l'ESA afin de leur apporter le complément nécessaire au développement de leurs propres compétences.

L'initiative a été adoptée par le Comité de la Politique industrielle (IPC) en mars 1998, pour une période d'essai de deux ans, et pour un montant de 5 M€. A la fin de cette période, une décision devrait être prise sur l'opportunité de continuer ou de modifier l'initiative, au vu des résultats obtenus et des bénéfices attendus.

Pour profiter au mieux des synergies offertes par d'autres programmes européens destinés aux PME, la définition adoptée dans l'initiative ESA correspond à celle proposée par la Commission Européenne dans sa Recommandation 96/280/CE, du 3 avril 1996, qui peut se résumer brièvement comme suit :

Sont considérées comme des PME les compagnies ayant un effectif de moins de 250 personnes et un chiffre d'affaires annuel inférieur à 40 M€, et qui sont indépendantes des non-PME (la définition des critères d'indépendance n'est pas répétée ici, car elle est très longue).

Deux types de PME sont visés par l'initiative : les PME de haute technologie (normalement, des sociétés de taille réduite, ayant des liens privilégiés avec des groupes universitaires ou des laboratoires de recherche) et des PME sous-traitantes des grands groupes.

Pour les PME de haute technologie, l'initiative PME se propose en particulier de leur faciliter l'accès aux plans de travail et d'approvisionnement de l'Agence. Ceci repose sur la conviction que ces sociétés peuvent apporter une vision alternative et améliorer considérablement les synergies entre l'activité spatiale et d'autres domaines collatéraux. C'est clairement le cas pour certains domaines techniques, tels que l'ingénierie système, le développement logiciel, l'analyse du signal et de l'image, l'électronique, l'ingénierie logiciel, etc... En outre, les PME de haute technologie, et les 'start-up' en particulier, peuvent avoir un effet très positif dans la génération de nouvelles idées et concepts. Ce coté 'iconoclaste' n'est pas à négliger, car il peut représenter une alternative valable et à considérer face aux souhaits et options proposés par les grands groupes. L'activité espace, par sa spécificité, aussi bien technique que politique et stratégique, a tendance à une certaine isolation. L'initiative PME essaie, avec des moyens très limités, de contribuer à remédier à cette situation.

Pour les PME en général, l'initiative prévoit des mesures visant à améliorer leurs conditions de vie (accès à l'information, accès privilégié aux installations et moyens techniques de l'ESA, ouverture de possibilités de contacter d'autres sociétés pouvant devenir des clients ou partenaires potentiels, etc.). Comme on peut le constater ci-après, beaucoup de ces mesures générales seront bénéfiques non seulement aux PME, mais à toutes les sociétés ayant des activités avec l'ESA, en particulier celles qui sont de taille réduite (PME ou pas), pour des raisons évidentes.

Mesures principales de l'initiative PME
Les mesures principales proposées dans l'initiative PME sont brièvement exposées ci-après:

Programme visant à encourager la participation des PME de haute technologie dans la définition de certaines activités technologiques de l'Agence (programme ARCOP)
Ce programme est construit d'une façon similaire aux 'exploratory awards' établis par la Commission Européenne dans le 4ème (et le 5ème) programme cadre de R & D. L'objectif est de donner la possibilité à des PME de réaliser des études de faisabilité ou des validations préliminaires visant à démontrer l'application de leurs technologies, produits ou procédures à la résolution de problèmes techniques auxquels les programmes spatiaux sont confrontés. La coopération des PME avec des organismes de recherche est particulièrement encouragée. Les contrats, d'un montant maximum de 30 k€, et d'une durée limitée généralement à six mois, sont alloués après évaluation par les services techniques compétents. Une Annonce d'Opportunité (AO) sera lancée courant 1999 pour cette mesure. Un montant de 500 k€ a été prévu, ce qui permettrait de financer une vingtaine d'activités.

Au cours de l'année 1998, on a déjà pu tester partiellement cette mesure : dans les quelques cas où l'on a accompagné et introduit de nouvelles PME auprès des services techniques à l'ESTEC (en particulier, dans le domaine du logiciel et du contrôle thermique) il s'est avéré que leurs capacités étaient considérées comme remarquables et qu'elles avaient une technologie très intéressante. L'idée d'une étude de faisabilité, pendant laquelle les PME seraient appelées aussi à entrer en contact avec les sociétés travaillant déjà dans le domaine spatial a donc été très bien accueillie par les services techniques correspondants.

Cette pratique de 'veille technologique' est déjà utilisée par certains services techniques. Ce que l'initiative PME propose est une généralisation de cette démarche à d'autres domaines, et avec un accès structuré aux PME de haute technologie.

Traitement particulier pour les PME dans l'AO limitée aux 'non-primes' pour des développements technologiques à vocation commerciale (en cofinancement)
Une première AO, financée par le TRP, pour des développements technologiques à vocation commerciale (en cofinancement) a été lancée en 1998, dans le cadre de la phase pilote pour l'adaptation de la politique industrielle de l'ESA, telle que définie dans la Résolution ministérielle de mars 1997. La réponse industrielle a été considérable (75 offres reçues, dont 36 soumises par des PME).

A l'intérieur de cette AO, les offres soumises par des PME ont deux chances d'être sélectionnées : d'abord en tant que PME, avec un financement spécifique et, si elles ne sont pas retenues, elles passent dans le groupe général des offres soumises par les 'non-primes'.

Un montant de 1 M€ avait été prévu à l'origine pour cette mesure. Il a été déjà presque totalement consommé dans l'AO de 1998 (0.9 M€). Un montant additionnel sera alloué dans l'AO à réaliser en 1999.

Programme de transfert de technologie de l'ESA. Action accrue visant les PME
Partant de la constatation que les PME de haute technologie sont bien placées pour le transfert de technologie, car dynamiques et naturellement présentes dans plusieurs domaines d'activité, il a été jugé opportun d'inclure dans l'initiative PME un volet transfert de technologie, qui devrait profiter au mieux des capacités de ces entreprises.

La spécificité du transfert de technologie tel que prévu dans l'initiative PME, est qu'il encourage la diversification dans des secteurs autres que l'espace (en d'autres termes, le transfert de technologie interne aux entreprises). La mesure vise donc des PME spatiales et essaye de contribuer à leur diversification dans d'autres domaines d'activité.

Une AO sera lancée en 1999. Un montant total de 1.1 M€ est prévu pour cette mesure.

Programme de formation et d'assistance technique aux PME
Cette mesure fut explicitement demandée par les Ministres au Directeur général dans la Résolution ministérielle de mars 1997. La mesure, en cours de définition, pourrait prendre deux formes complémentaires:

(a) Les moyens techniques de l'ESA sont mis à la disposition des PME qui en font une demande justifiée, pour l'aide à la résolution de problèmes techniques auxquelles elles sont confrontées (par exemple, une firme travaillant dans le domaine de l'électronique qui aurait besoin d'un support ponctuel dans des analyses ou validations structurelles, ou de compatibilité électro-magnétique, etc...). L'essentiel de la mesure est de faciliter la mise à disposition des experts de l'ESA dans les différentes disciplines pour des actions ponctuelles auprès des PMEs qui en ont besoin. Les moyens techniques étant en priorité affectés aux activités de base de l'ESA, cette mesure, quoique importante pour certaines PME, reste limitée en fonction des disponibilités.

(b) Les PME sont invitées à détacher leur personnel aux installations techniques de l'ESA, pour de courtes périodes de formation/familiarisation avec les procédures et techniques ESA (contrôle de qualité, tests, préparation des offres, laboratoires, etc...).

Un montant de 500 k€ a été prévu pour cette mesure. Il est destiné à financer les frais de mission des ingénieurs ESA en déplacement au sein des PME et à financer partiellement l'accès du personnel des PME à la formation ESA.

Programme d'accès privilégié des PME aux installations et laboratoires de l'ESA
Cette mesure se décompose en deux volets :

(a) Un accès des PME aux moyens techniques ESA à des taux favorables. Une politique d'imputation financière des coûts d'utilisation des installations et laboratoires de l'ESA à des taux favorables pour des PME est en cours de proposition aux instances correspondantes (AFC et Conseil) dans le cadre des nouvelles règles pour l'utilisation des installations et moyens de l'ESA par des tiers. Il est proposé l'application du 'coût marginal' aux PME en ce qui concerne tous les services fournis par des experts et des laboratoires de l'Agence en vue de compléter les capacités techniques nécessaires au développement de leurs compétences.

(b) Une meilleure information sur les moyens disponibles. En parallèle, une meilleure publicité des moyens disponibles (plaquettes descriptives des installations) sera réalisée dans le court terme.

Un montant de 270 k€ est prévu pour cette mesure. Il est destiné à la réalisation de plaquettes descriptives des diverses installations et à la fourniture de support ponctuel, si nécessaire, pour l'utilisation par des PME des dites installations.

Clause visant à encourager la passation de sous-contrats à des PME
Cette mesure prévoit que, pour certains approvisionnements technologiques en compétition, l'Agence encourage les fournisseurs potentiels à intégrer des PME dans leurs offres, avec une participation industrielle non négligeable. L'élément essentiel de la mesure est que l'Exécutif prendra en compte dans l'évaluation des offres, outre la qualité technique (reflétée dans la notation technique) et le prix, l'inclusion de PME à un niveau adéquat de participation. Cela est clairement indiqué aux soumissionnaires dans l'appel d'offres. Cette mesure est combinée avec la mise en œuvre d'une nouvelle application dans le système électronique par lequel l'industrie reçoit les appels d'offres, via Internet (EMITS), permettant aux soumissionnaires potentiels de connaître les PME ayant des capacités et souhaitant participer aux activités concernées.

Les actions visées par cette mesure sont des activités technologiques innovatrices auxquelles il est jugé intéressant d'associer des PME travaillant déjà dans des domaines connexes, pour bénéficier d'éventuelles synergies.

Une première liste d'activités a été proposée à l'IPC dans le plan TRP de 1998, et approuvée à l'unanimité par ce Comité, qui a aussi demandé à l'Exécutif d'identifier des actions susceptibles de faire l'objet de la clause de sous-traitance PME dans le plan 1999. Les activités identifiées par l'Exécutif dans le plan 1999 représentent 30% du montant total des activités prévues dans le TRP pour cette année, ce qui pourrait donner une participation des PME de l'ordre de 8%. Immédiatement après approbation du plan par l'IPC de Janvier, l'industrie (et en particulier les PME) sera notifié, par le système EMITS.

Une Instruction administrative est en préparation. Elle déterminera la procédure de prise en compte de la clause de sous-traitance PME dans l'évaluation des offres industrielles.

Amélioration de l'information : création d'un site spécifique dédié à l'industrie dans la page Internet de l'ESA ('ESA Industry homepage')
L'ESA Industry homepage, en préparation, répond à deux objectifs majeurs :

(a) Permettre à l'industrie en général (et aux PMEs en particulier) d'obtenir l'information nécessaire pour participer d'une façon optimale aux activités de l'ESA, et pour développer cette participation. Pour cela, les informations disponibles dans les différents serveurs ESA, autant internes qu'externes, et qui présentent de l'intérêt pour l'industrie, ont été regroupées.

(b) Permettre aux entités ayant travaillé pour l'ESA (industries et organismes de recherche en général) de se voir offrir la possibilité sur ce site spécifique d'annoncer leurs produits et capacités, d'établir des liens avec leurs pages Internet respectives, d'établir des forums de discussion, entre elles et avec l'Exécutif, de recherche de partenaires, etc.

Une première version de 'l'ESA Industry Homepage' sera disponible prochainement.

Organisation par l'ESA d'ateliers visant à mettre en contact des PME européennes avec des clients potentiels
L'idée est d'organiser des rencontres, à l'échelle européenne, entre des PME et des clients potentiels (des Agences et des industriels spatiaux, maîtres d'œuvre et équipementiers) pour permettre à ces derniers de rencontrer des PMEs innovantes qui pourraient les aider à augmenter leur compétitivité.

Des représentants de l'Exécutif ont eu l'occasion, au cours de l'année 1998, de participer à des réunions de ce type, organisées dans des domaines tels que l'Analyse du Signal et de l'Image et le Génie Logiciel. L'expérience a été très positive, car on a pu rencontrer, dans une seule journée de travail, des petites sociétés ayant une technologie et des produits qui, dans certains cas, étaient au-delà des capacités requises par les systèmes spatiaux. Cette expérience a confirmé une fois de plus que, dans certains domaines techniques, une ouverture à d'autres secteurs (via des PME) donnerait lieu à des synergies très intéressantes.

Un premier atelier sera organisé à l'ESTEC au cours du premier semestre 1999, avec le support technique du Comité Richelieu (organisation des PME françaises de haute technologie).

Création d'une Unité de coordination PME au sein de l'ESA
Pour mettre en œuvre l'initiative PME, une Unité de coordination PME a été créée dans la section des Relations industrielles, au sein du Bureau de la Politique industrielle, Direction des affaires industrielles et des programmes technologiques.

Cette unité est responsable de la mise en œuvre des actions mentionnées ci-dessus. Elle assure aussi la fonction de 'guichet unique' afin de permettre aux PME un accès plus efficace aux diverses activités de l'Agence, ainsi qu'aux mesures spécifiques envisagées dans l'initiative PME. Elle peut être contacté à l'adresse électronique suivante: sme-unit@hq.esa.fr

Conclusion
L'initiative PME de l'ESA est un premier pas, et avec des moyens très limités, mais elle est une occasion qu'il ne faut pas rater. Elle apporte beaucoup d'éléments de normalisation et de rapprochement de l'activité espace avec les pratiques dans d'autres secteurs, en soutenant les PME comme élément d'innovation et d'établissement de synergies avec d'autres domaines technologiques. En outre, elle introduit une dimension qualitative intéressante dans la politique industrielle de l'Agence. Finalement, elle apporte un argument supplémentaire aux pouvoirs publics pour justifier la participation aux activités de l'ESA.

Finalement, la notion du rôle des PME dans la politique technologique est très importante. Les propos du ministre français de l'Education nationale, de la Recherche et de la Technologie, M. Claude Allègre, à ce sujet, auxquels nous souscrivons totalement, sont très intéressants :

'Nous aidons trop la recherche dans les grandes entreprises et pas assez celle des PME-PMI. Comme le soulignait un rapport fait par l'Académie des Sciences des Etats-Unis à la demande du Président Clinton, lorsque la recherche privée des grands groupes est financée par l'Etat, elle est aussi pilotée par ce dernier, c'est-à-dire par des technocrates, alors qu'il faut que la recherche privée soit pilotée par le marché. Sauf pour les très grands projets comme l'aéronautique, il est préférable que les fonds publics de recherche s'orientent vers les PME-PMI innovantes – les grands groupes dont le rôle est ensuite essentiel ayant une position de capteurs-développement vis-à-vis de ces PME-PMI.' esa

Payload-Mass Trends for Earth-Observation and Space-Exploration Satellites

M. Rast, G. Schwehm & E. Attema
ESA Directorate for Scientific Programmes, ESTEC, Noordwijk, The Netherlands

This article reviews the factors and trends that have dictated the sizes of Earth Observation and Space Exploration satellites over the past 15 years and draws some conclusions regarding their expected evolution in the future.

Introduction

Space Exploration and Earth Observation from space using satellites are both still comparatively young scientific disciplines. Remote sensing from space was born in the early seventies, with the advent of the US Landsat satellite series. It has evolved rapidly during the past 25 years and today provides a wealth of information for environmental research and other applications that are crucial to the future of mankind. Over the same time span, space scientists have started to investigate both the near-Earth environment and our planetary system with satellites and space probes, starting with comparatively simple 'particles and fields' missions and progressing to complex, largely autonomous planetary orbiters. The operation of space-borne observatories has helped astronomers to expand their science into wavelength domains that are not accessible from ground-based telescopes due to the observational limitations imposed by the Earth's atmosphere.

As the goals have become more sophisticated and the demand for ever more exacting data has soared, there has been a perceived tendency towards using larger platforms, like Envisat, to carry the wide range of instruments proposed for Earth Observation missions, compared with the smaller spacecraft being used for Space Exploration. Given the current popularity of the 'smaller, faster, cheaper' approach to space missions in general, now is perhaps a timely moment to examine whether the perception is indeed correct and whether it is a trend that will continue.

The fact that satellite payloads have evolved dramatically over the years not only in terms of their technological sophistication, but also in terms of their mass and size, has had implications both for the launch requirements and ground-segment structures. However, this trend towards ever larger space infrastructures has slowly reversed in recent years, due to both political and financial constraints.

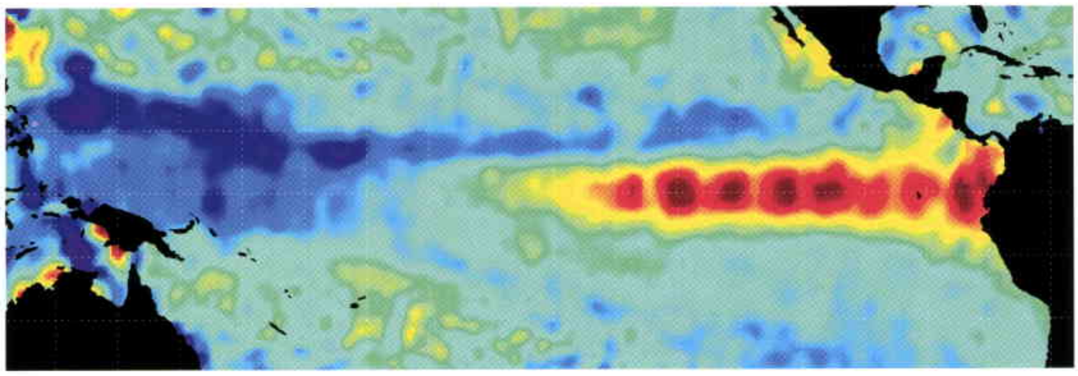
The differences in mission requirements

Today the requirements for Earth Observation missions are more stringent, and therefore more resource-hungry, than for Space Exploration because our knowledge of the Earth is more advanced. The remote-sensing observations made from orbit can be directly validated in the terrestrial environment that is being investigated. Earth Observation missions are only justifiable, therefore, if they have clear advantages over alternative ground-based measurements. Such advantages can include time series of data, large-scale synoptic viewing, and global access and coverage.

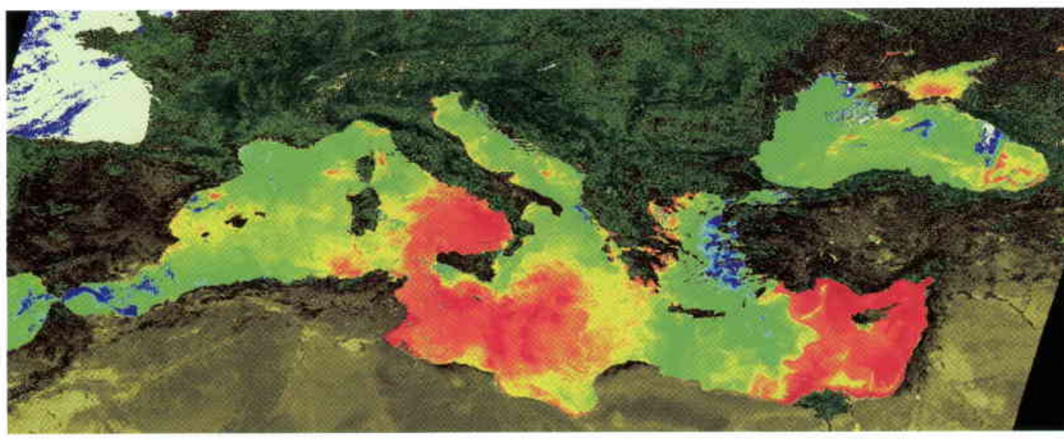
Earth Observation missions are generally more demanding in terms of accuracy, stability, global coverage, revisit frequency, spatial and spectral resolution, as the targets have to be measured with high precision in order to satisfy the requirements of geo-biophysical retrieval procedures and the related models. Sea-surface height, wind speed and surface temperature are three examples of such geophysical variables that need to be mapped frequently and with high accuracy with the aid of precision space-borne satellite sensors (Fig. 1). It is this combination of measurement precision and high repetition rate that drives Earth Observation sensor sizes and masses.

The major advantages of remotely sensed data lie in the synoptic context that these observations provide and in their timely coverage of targets that could only be achieved with enormous effort if one still had to rely only on ground-based and airborne measurements. Many of the more critical applications require long-term observation and thus a long satellite

Figure 1. A selection of operational remote-sensing products
(a) Sea-surface height from ERS-2 Radar Altimeter observations during the 1997 El Niño event
(b) Sea-surface temperature in the Mediterranean derived from ATSR
(c) Gridded wind fields in the Indian Ocean derived from ERS-1 Wind Scatterometer data, indicating both direction and speed



(a)



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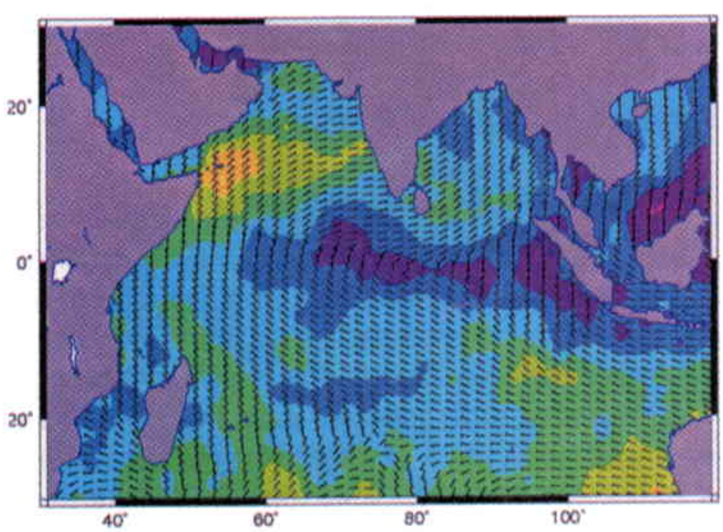


(c)

lifetime and high sensor stability. Such a combination of performance requirements often challenges the physical and technological limits, even today.

Earth Observation missions can be and are being commercially exploited and are making an important contribution to the accurate forecasting and monitoring of economically and politically important parameters. The risk that these missions might fail therefore has to be minimised, which inevitably leads to a maximum-redundancy approach being pursued onboard the satellite, adding to sensor complexity.

Space Science missions are generally more exploratory in nature (Fig. 2), do not have to satisfy operational requirements, and consequently have less-stringent resolution and stability requirements than Earth Observation missions. Moreover, the tasks assigned to Space Exploration satellites are usually highly focussed, whilst Earth Observation satellites have traditionally been designed to serve a broader range of disciplines and consequently of users.

These are prime factors in explaining the fact that Earth Observation payloads and missions have tended historically to be larger than their Space Science counterparts.

Factors influencing mission scope and payload complexity

Mono-disciplinary versus multi-disciplinary missions

ESA's currently operating and planned Earth Observation missions are designed to serve a wide range of scientific objectives and operational user communities. The ocean/ice-oriented ERS-1 and -2 missions are also serving atmosphere and land applications. The scientific astronomical observatory missions, on the other hand, are designed for very focussed missions and operate in very specific wavelength ranges, e.g. infrared, X-ray, or the submillimetre. The Solar System exploration missions also have to address a wider range of scientific objectives in order to gain the support of the wider science community, given the small number of flight opportunities that ESA can provide within its severely constrained Science Programme.

Operational versus research objectives
Operational remote-sensing missions require high reliability, long lifetimes and a high level of redundancy. Space Science missions can accept a greater degree of risk because they do not have to satisfy operational requirements, such as guaranteeing the provision of continuous data inputs for numerical weather forecasting.

Sensor technology evolution versus mission requirements
It is important when entering into discussions about the differences between operational and research missions to view missions and instruments (sensors) separately.

Taking the evolution of space-borne Synthetic Aperture Radars (SARs) in Europe as an example, it is clear that owing to increasing observational requirements, the mass, spacecraft size and resource demands have gone up significantly between the ERS-1/2 type SAR (378 kg incl. the Wind Scatterometer) and the Advanced SAR on Envisat (830 kg). On the other hand, advances in technology, particularly in the electronics and detector areas, have led to a reduction in the sizes and masses of the individual instruments. The evolution of interferometers and spectrometers is a good example in this respect. Overall, therefore, there is a balancing effect between the demand for increased performance on the one hand, and the technical solutions being devised to satisfy the need for lighter and smaller instruments on the other.

As far as the 'active' instruments like lidars and radars are concerned, the power requirements dictate the size of the solar panels and thus the overall mass budget for the mission. Together with the complex electronic hardware needed, this often leads to higher mass budgets compared with the scientific missions, which tend to rely on passive instrumentation.

Small versus large satellites
Both scientific and operationally oriented missions can, of course, be implemented using a number of smaller rather than one large spacecraft. This reduces the risk, but at the same time results in a loss of synergistic capability for the various instruments. The latter is one of the main reasons why Earth Observation satellites have tended to increase in size as more exacting requirements have been imposed, rather than opting for several smaller spacecraft. In the case of operational meteorological satellites, the evolution from NOAA's Tiros series to ESA's Metop satellite series provides a clear example of this trend.

Political and financial constraints
Political and financial conditions are also highly determining factors because the mission designers always try to fully exploit available launch capacity, e.g. Ariane-4, Ariane-5 or Space Station, as well as the available financial envelope. This aspect has been clearly demonstrated by the development of Envisat and Metop, which started life as a single large so-called 'Polar Platform', with the present Envisat payload, plus a Wind Scatterometer and the complete NOAA TIROS payload (the latter two now form the bulk of the Metop mission payload).

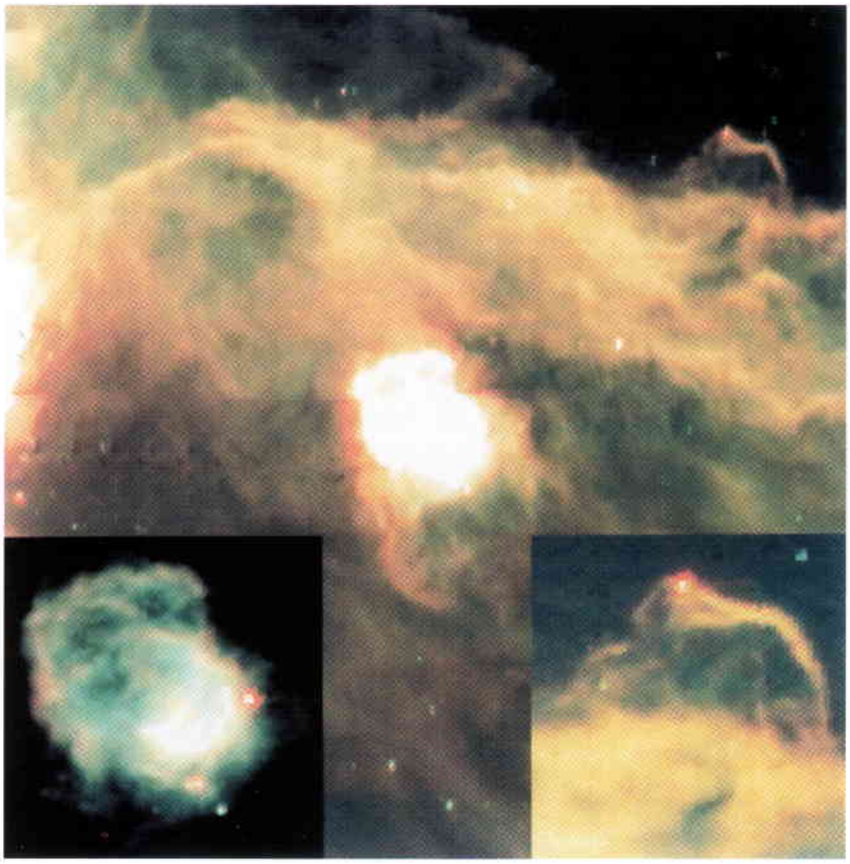


Figure 2. The Horsehead nebula region imaged by ISO. The three bright reddish dots, visible in the insets, are recently-born stars

A further financial constraint is the fact that many Earth Observation and Space Science missions require specific orbits, which often prevent shared launches and hence the optimum exploitation of the multiple-launch capabilities of Ariane-4 or Ariane-5.

The influence of changing political and financial constraints on the sizes of Earth Observation and Space Science missions is certainly reflected in Figures 3 and 4.

Payload mass evolution
In order to make a meaningful comparison of

Earth-observation and scientific spacecraft and payload masses, one has to break down the payloads in each case into the sensor or instrument element and the supporting mechanical and electrical equipment. In the case of Space Science missions, for example, support equipment for probes, including shielding and landing (e.g. parachute) equipment, should not, strictly speaking, be counted as 'true' payload.

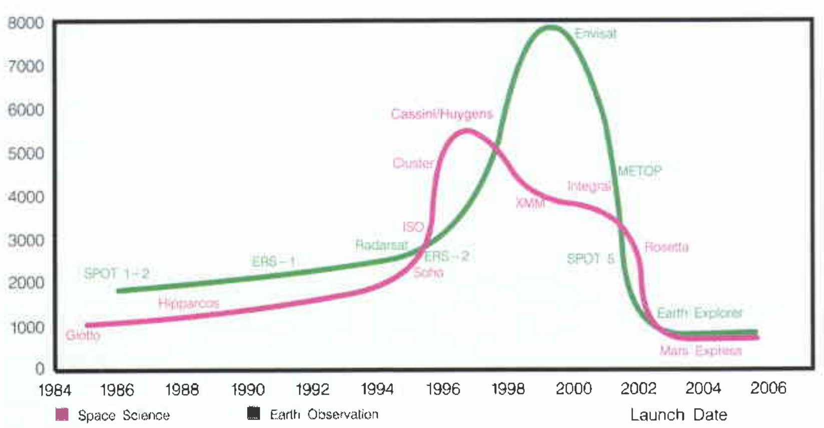


Figure 3. Launch-mass histories for Science and Earth-Observation satellites

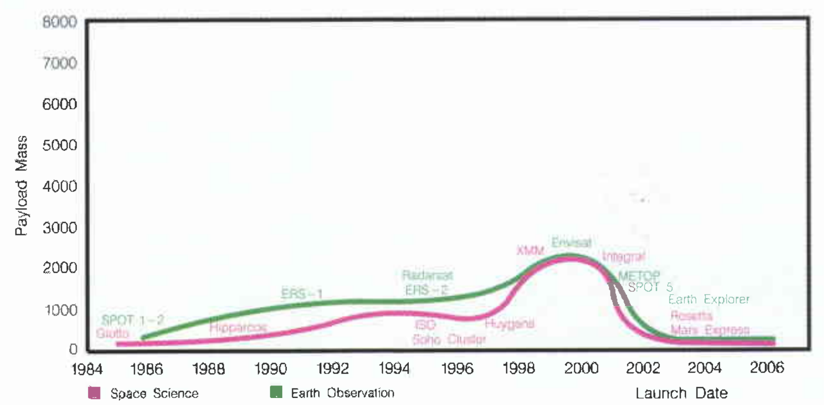


Figure 4. Payload-mass histories for Science and Earth-Observation satellites

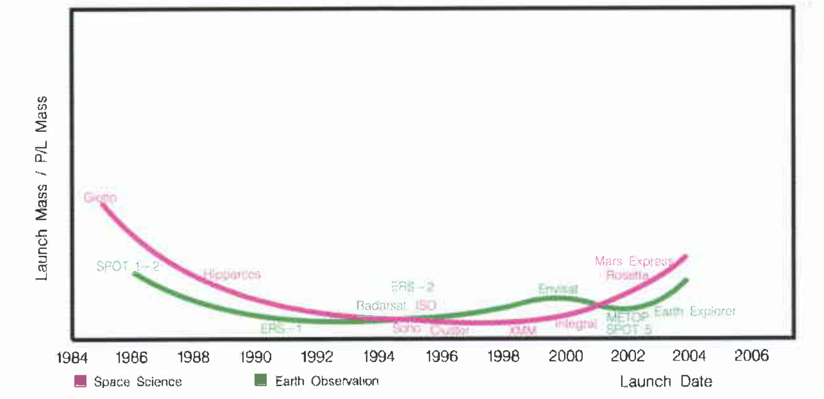


Figure 5. Launch-mass/payload-mass ratios for past, current and future Earth Observation and Space Science missions

In Figures 3 and 4, the launch masses of various satellites (including platform, fuel and ancillary equipment) are compared with the so-called 'dry payload masses', i.e. excluding interfaces, fuel and harnesses. If one then looks at the launch-mass/dry-payload-mass ratios depicted in Figure 5, the 'efficiency' of the larger satellites no longer looks so unfavourable compared to the alternative of undertaking a sequence of several smaller missions. This having been said, both the Earth Observation remote-sensing graph and the one for Space Exploration still indicate that the general tendency, at least for the near future, is towards reduced spacecraft sizes for both types of missions.

Is smaller also cheaper?

By spreading the cost of a sequence of smaller missions over time, the immediate financial burden is lower compared with a large mission like Envisat. This does not mean, however, that the total mission costs associated with meeting the requirements of comprehensive Earth Observation or Space Exploration missions are necessarily reduced when the route of 'more and smaller satellites' is followed. To realise the original mission objectives for a large payload mission with small satellites, several missions have to be flown simultaneously and therefore at the end of the day the overall resource demands do not decrease.

The degree of risk associated with a suite of smaller satellites is less than that associated with a single large satellite with a more comprehensive payload (i.e. not all eggs are in one basket!), but it is more difficult to fulfil synoptic and coverage/synergy requirements with a number of smaller satellites. The suite of smaller satellites also requires a flexible launcher family for multiple launches satisfying specific mission requirements, such as contemporaneous observations and mission synergy.

Thus, generally speaking, the 'financial relief' is only of a temporary nature, as ultimately similar financial demands are spread out over a longer period of time, which in itself involves additional costs.

Past and future trends

Until the early nineties, the primary limitation on spacecraft size was the available launcher capability and the readiness of the necessary enabling technology, with missions tending to expand to fill the available launch mass. Even though ESA had always had to comply with predefined financial targets, only the Horizon 2000 Programme brought hard upper limits for the scientific Cornerstone or Medium-Sized missions. This setting of a priori defined financial limits has the unfortunate consequence of ruling out some demanding but extremely interesting long-term scientific missions, such as those to the outer planets.

NASA has even gone a step further with its Explorer or Discovery series, where deliberately low budget targets are set and the scientific return has to be optimised within these targets. However, NASA has the advantage of benefiting from technology developed as part of the former Strategic Defense Initiative, which has provided a wealth of innovative technology in terms of instrument miniaturisation. These missions are very focussed in terms of scientific objectives, usually carrying just a few payload elements. Yet they are still designed with the launcher capabilities in mind, either in terms of cost or launchable mass for the required trajectory. The US has an advantage here too in that it has a wide variety of launchers available covering a broad range of launch categories. Nevertheless, when one analyses the mass figures for a variety of NASA missions, the same trend is found, i.e. the payload/dry spacecraft mass ratios for their 'faster, better, cheaper' missions are still in a comparable range of 12 to 20%.

The recent imposition of the concept of 'affordability' implies that not only Earth Observation, but also Space Exploration missions must become smaller at the expense of mission objectives and performance requirements. Nevertheless, to realise the original mission objectives for a large-payload mission with small satellites, several missions have to be flown simultaneously and therefore the overall resource demands do not decrease. Higher performance requires more sophisticated facilities if real scientific progress is to be made, which means increased complexity and therefore risk.

At the end of the day, for both the Space Science and Earth Observation domains, the acquisition of increased knowledge tends to demand more resources rather than less.

Conclusions

Looking to the future of space exploration, with mankind pushing further and further into deep space and possibly visiting other planets, the demand for knowledge and the resulting requirements will become even more exacting. The size of the individual missions could be reduced by splitting up the payload complements to allow smaller, dedicated and more focussed spacecraft to be flown. However, where the overall mission goal is comprehensive Earth or space 'system' observation, such as for climate monitoring, the end result will be very similar, or even higher resource demands.

It is important to remember in this context that the limiting factor in recent years has been the launch capability, and not so much the availability of financial resources. History also shows that the instruments (or payloads) in both the Earth Observation and Space Science disciplines can be expected to get smaller as technology advances. However, this will play only a subordinate role, because the growth in requirements will drive sensor mass and size and balance out the 'technological savings'.

The historical evolution of instruments and missions in both Earth Observation and Space Exploration has demonstrated that the user/science community has responded to political pressure and financial constraint by first increasing and later decreasing the sizes of its spacecraft in its efforts to make savings. The net effect has been a cyclic development scenario whereby the payload masses for currently planned launches tend to be of the same order of magnitude as those 15 to 20 years ago.

Given the much more sophisticated nature of today's mission objectives, the imposition of further reductions in mission size for either discipline – Earth Observation or Space Exploration – would probably drive capacities/capabilities below the threshold at which meaningful missions can be conducted, despite the greater capabilities of today's – and tomorrow's technology. Even if the overriding goal is lower financial spending, a reasonable sized framework of Space Exploration and Earth Observation missions needs to be maintained if Europe is to protect its scientific and cultural standing in the World. esa

Focus Earth – Botswana

J. Lichtenegger, M. Barbieri & G. Calabresi
Remote Sensing Exploitation Division, ESA Directorate for Application Programmes, ESRIN, Frascati, Italy

The area around Gaborone, the country's capital town, was selected to demonstrate the potential of information derived from Earth-observation satellites at a local Workshop for remote-sensing educators on 18-21 October 1998. A series of images from the Synthetic Aperture Radars (SAR) on board ESA's European Remote Sensing Satellites (ERS) were generated especially for the event.

With a population of 1.5 million and territory covering 581 000 km^2, Botswana's economy still depends mainly on its diamond-mining industry. However, tourism has also been recognised as a potential source of considerable income, with a large portion of the territory now designated as a National Park. Up-to-date knowledge of the land cover has therefore become a priority for its sustainable development. This can be achieved more easily with the help of space remote-sensing techniques, which are particularly suitable for monitoring such a large area.

The Workshop, organised by the United Nations Office of Outer Space Affairs in Vienna, Austria, together with the Universities of Stockholm and Botswana, brought together 35 lecturers from across the whole African Continent. The ERS SAR images presented at the Workshop were also used by the Participants during a short field trip for them to make their own comparisons with in-situ ground observations.

Five particular types of SAR image products were prepared and analysed:

- a multi-temporal image composed of three data acquisitions, on 2 July 1994 (displayed in blue), on 26 December 1995 (displayed in green), and on 27 December 1995 (displayed in red) (Figs. 1 & 2)
- a coherence image, generated from the 26 and 27 December 1995 tandem-pair acquisitions (Fig. 3)
- a multi-temporal image composed of the mean values from the 26 and 27 December 1995 acquisitions (displayed in red), the 2 July 1994 acquisition (displayed in green) and the 26 and 27 December 1995 coherence image (displayed in blue) (Fig. 4)
- a hill-shaded relief map with colour-coded height information, based on the digital terrain model resulting from the interferometric processing of the 26 and 27 December 1995 tandem-pair (Fig. 5)
- a hill-shaded relief map with the thematic information from the multi-temporal colour-coded SAR image (Fig. 6).

Brief description of the area

Botswana is part of the South African plateau. It is characterised by hilly grasslands and ephemeral watercourses in the east, and by the Okavango swamps and Kalahari desert in the west. The vegetation consists primarily of semi-desert thorn scrub. The annual average rainfall is around 500 mm, varying between 100 to 800 mm from one year to the next. Agriculture is purely rain-fed. Agricultural activity around Gaborone includes essentially cereals, sorghum and grazing land.

Multi-temporal SAR images

The multi-temporal SAR image shown in Figure 1 was obtained by combining images acquired at the beginning of the dry winter season (July) and of the wet summer season (December). Close to the centre of the image, one can clearly pick out the town of Gaborone (bright dots and patches), situated just north of an artificial lake (blue and red-green). The town's old centre to the south can be detected as a particularly bright area. It consists of small houses or huts, many of which have corrugated-iron roofs (see Fig. 2 for greater detail).

Hills in the surroundings, some of which are cone-shaped and others in the form of raised plateaus, are covered by small trees and scrub. The plain is part fields and part scrub, the latter appearing in a dark homogeneous colour. Fields shown in blue are probably sorghum fields, whilst the yellow-greenish hues would be synonymous with cereals or set-aside fields. Light yellow indicates wet soils or swampy land, while watercourses appear bright grey.

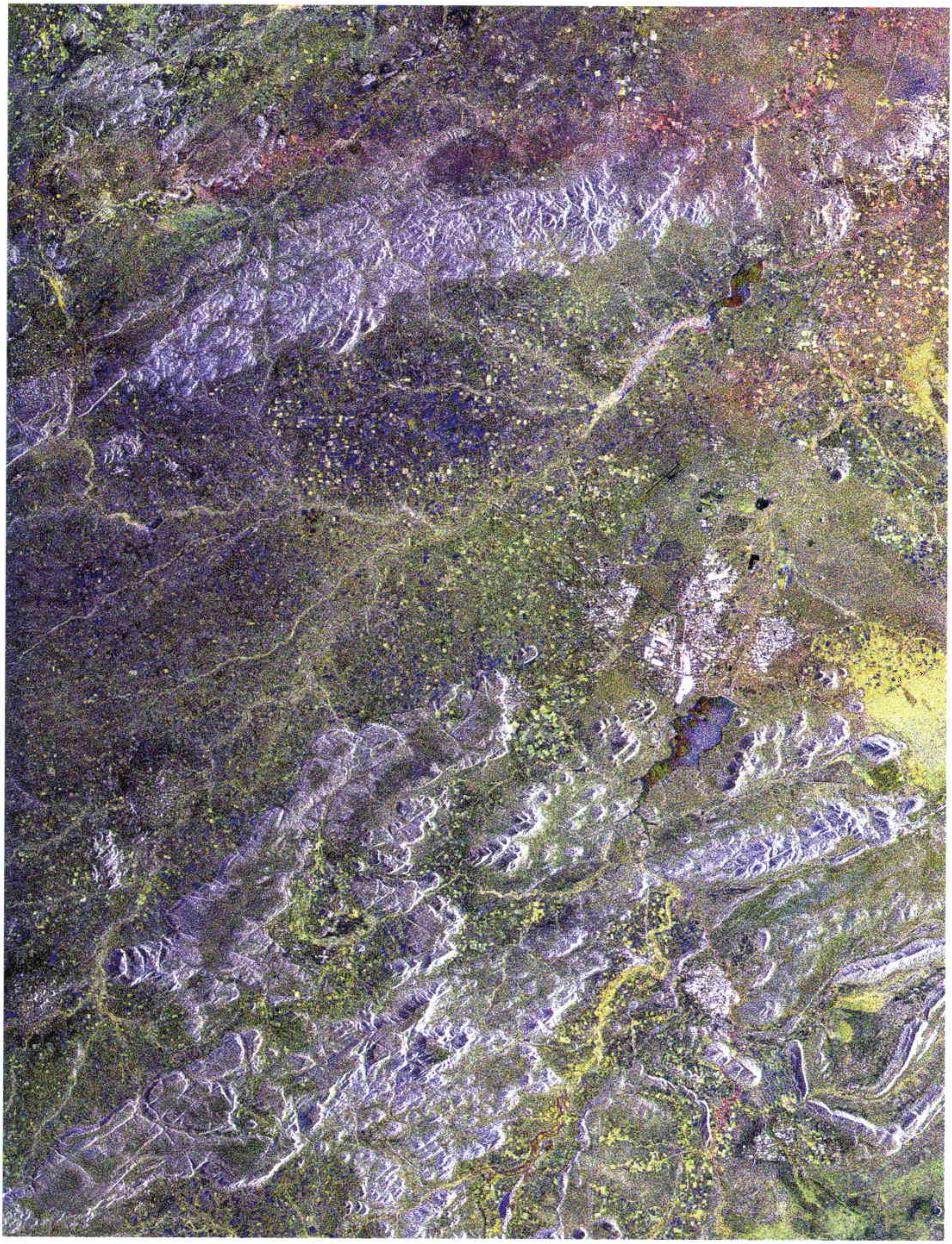


Figure 1. Multi-temporal ERS SAR image, representing an area about 70 km by 100 km, composed of 3 data acquisitions: 2 July 1994 (blue), 26 December 1995 (green) and 27 December 1995 (red). Gaborone lies right of centre in the image, just north of a dammed lake appearing in blue and red. The area in the bottom right corner is part of the Republic of South Africa (data acquisition by the SAC/Micomtek/CSIR South African station)

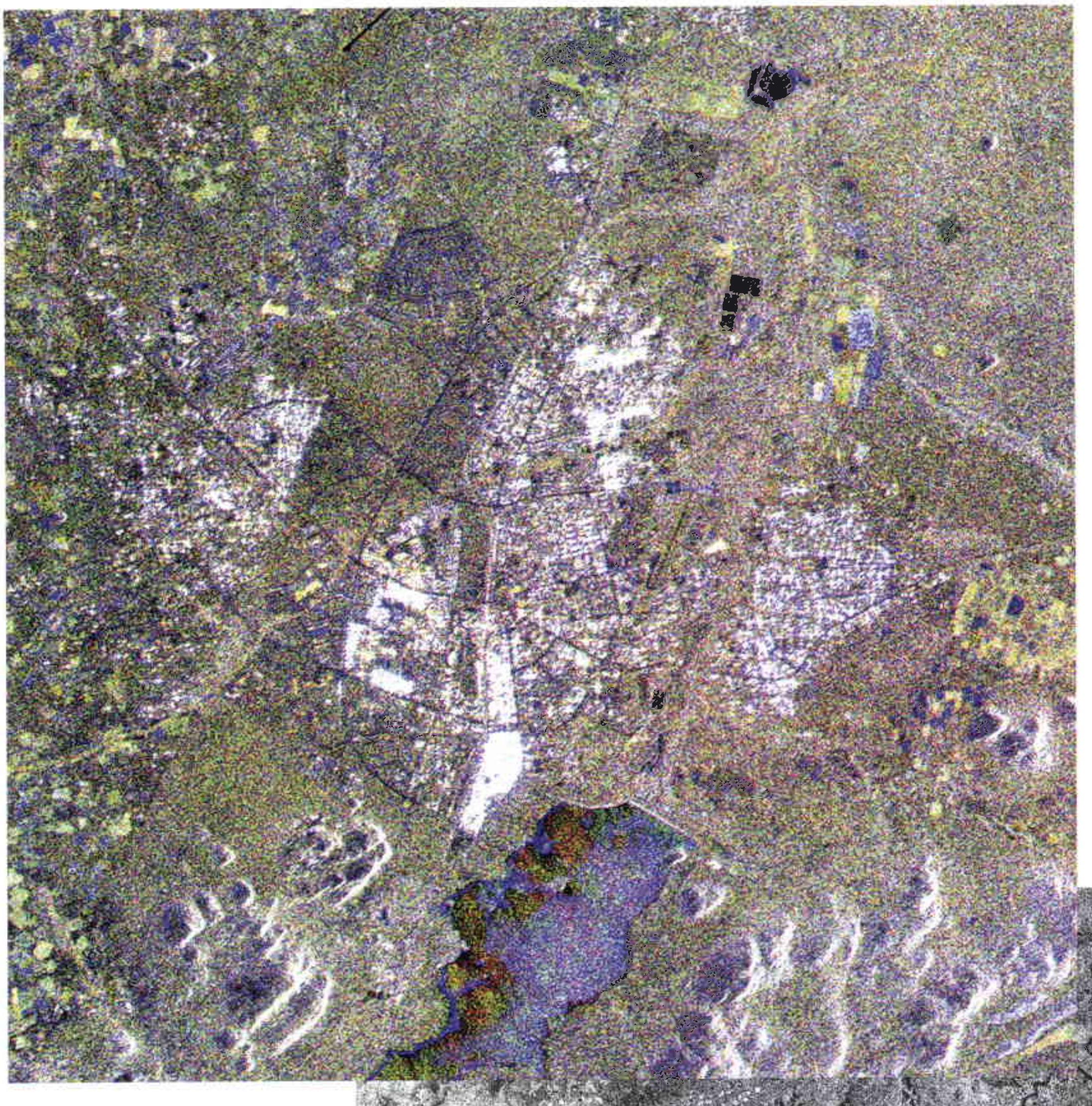


Figure 2. Enlargement of Gaborone and its surroundings, extracted from Figure 1

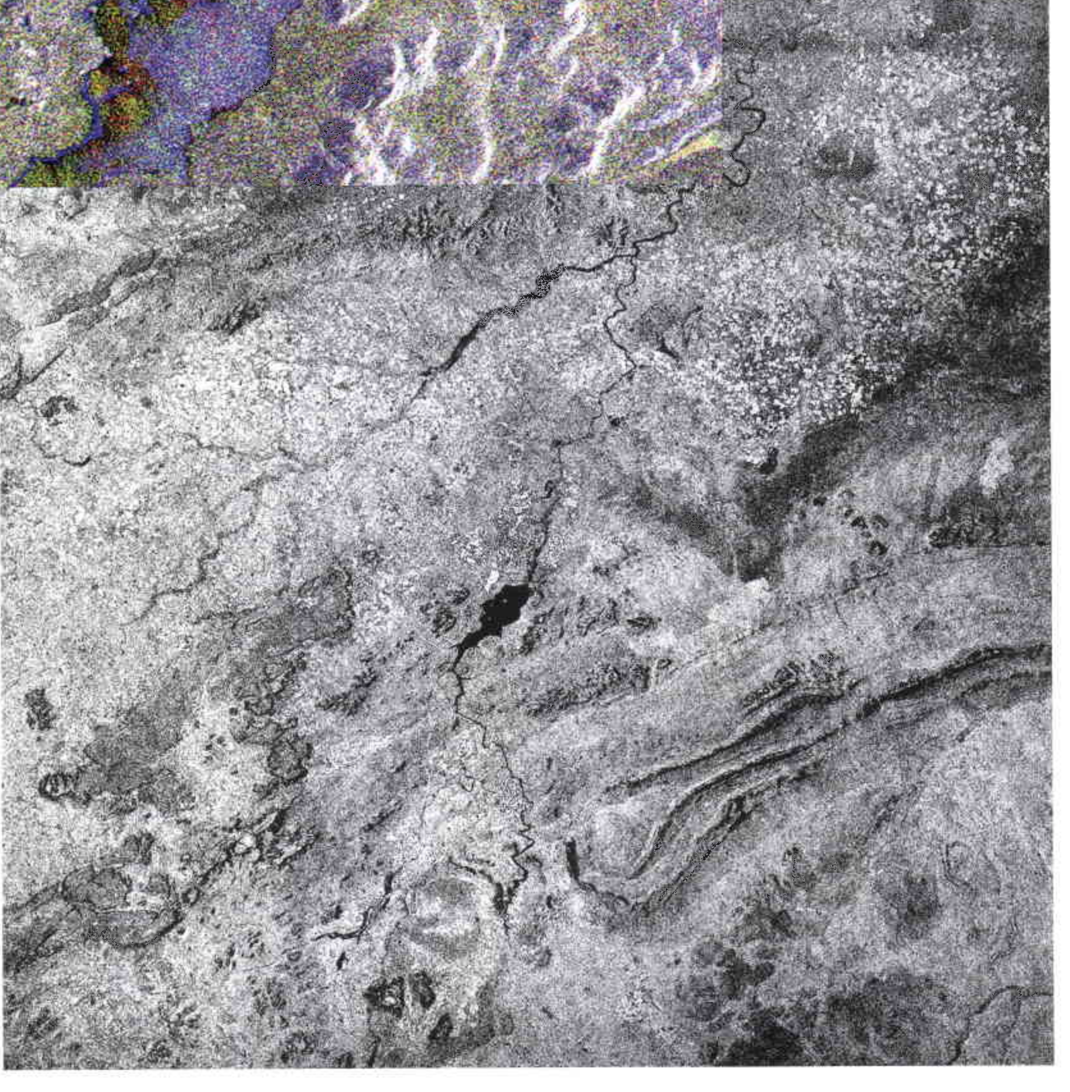


Figure 3. Coherence image, 100 by 100 km, generated from the tandem-pair of 26 and 27 December 1995 acquisitions. Bright areas relate to high coherence and include settlement and agricultural areas. Bodies of water decorrelate the phase and appear black. The denser the vegetation, the darker grey it appears. Layover areas, such as vertical walls, also appear black

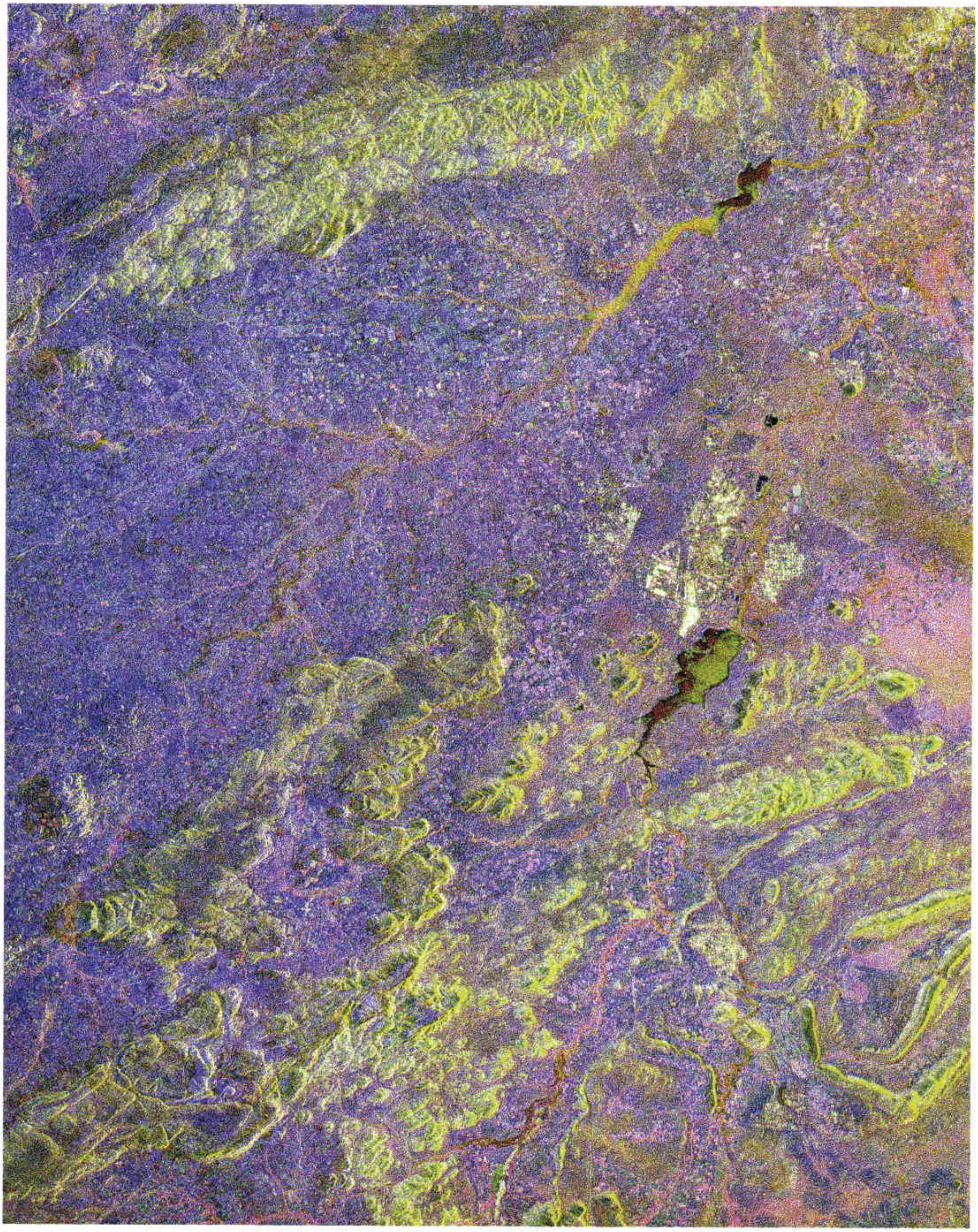


Figure 4. SAR imagery composed of the radar intensity of a multi-temporal image such as in Figure 1 and of the coherence image as shown in Figure 3. This colour image is especially valuable for delineating bodies of water and discriminating different vegetation types and settlements.

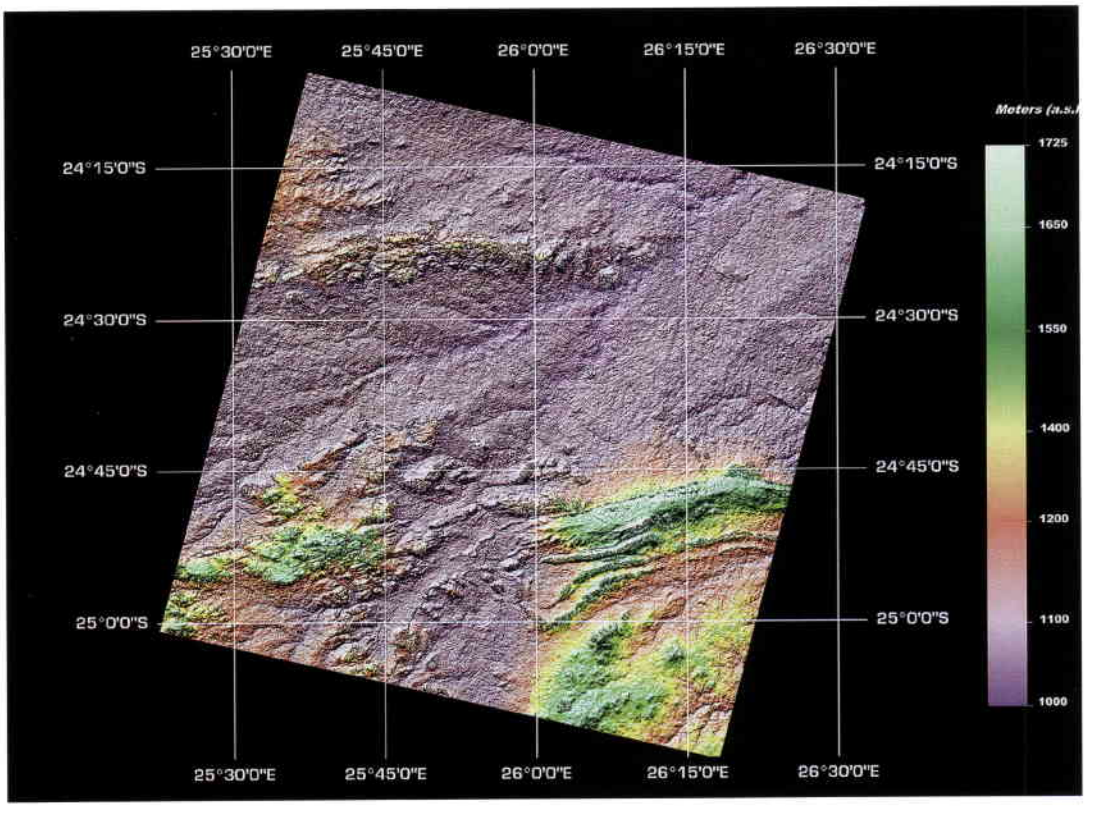


Figure 5. Hill-shaded relief map with colour-coded height information, computed from a digital terrain model. The model is a result of the interferometric processing of the ERS SAR tandem-pair acquired on 26 and 27 December 1995. This image product is of interest to geologists for geomorphologic studies, but can also serve as a basis for thematic maps to be used in schools and for land management

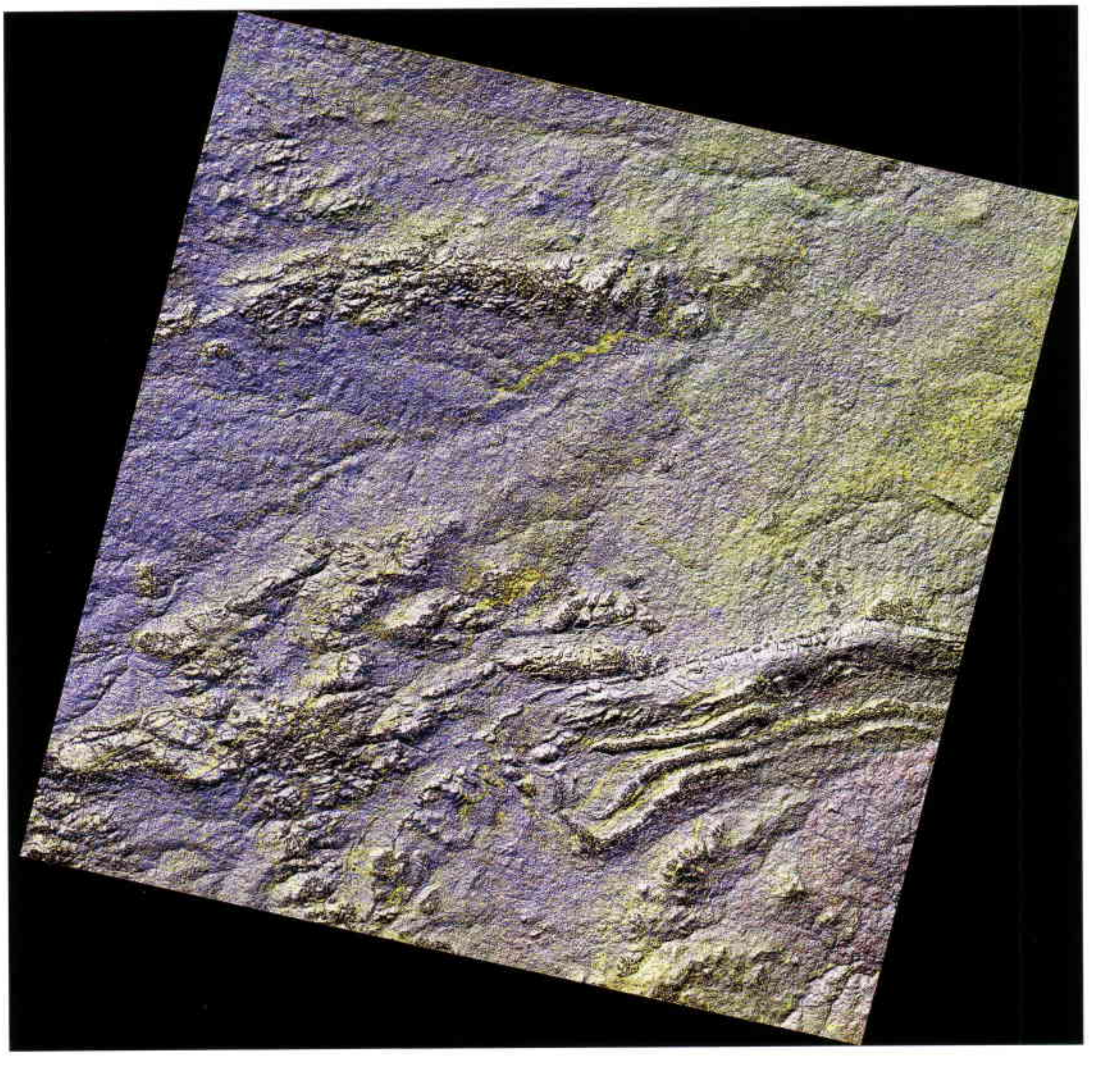
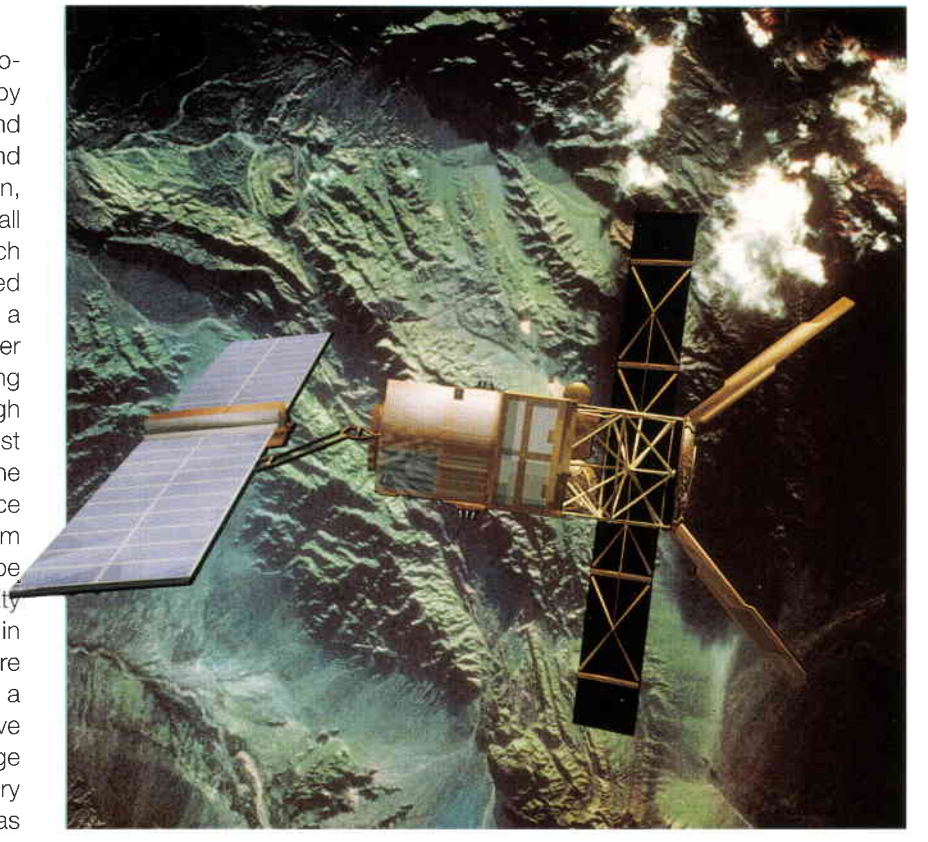


Figure 6. Enriched satellite image product suitable for use as a background for thematic maps (e.g. road maps). It is composed of SAR intensity (multi-temporal) and coherence (tandem-pair) data. The hill-shading is based on the digital terrain model and determines the intensity of the image, whilst colours (hue) and colour saturations are provided by SAR backscatter and coherence, respectively



Further information can be retrieved from a so-called 'coherence image' (Fig. 3), produced by correlating phase information from ERS-1 and ERS-2 on successive days, namely the 26 and 27 December 1995. The degree of correlation, or 'coherence', is a measure of the very small changes (in terms of geometrical structure such as surface roughness, etc.) that occurred between those two days. It also represents a measure of the bio-mass, because the denser the vegetation cover, the lower the resulting correlation will be. Agricultural fields show high coherence and are therefore very bright, whilst scrub appears in grey, and high trees on the hills are imaged in dark grey. In the coherence image, eroded areas can be discriminated from higher trees. Such a distinction cannot be made using a 'normal image' just with intensity values. Watercourses appear in dark hues in areas where higher trees grow. However, there is no difference between those trees and a body of water (top right), as both features have low coherence. In this case, the intensity image can be consulted. Steep hill-slopes appear very dark or black. They are often vertical walls, as could be verified during the field trip. This means that the combination of multi-temporal data with at least one coherence image allows the maximum amount of information to be displayed (Fig. 4).

Basic products for cartography

In an attempt to generate a hill-shaded map-base, further interferometry techniques were applied using commercially available software. Relying on a very limited number of elevation points and some additional check points, a surprisingly detailed Digital Elevation Model (DEM) could be generated. As a next step, the height information was converted into a hill-shaded map display by means of standard image processing software, and the elevation information was added in colour (Fig. 5).

The final product so obtained can be used as a basis for various types of maps, but is especially useful for geo-morphologic/tectonic studies. It can also serve as map-base for educational and administrative purposes, simply by adding the boundaries, etc., or it could be used as background information for road maps. Generally speaking, it represents a basic input (DEM and derivatives) to a Geographical Information System.

In Figure 5, the radar-derived information includes only heights and locations, but no ground features as they appear in Figure 1. In Figure 6 an attempt has been made to combine the two. This image includes the thematic information from SAR intensity and coherence (26 and 27 December only), and the real hill-shaded topographic information. To make this merge, a colour transformation is needed, which is commonly referred to as an 'intensity-hue-saturation' transformation. In our case, the image intensity is given by the hill-shading values, while hue and saturation are contributed by the intensity and coherence measurements. The result is a first step towards a radar space-map product, to which additional information such as the names of mountains, rivers, settlements, roads, etc. can be added. Combination with a three-date multi-temporal SAR data set would further enrich the image content. If map scales of better than 1:100 000 are required, a merge with very-high-resolution optical imagery is necessary.

As has been demonstrated here for the Botswana Workshop, ERS SAR is potentially the most complete, integrated data source for detailed digital mapping over large geographical areas. SAR's independence from cloud-cover makes it an indispensable information source for land-mapping in tropical, as well as higher latitude areas. esa

DESCW: PC Software Supporting Remote Sensing Data

S. D'Elia
Earth Remote Sensing Exploitation Division, ESA Directorate for Application Programmes, ESRIN, Frascati, Italy

R. Biasutti
Earth Observation Satellite Services Division, Eurimage, Rome, Italy

DESCW software performs multi-mission inventory searches for the major ESA-supported remote-sensing missions (ERS-1, ERS-2, JERS-1, Landsat and Envisat) by displaying the satellites' coverage over an Earth map. It features 'Quick Looks' for the Landsat-5 TM, ERS SAR and JERS-1 VNIR missions and prepares orders for selected scenes.

In version 4.0, special functions were added in order to simplify the selection of image pairs suitable for interferometric applications.

In the latest version of the software (v. 4.1), 'Interferometric Pairs Selection' is assisted by a new feature, 'Tandem Pairs Selection', specifically tuned for speedy identification of ERS-1 and ERS-2 scenes acquired as tandem pairs. With this feature, it is also possible to identify those pairs best suited for specific interferometric applications.

What is DESCW?

DESCW (Display Earth remote sensing Swath Coverage for Windows) is a software tool for personal computers developed by Eurimage in collaboration with ESA/ESRIN in 1992 and improved over time in response to user requirements, comments and suggestions.

Weekly updates to inventory files ensure the provision of scene locations, whether 'available' (already acquired), 'planned' (future passes) or 'visible' (technically acquirable).

The most important features of DESCW are a user-friendly graphical interface, a powerful multi-area search mechanism and mission-specific filtering tools (Fig. 1).

Background

The first version (1.xx), called DESC (Display ERS-1 SAR Coverage), was limited to ERS-1 satellite data and ran under DOS (Figure 2 shows the Data Selection screen of this early version). The software followed the evolution of the ERS-1 Mission Phases and was complemented by a separate package to view the ERS-1 'Quick Looks'. Related manuals were printed in three issues until September 1993.

In version 2.00, the software progressed into DESCW (Display Earth remote sensing Swath Coverage for Windows), a multi-mission tool supporting ERS-1, ERS-2, JERS-1 and Landsat-5 (also with Quick Look display), re-designed to run under MS Windows 3.1x. The first release, issued in March 1995, was enhanced over time with many new features, the most important of which were the addition of a layered and tiled map in three levels of resolution, and the polar projection view (June 1996).

In May 1997 version 3.00, running in both the Windows 3.1x and Windows '95 environments, was completed and included:

- a new combined Mission/Filter window
- an improved Frame List window (with sort, selection and undelete)
- geographic/graphic definitions of Landsat TM full-, quarter- and mini- floating scenes
- an improved Quick Look viewer for Landsat TM and JERS-1 VNIR
- area definitions by town or country name
- a new, simplified installation procedure
- the possibility to select Scene List columns for printing or saving in a file.

In February 1998, version 4.00 was released (the related manual was printed in May 1998) with:

- binary inventory files for ERS-1 and ERS-2 providing additional details per frame on acquisition stations, Processing and Archiving Facilities (PAFs) and quality
- the possibility to select interferometric pairs through a graphical and user-friendly interface
- the display of main Envisat swaths (for the ASAR, AATSR and MERIS instruments)
- multi-area support (single search performed

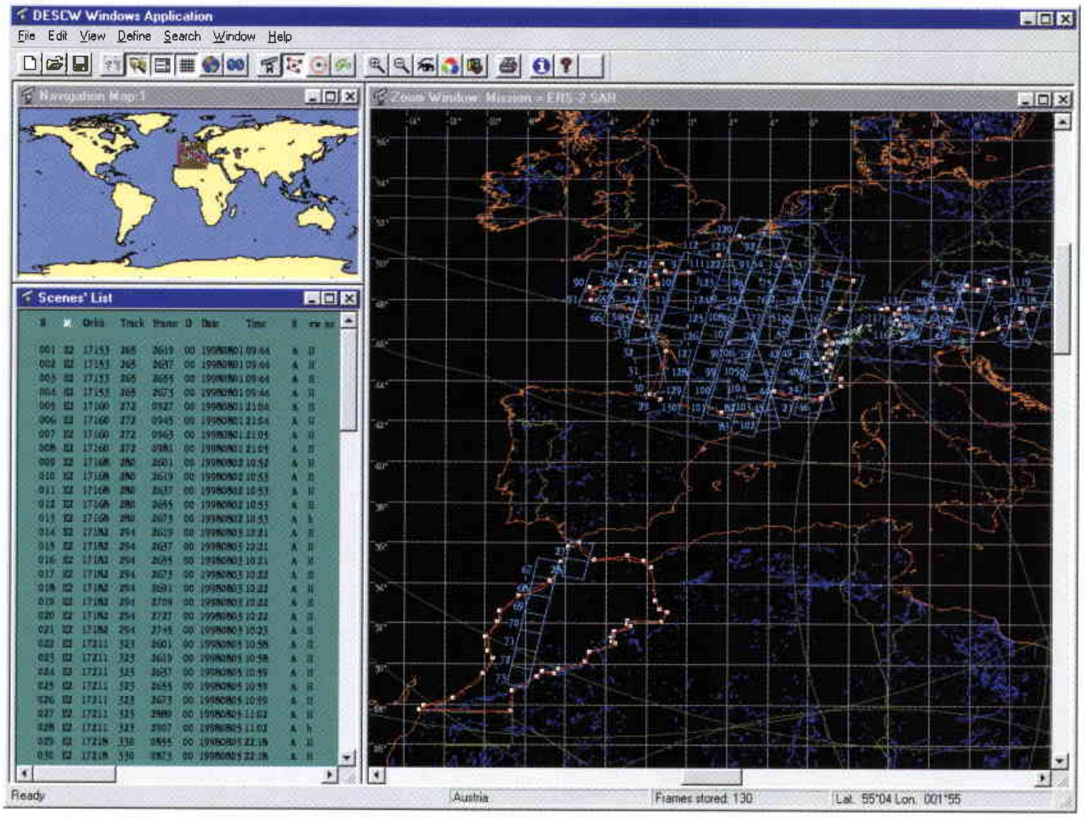


Figure 1. DESCW windows – multi-area search

against a complex area made up of a collection of polygons, as for Italy or France).

Also, the distribution format of the software and the related inventory files moved from diskettes, to CD-ROM, to online download and, finally, to online push (April 1998).

What's on the DESCW screen

The major elements of the DESCW screen are the Menus, the Toolbar, the Status Bar and the Interaction Windows.

At the top of the screen, the Menu bar is displayed. Just below it, the Toolbar allows quick access to commonly used commands.

At the bottom of the DESCW screen, the Status bar provides such information as:

- current active process
- search area name
- number of scenes retrieved by the most recent query
- geographical coordinates (in degrees and minutes) of the mouse position in the Zoom window.

DESCW provides a number of Interaction windows to the user. The three major ones are the Navigation Map window, the Zoom window and the Scene List window.

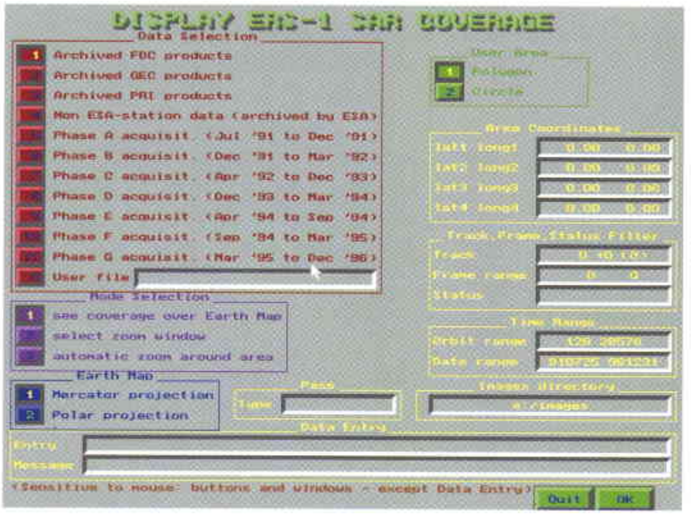


Figure 2. DESC data selection screen (1993 version)

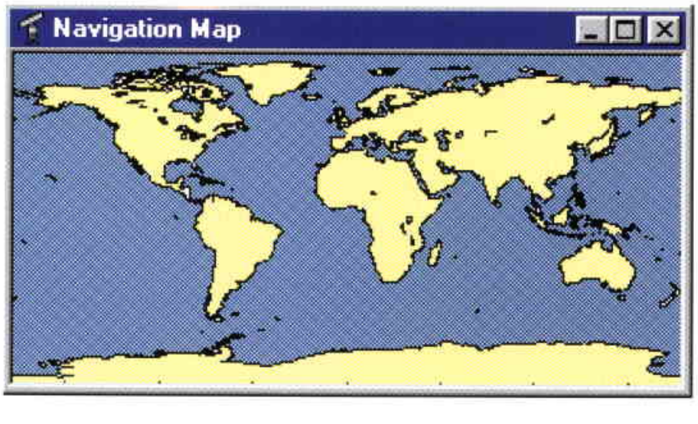
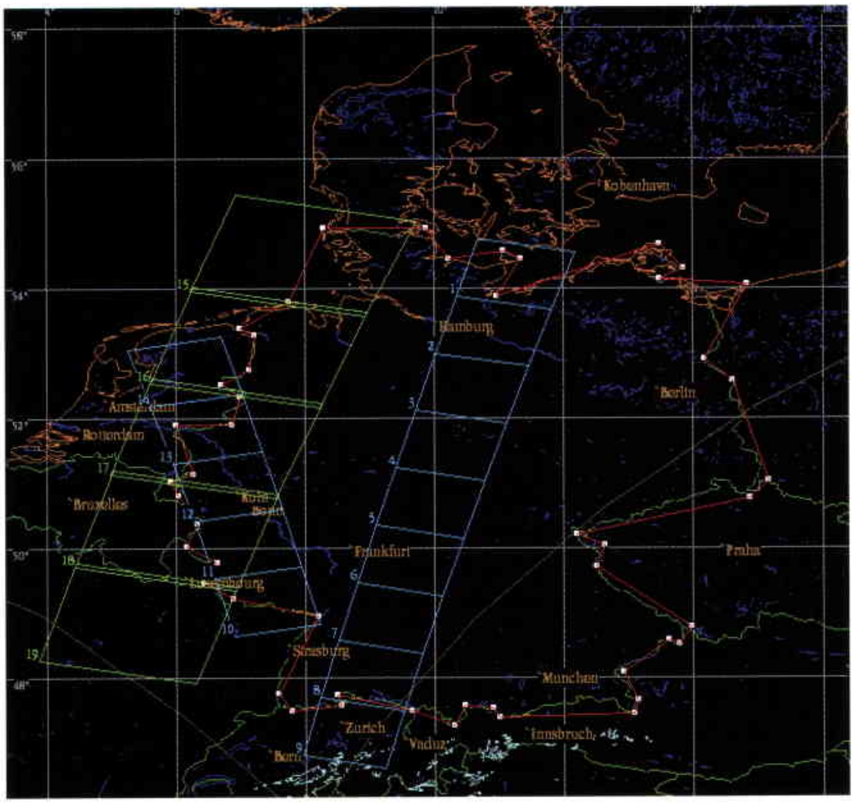


Figure 3. Navigation Map window



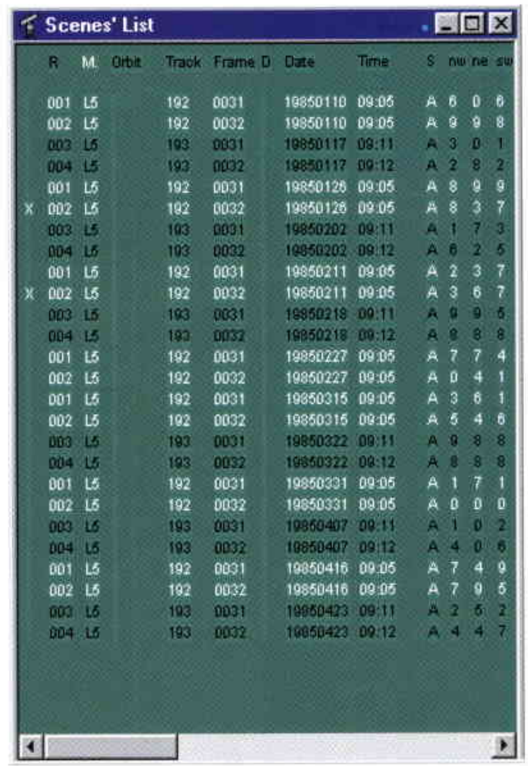


Figure 4. Zoom window – one-day acquisition of Landsat-5 (green) and ERS-2 (blue) data over Germany

Figure 5. Scene List window

Navigation Map window

The Navigation Map window (Fig. 3) is a small map of the Earth from where it is possible to choose an area of interest – the Focus Rectangle – to be displayed in the Zoom Window. By moving the Focus Rectangle, the area enlarged in the Zoom Window moves accordingly. Conversely, by changing the area in the Zoom window (through the scroll bars), the Focus Rectangle moves.

Zoom window

The Zoom window (Fig. 4) is displayed either by selecting the Zoom window option on the View menu or by clicking, or dragging, on the Navigation Map window. It expands the area contained in the Focus Rectangle from the Navigation Map window, at a level of detail determined by the Map Layers option. It is possible to zoom in and out using the Zoom options on the View menu. Search area polygons can be drawn in this window. When a search has been completed, frames outlining each of the scenes found are displayed in the window.

Scene List window

When a search has been completed, this window (Fig. 5) will list the scenes found. Moving the cursor over a column in the window will highlight all scenes with the same value in that column. For example, if the cursor is over a number in the Track column, DESCW will highlight all scenes with the same Track Number; the same scenes will also be highlighted in the Zoom window.

Full details about other windows and related functions can be found in the manual and the online help.

How it Works

A high-level view of the DESCW structure and possible sequence of operations is shown in Figure 6. After having broadly selected the region of interest through the Navigation Map window, it is possible to graphically draw the polygon detailing the area of interest. The next step is to identify the missions and date ranges of interest, as well as other specific filtering parameters (Fig. 7). The search can now start using the data of the Inventory files (updated weekly from the Internet). The search result is stored in the Working Set and displayed on the Scene List window. Unwanted scenes can be removed from the Working Set by selecting them and clicking with the right mouse button (all selected scenes will be removed from the list and the Zoom Window).

Other functions can be activated for the selected scenes. For example, double-clicking on the Status column of a scene will display its Quick Look (if generated and the related CD-ROM is available), permitting also limited image manipulation. Additional support functions (e.g. show full coverage, show sub-satellite track,show current satellite position show scene details, compute shifted scenes, change map layers/colours, save/load areas, para-meters or user requests, etc.) can be activated through other specific interaction windows.

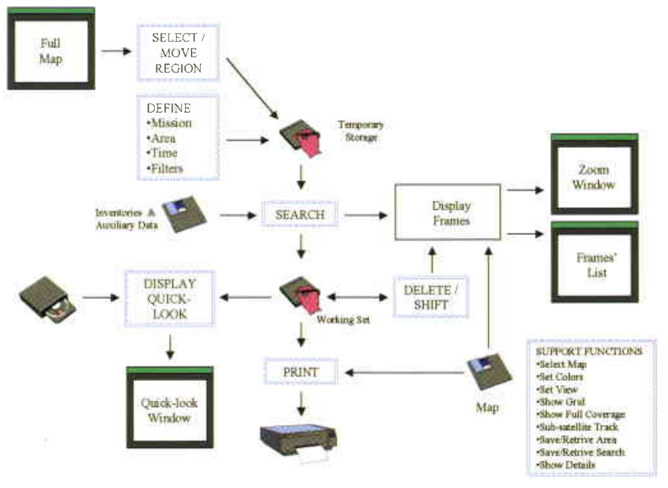


Figure 6. DESCW structure

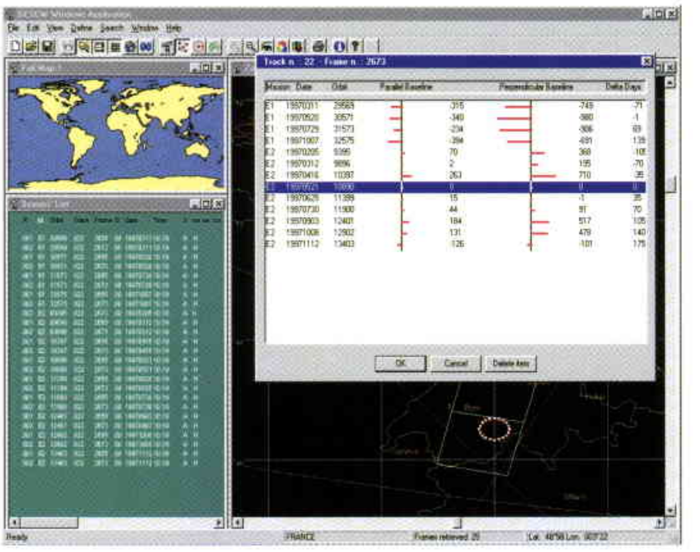


Figure 7. DESCW baseline tool

Interferometric Pairs Selection

Interferometry is being successfully used for:

- Digital Elevation Model (DEM) generation
- movement detection (differential interferometry):
    - ice surface displacements
    - landslides
    - subsidence
    - earthquakes
    - volcanoes
- land-cover mapping through coherency maps.

A special function has been added in order simplify the selection of image pairs suitable for interferometric applications.

Clicking on one specific column of the selected scene, in the Scene List window, will open the Interferometric Baselines window, showing all the scenes with the same track and frame number. For each scene, the orbit number, the acquisition date, the values of the parallel and perpendicular baselines and the time interval between the acquisitions, are shown.

Double-clicking on the orbit will re-compute all the baseline values and the day interval with respect to this orbit. It is also possible to delete the orbits that are not of interest and to print the dialogue box. The tool is also able to compute the baselines between ERS-1 and ERS-2 acquisitions. The sole constraint is that only ERS-1's phase C or G can be selected (35 day cycles). Baseline values over 1024 m (parallel) and 4096 m (perpendicular) are set to these limits.

ERS-1 & 2 Tandem Pairs Selection

In version 4.1, the Interferometric Pairs Selection is assisted by a new function, which is specifically setup for fast identification of ERS-1 and ERS-2 scenes acquired as tandem pairs (i.e. acquired at one-day interval), with perpendicular baseline values falling within a pre-defined range and, therefore, best suited for specific interferometric applications (Fig. 8).

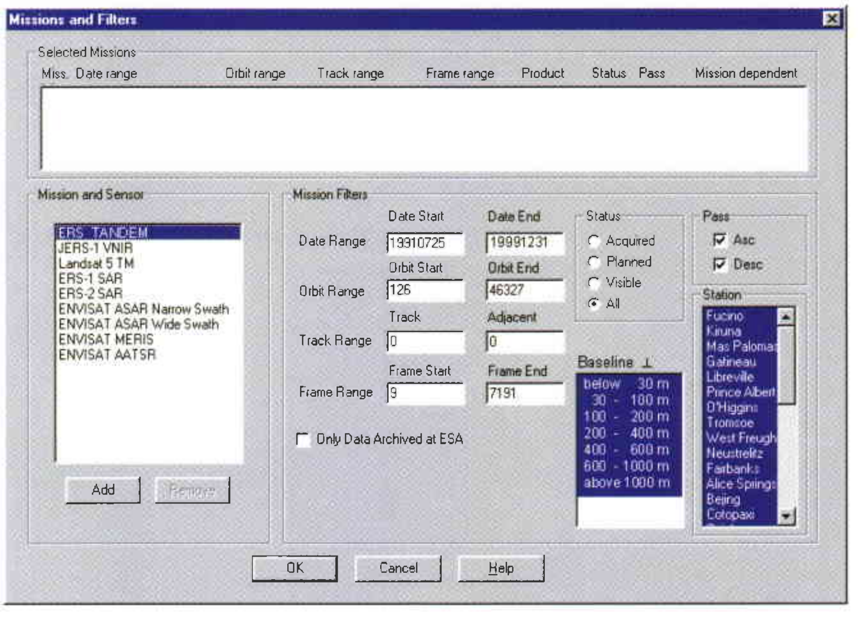
For this function, a new set of ERS-1 and ERS-2 inventory files were generated, separating the scene pairs into a number of different files according to the difference in the perpendicular baseline values as follows:

- below 30 m
- 30 – 100 m
- 100 – 200 m
- 200 – 400 m
- 400 – 600 m
- 600 – 1000 m
- above 1000 m.

This is a preliminary list; the final set of ranges will be selected after the completion of more tests.

Practical experience indicates that certain ranges of perpendicular baseline values are preferred for different application types. As a very broad guideline for DEM generation and land-cover mapping, values between 50 to 400 m are normally used, while for movement detection a value below 50 m is suggested.

Figure 8. DESCW mission selection – tandem mission



However, this does not preclude good results with baseline values outside these ranges.

It is necessary to select all inventory files for ERS-1 and ERS-2 containing scenes with perpendicular baseline value differences falling in the required range. For example, should the required baseline be within 150 and 250 m, two pairs of files will have to be selected. After this initial selection, all the other DESCW features can be applied as usual, including the Interferometric Pairs Selection.

With this new option, it is possible to use the baseline range as a filter for the different interferometric applications and, therefore, the screen displays only the couples with a one-day interval between the two acquisitions.

Other new features

Version 4.1 includes other new features or enhancements in addition to the above described ERS-1 and ERS-2 Tandem Mission Support. The main ones are:

- Multiple filters: it is now possible to define more than one filter set for each mission and include more than one time range, which copes, for example, with seasonal searches over the same area. Each filter set appears as a separate line in the 'Selected Missions' list and can be handled separately.
- Increased performances: the query time (search and frames display) is greatly reduced, with a more than an order of magnitude improvement. This was achieved by multi-threading, permitting full exploitation of the CPU, and optimising memory usage.
- Current satellite location: it is possible to see in real time where the sub-track of the selected satellite(s) is currently located. The satellite icon moves with time. This representation is generated from nominal orbital parameters and is linked to current computer date and time settings.
- Simplified maintenance: the software has been fully restructured, permitting faster reaction to new requirements in the future.

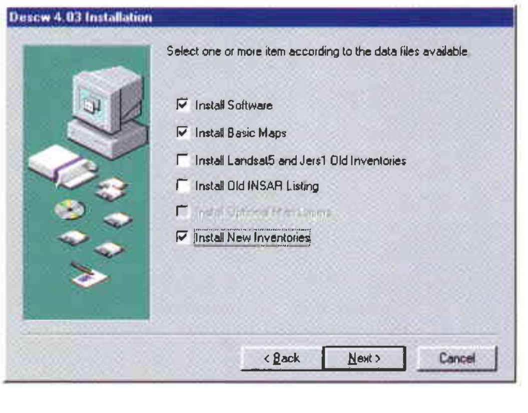


Figure 9. DESCW setup

Installation and updates

The DESCW software and related inventory files (updated weekly) are available. for free installation and updates offline (see 'Support' section) or online from the ESA/ESRIN server.

FTP access

Address	earthnet.esrin.esa.it
Username	anonymous
Password	(your e-mail address)
Directory	/FTP/software/descw

World Wide Web access

http://earthnet.esrin.esa.it

Follow 'Software Gallery', then 'Software to Obtain Satellite Earth Coverage'.

BackWeb

BackWeb is a client-server application that sends data from a server, via the Internet, to all clients who have subscribed to a specific 'channel'. It applies data-push technology using idle online time and check-point/restart (after a break the transmission resumes from the point of interruption). The BackWeb client is free of charge and can be downloaded from:

http://www.backweb.com

Once the BackWeb client is installed, subscribe to the DESCW channel from:

http://earth1.esrin.esa.it/backweb

In order to complete the installation or updates, select the required options (Fig. 9), and follow the instructions provided by the installation package.

Support

The DESCW software and manual are also available offline. For a free copy please contact:

ENVISAT & ERS Help Desk
ESA/ESRIN
Via Galileo Galilei
I - 00044 Frascati - Italy
Tel: +39-06-94 180 777
Fax: +39-06-94 180 272
e-mail: eohelp@mail.esrin.esa.it

For more information, queries and suggestions about DESCW contact:

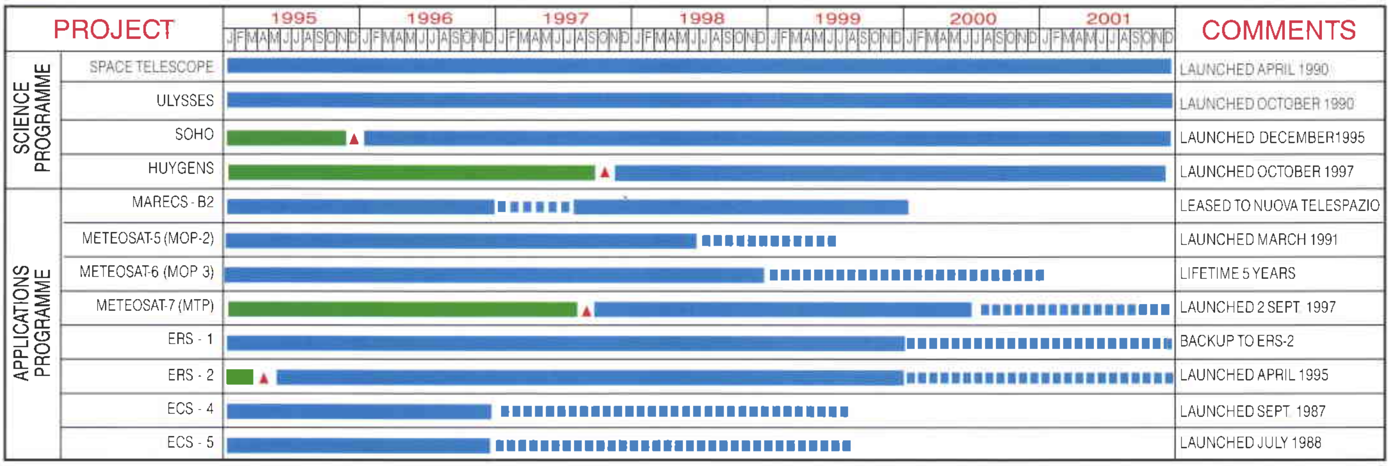
DESCW Technical Support
ESA/ESRIN
Via Galileo Galilei
I - 00044 Frascati - Italy
Tel: +39 -06 94 180 744
Fax: +39 -06 94 180 862
e-mail: descw-help.desk@eurimage.it

esa

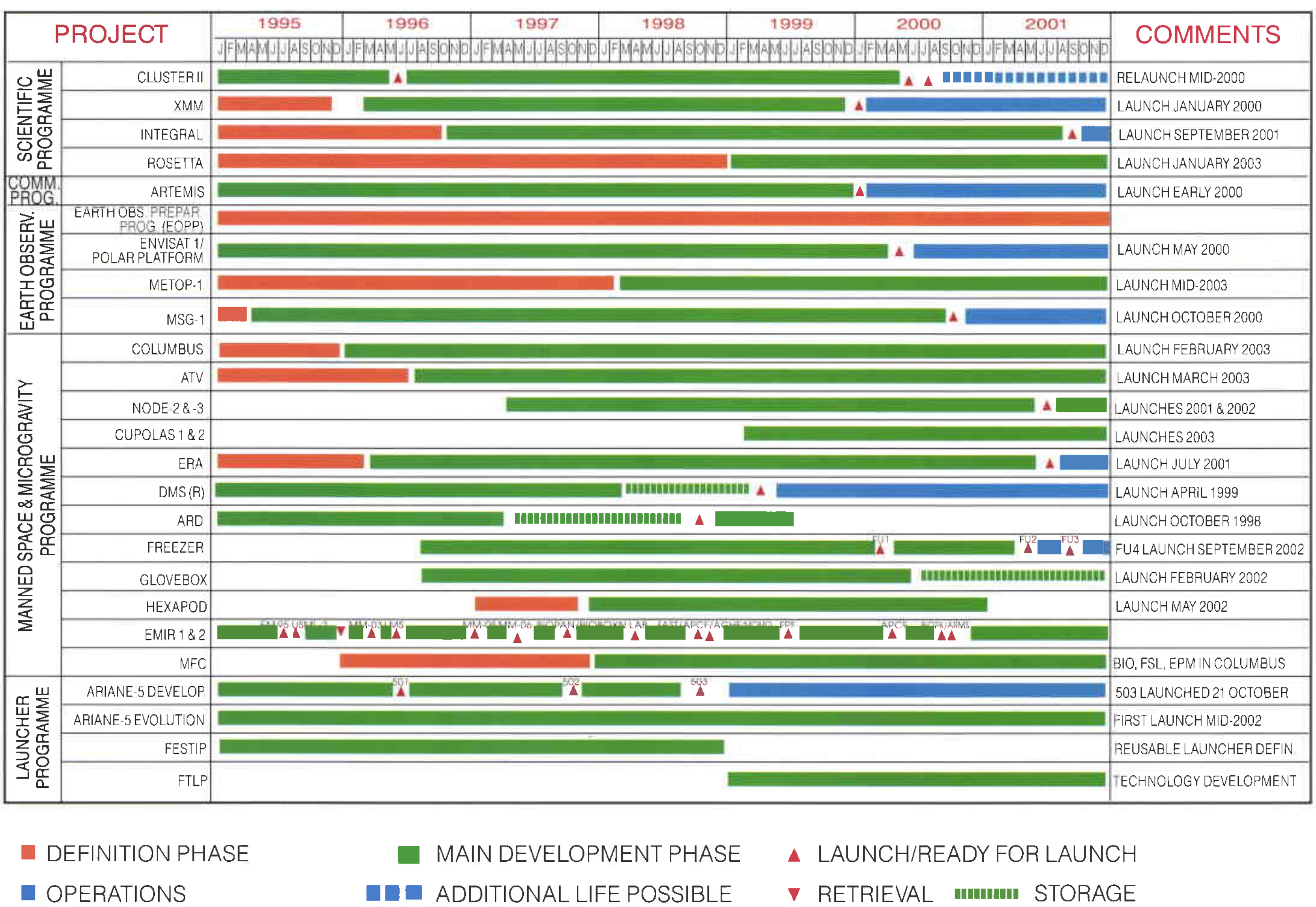
Programmes under Development and Operations
Programmes en cours de réalisation et d'exploitation

(status end December 1998)

In Orbit / En orbite



Under Development / En cours de réalisation



ISO

Une importante conférence internationale sur les récents résultats de la mission ISO s'est déroulée à Paris, du 20 au 23 octobre 1998. Les quelques 400 astronomes qui y ont participé ont présenté une soixantaine de communications et plus de 220 affiches. Les actes de cette conférence devaient être publiés en février 1999 par la Division des publications de l'ESA, dans la série SP. Parmi les sujets d'un grand intérêt abordés au cours de cette conférence, la presse a notamment relevé la présentation d'une nouvelle vue de la nébuleuse d'Andromède (réalisée dans de très grandes longueurs d'ondes infrarouges), l'utilisation de télescopes naturels (ou 'lentilles gravitationnelles') pour remonter à une époque où l'Univers semble avoir été beaucoup plus actif qu'aujourd'hui, et la révélation d'un anneau de matière organique autour de l'une des étoiles de notre Galaxie.

L'ensemble des données fournies par le satellite a été retraité au cours de l'été 1998 par le Centre des données ISO de Villafranca (E), au moyen de la version 'fin de mission' du logiciel de traitement et des fichiers d'étalonnage 'pipeline'. Ce travail a permis de constituer les premières archives complètes et homogènes de données ISO. En décembre, la communauté scientifique a commencé à avoir accès à ces données via le Web. Les utilisateurs disposent aujourd'hui de nouveaux 'produits de consultation', permettant de livrer un aperçu rapide mais précis du contenu scientifique de chacune des 26 000 observations et plus figurant dans la base de données. L'interface utilisateur offre aux experts comme aux non spécialistes d'importantes capacités de recherche appelées à être développées dans l'avenir. Les utilisateurs peuvent obtenir les données désirées par CD-ROM ou via un site FTP. Une 'bibliothèque' de documents explicatifs existe également sur le Web et permet de faire le meilleur usage possible des données proposées. Le même site Web (www.iso.vilspa.esa.es) propose enfin différents logiciels permettant de réduire et d'analyser les données de manière interactive.

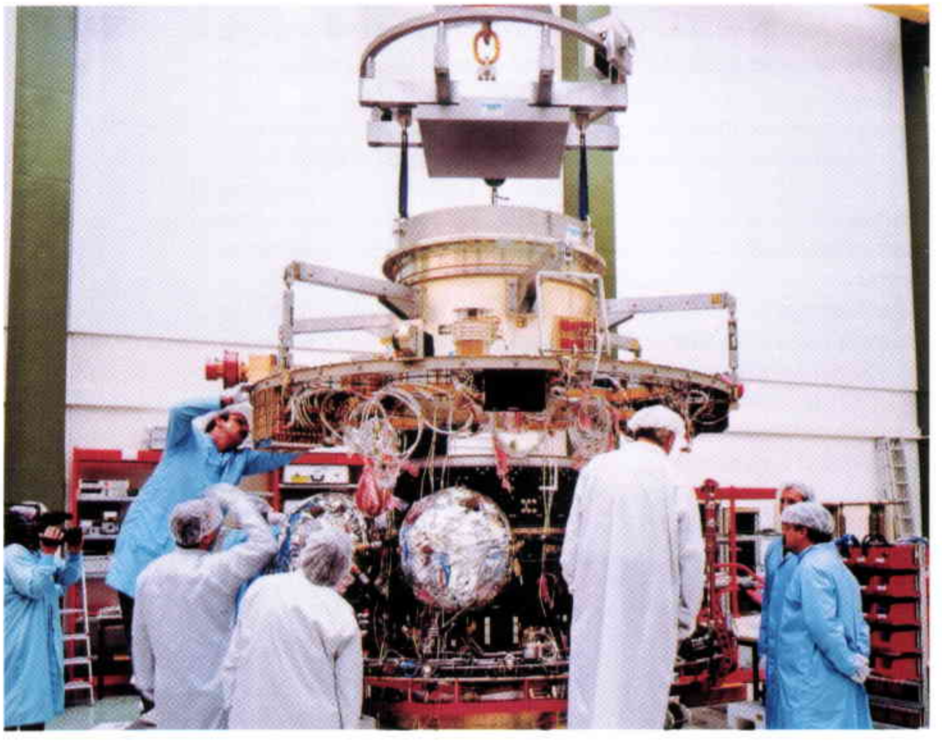
Cluster-II

La revue de validation de la mission a été réalisée avec succès en décembre. Elle a permis d'examiner la compatibilité de l'ensemble des éléments conçus pour la mission et de qualifier plus particulièrement ceux qui ont été modifiés depuis la mission Cluster d'origine. Chaque élément de la mission (charge utile, satellite, secteur sol, système de données, lanceur) a été examiné.

L'intégration du premier modèle de vol (FM6) des nouveaux satellites s'est déroulée conformément aux prévisions. La charge utile complète est désormais installée et les essais fonctionnels au niveau du système du satellite étaient programmés pour le début 1999; puis il sera expédié en mars chez IABG à Munich pour y subir son programme d'essais d'ambiance. Les travaux d'intégration du deuxième modèle de vol (FM7) ont également débuté et devraient s'achever 3 mois environ après ceux du FM6. Les unités de vol de l'ensemble des éléments ont été vérifiées avec succès, et notamment celles du nouvel enregistreur à état solide et du nouvel amplificateur haute puissance.

Une équipe de l'ESA est allée en novembre constater l'état d'avancement du lanceur Soyouz et de son nouvel étage supérieur Frégate. L'équipe a été très favorablement impressionnée par la compétence et l'engagement du partenaire russe, tout en étant pleinement consciente qu'il reste beaucoup de travail à accomplir avant que Frégate puisse être déclaré opérationnel. Les ultimes négociations relatives aux assurances à souscrire pour le lancement se sont achevées positivement, avec la possibilité d'un lancement de secours à bord d'Ariane-4 si les délais de réalisation de l'ensemble Soyouz-Frégate s'avéraient trop longs. Le contrat de lancement signé par l'ESA avec le consortium franco-russe Starsem prévoit deux lancement réussis du tandem Soyouz-Frégate avant que l'on puisse autoriser celui de Cluster-II.

Des revues ont également été organisées pour le secteur sol, le système d'accès aux données scientifiques de Cluster et le Centre commun d'opérations scientifiques, qui ont permis de confirmer que toutes les mises à jour du système étaient compatibles avec les impératifs et le calendrier d'ensemble de la mission. Le transfert de la station sol primaire d'Odenwald (Allemagne) à Villafranca (Espagne) a débuté.



Integration of the Cluster-II FM6 flight model, at Dornier (D)

Intégration du modèle de vol FM6 de Cluster-II, chez Dornier (D)

ISO

A very successful international conference, dedicated to recent ISO results, was held in Paris from 20-23 October. It attracted nearly 400 astronomers, who presented and discussed approximately 60 talks and over 220 posters during the course of the meeting. The Proceedings will be published by ESA Publications Division in the ESA SP series in February 1999. Some of the highlights picked up by the press were a completely new view of the Andromeda nebula (seen at very long infrared wavelengths), the use of natural telescopes (the so-called 'gravitational lenses') to look back to a time when the Unverse seems to have been much more active than now, and a ring of organic matter surrounding a star in our galaxy.

During summer 1998, all ISO data were re-processed at the ISO Data Centre in Villafranca (E) using the 'end-of-mission' version of the pipeline processing software and calibration files, in order to produce the first complete homogeneously-processed archive of ISO data. In December, community access started via the World Wide Web (WWW) to this data, which includes some new 'browse' products designed to give a quick but accurate impression of the scientific content of each of the more than 26 000 observations in the database. A wide range of search capabilities for both general and expert users is provided by the user interface and will be further expanded. Depending on the volume to be retrieved, data is provided to users either via FTP or on CD-ROM. A 'library' of explanatory documents to help users get the best out of the data has also been made accessible via the Web. Various software tools to reduce and analyse the data interactively are also available via the same site (www.iso.vilspa.esa.es).

Cluster-II

In December, the project successfully underwent its Mission Validation Review (MVR). This Review examined the compatibility of all elements of the mission design and in particular addressed all areas of the Cluster-II mission that have changed since the original Cluster mission and certified their compatibility and qualification status. Inputs for the MVR were identified from reviews of each project element – payload, spacecraft, ground segment, data system and launch vehicle.

Integration of the first new flight-model satellite (FM6) has proceeded according to plan. The complete payload is now installed and the spacecraft will undergo system functional testing early in 1999, before being shipped to IABG in Munich in March for the environmental test programme. Integration on the second flight model (FM7) has also started and will follow approximately 3 months behind FM6. Verification of all units has been successful, including the newly developed solid-state recorder and high-power amplifier.

In November, an ESA team reviewed the status of the Soyuz launch vehicle and its new Fregat upper stage. The review team came away with a most favourable impression of Russian expertise and dedication, though fully aware that a great deal of work still needs to be done before the Fregat becomes operational. Final negotiations over launch insurance have been successfully completed, providing for a back-up launch on an Ariane-4 if long delays should arise in the Soyuz-Fregat development schedule. The launch contract signed by ESA and the French-Russian Starsem consortium stipulates that two successful Soyuz-Fregat launches must be completed before the Cluster-II lift-off.

Successful reviews have also been held for the Ground Segment and the Cluster Science Data System/Joint Science Operations Centre. These have confirmed that all upgrades of the systems are compatible with the mission requirements and the overall schedule. The transfer of the primary ground station from Odenwald in Germany to Villafranca in Spain has commenced.

XMM

The service module of the flight satellite is undergoing environmental and functional testing at ESTEC in Noordwijk (NL). Vibration tests were successfully concluded at the end of November. Before the Christmas break, the service module was installed in the Large Space Simulator (LSS) and the thermal-vacuum test was due to start on the first working day of 1999.

The focal-plane assembly, which carries the X-ray instrumentation, will arrive at ESTEC in February. This assembly will follow the service module into the LSS to start its test sequence also with a thermal-vacuum test.

Three flight X-ray mirror assemblies, built by Media Lario (I) under a direct ESA contract, were formally handed over to Dornier (D) in December. They will replace the structural models, which are currently integrated on the flight spacecraft to protect the flight optics from contamination during the test programme.

At Centre Spatial de Liège (CSL) in Belgium, the combined testing of the flight mirror module with the associated X-ray baffles and reflection gratings has been completed. Following the shipment of the flight mirror modules to ESTEC, a last flight-spare mirror module will arrive from Media Lario in early January to undergo acceptance testing.

X-ray instrument flight hardware delivery was completed in late November with the shipment of the EPIC pn camera to Dornier to be integrated onto the focal-plane platform of the flight satellite.

The efforts of the instrument groups are now concentrated on finalising software and documentation to prepare for the testing and operation of their instruments.

The mission analysis conducted by ESOC has confirmed the feasibility of the new launch date in January 2000.

Deliveries of mission-control software elements continue as planned. A first combined test, linking mission-control software at ESOC and the flight spacecraft at ESTEC, was successfully conducted in October. Preparations are now underway for the first system-level validation test in March. During this test, the spacecraft will be fully controlled for the first time by the ESOC mission-control system.

Integral

Spacecraft and payload
The shock and vibration testing at IABG (D) were finished in the autumn, thereby successfully completing the Structural and Thermal Model (STM) testing programme. The mechanical integration

XMM

Le modèle de vol du module de service subit actuellement des essais fonctionnels et d'ambiance à l'ESTEC, Noordjwijk (NL). Les essais de vibration ont été accomplis avec succès fin novembre. Le module a été installé à la veille des vacances de Noël dans le grand simulateur spatial (LSS) pour y subir ses essais thermiques sous vide prévus pour les premiers jours de 1999.

L'ensemble au plan focal, qui comprend l'instrumentation rayons-X, doit être livré à l'ESTEC en février. Il succédera au module de service dans le LSS en vue d'une série de tests qui commenceront également par des essais thermiques sous vide.

Trois modèles de vols des ensembles de miroirs destines a l'etude du rayonnement X, réalisés par Media Lario (I) au titre d'un contrat signé directement avec l'ESA, ont été officiellement livrés chez Dornier (D) en décembre. Ils remplaceront les modèles structurels qui sont actuellement en cours d'intégration dans le modèle de vol du satellite afin de protéger les optiques de vol de toute contamination pendant le programme d'essais.

Les spécialistes du Centre spatial de Liège (CSL), ont achevé les essais combinés des modules de miroirs de vol avec les déflecteurs rayons-X et les grilles de réflexion associés. Après la livraison de l'ensemble des modules de miroirs à l'ESTEC, Media Lario devait encore faire parvenir, début janvier, un module de miroirs de rechange aux fins d'essais de recette.

La livraison du matériel de vol de l'instrumentation Rayons-X s'est terminée fin novembre par l'arrivée chez Dornier de la caméra photonique EPIC qui doit être intégrée à la plate-forme au plan focal du modèle de vol du satellite.

Les activités des groupes 'instruments' se concentrent désormais sur la mise au point finale des logiciels et de la documentation nécessaires aux essais et à l'exploitation de leurs instruments.

L'analyse de la mission réalisée par l'ESOC a confirmé qu'il était possible de maintenir le lancement en janvier 2000.

La livraison des logiciels de contrôle de la mission se poursuit comme prévu. Des essais combinés, associant les logiciels de contrôle de la mission à l'ESOC et le modèle de vol du satellite à l'ESTEC, ont été menés à bon terme en octobre. On prépare actuellement les premiers essais de validation au niveau système qui doivent se dérouler en mars. Ces essais, réalisés au moyen du système de contrôle de mission de l'ESOC, permettront de procéder pour la première fois à une vérification complète du satellite.

Intégral

Satellite et charge utile

Le programme d'essais du modèle structurel et thermique (STM) s'est achevé à l'automne par les essais de chocs et de vibrations réalisés chez IABG (D). L'équipe d'intégration mécanique devrait s'attaquer, début 1999, au modèle de vol du module de servitude (SVM).

Une revue de conception du matériel s'est tenue début septembre afin d'évaluer la possibilité d'engager les activités liées au niveau système du modèle d'identification. L'examen du satellite n'a révélé aucun problème important. La conception du système a été confirmée sur le plan des performances, de la tolérance aux pannes et de l'exploitabilité. Le développement des éléments spécifiques d'Intégral ne présente également aucun problème technologique. La commission a exprimé son inquiétude quant à la disponibilité des modèles d'identification des instruments.

Les travaux relatifs à ces derniers ont véritablement commencé à la suite de cette revue. En dépit des retards de livraison et des dysfonctionnements constants présentés par l'élément central de l'équipement électrique de soutien au sol, des progrès importants ont été accomplis au cours des derniers mois et l'achèvement du programme de modèles d'identification est toujours prévu pour la mi-1999.

Secteur sol

Conformément aux recommandations formulées lors de la dernière revue du secteur sol de décembre 1997, on s'est employé à faire progresser la conception et la définition du plan de gestion global de ce secteur. Une nouvelle revue d'avancement, visant à évaluer les progrès accomplis et à faire le point sur le secteur sol, a démarré en décembre 1998 et devait s'achever début 1999.

Rosetta

Le Comité de la politique industrielle de l'ESA (IPC) a définitivement approuvé le contrat de phase C/D (phase principale de développement) de Rosetta au cours de la réunion qu'il a tenue le 26 novembre à Paris. Cette approbation met fin à la procédure de sélection du contractant industriel rendue compliquée par la sévérité de la compétition.

La conception du satellite a fait, pendant ce temps, d'importants progrès. La configuration d'installation des instruments est désormais stable et l'on a achevé la première série d'analyses mécaniques et thermiques. Après un certain nombre d'itérations, il se confirme que la conception thermique du satellite est compatible avec l'énergie solaire réduite disponible au point le plus éloigné du Soleil.

La phase B du projet s'est achevée par une importante série de revues qui ont permis d'étudier en détail la conception et l'état d'avancement de tous les éléments de la mission Rosetta, dont le satellite, la charge utile et ses instruments, le secteur sol et le lanceur. Une équipe indépendante a également procédé à une revue de conception spéciale de l'atterrisseur.

Sans méconnaître le caractère particulièrement critique du calendrier d'ensemble de la mission, la commission de revue de conception du système a estimé, début décembre, que l'on pouvait raisonnablement avoir confiance dans le succès de la mission et de tous ces éléments.

Artémis

Le programme d'essais d'Artémis se poursuit à l'ESTEC, Noordwijk (NL). Les essais de simulation solaire ont été conduits avec succès et le satellite est à présent soumis à une série d'essais acoustiques et de vibrations.

Le terminal de relais de données en bande S de l'ESA a été soumis à une team is expected to start work on the flight model of the Service Module (SVM) programme at the beginning of 1999.

A Hardware Design Review was held in early September to assess readiness to start the engineering model system-level activities. No major problems were found on the spacecraft. The system design was confirmed in terms of performance, fault tolerance and operability. Also, the Integral-specific development items did not present any technology problems. The Board expressed concern over the availability of instrument engineering models.

Following this Review, work on the engineering models began in earnest. Despite delays in deliveries of instrument engineering models and continuous troubleshooting for the core electrical ground support equipment, significant progress in these activities has been made in the last months and completion of the engineering-model programme is still expected by mid-1999.

Ground segment

Good progress has been made on defining the overall management scheme and design of the ground segment, as recommended by the previous ground-segment review in December 1997.

A new Ground Segment Status Review aimed at verifying this progress and assessing the overall status of the ground segment was kicked-off in December and should be completed by early 1999.

Rosetta

The ESA Industrial Policy Committee (IPC), meeting in Paris on 26 November, gave the final approval for the Rosetta Phase-C/D (main development) contract. This concludes a rather complex process of industrial contractor selection, which at times has seen very heavy competition.

In the meantime, the spacecraft design has made considerable progress. A stable configuration for the instrument accommodation has been achieved and the first round of mechanical and thermal analyses has already been completed. After a number of iterations, the spacecraft thermal design has been confirmed to be compatible with the limits of available solar-array power at the farthest distance from the Sun.

As a conclusion to the project's Phase-B, an extensive series of reviews has closely scrutinised the design and development status of all elements of the Rosetta mission, including the spacecraft, the instrument payload, the ground segment and the launcher. The Rosetta Lander has also been subjected to a special design review by an independent team.

Without ignoring the very critical overall schedule situation, the Mission System Design Review Board concluded in early December that there is a good degree of confidence in mission success for all of the elements.

Artemis

The Artemis satellite test programme is continuing at ESTEC in Noordwijk (NL). The solar-simulation test has been successfully carried out and the satellite is now proceeding to the vibration and acoustic test phases.

Following the successful checkout of the ESA Silex optical data-relay terminal on board the CNES Spot-4 Earth-observation satellite earlier this year using stars as counter terminals, a series of tests on the ESA S-band data-relay terminal has now been carried out. Spot-4 telemetry data has been successfully relayed to the Spot-4 Control Centre in Toulouse (F) via the US TDRS data-relay system.

EOPP

Strategy and future programmes

The main emphasis in the reporting period has been on attempting to identify the way ahead for Earth Watch activities. Earth Watch programmes are foreseen to be developed in partnership schemes with the objective of establishing sustainable systems. Although the task of identifying an acceptable approach has proved to be rather complex, by early December the Director General had succeeded in convincing the main industrial groups to work together.

Artemis being prepared for solar-array deployment testing at ESTEC (NL)

Préparation d'Artemis aux essais de déploiement du générateur solaire à l'ESTEC (NL) *série d'essais. Auparavant, on avait vérifié le terminal de relais de données Silex de l'ESA placé à bord de SPOT-4, le satellite d'observation de la Terre du CNES en utilisant les étoiles comme base de comptage. Les données de télémesure ont été relayées avec succès vers le centre de contrôle SPOT-4 à Toulouse (F), via le système de relais de données américain TDRS.*

EOPP

Stratégie et programmes futurs

Au cours de la période de référence, on s'est surtout intéressé aux moyens de développer les activités de surveillance de la Terre. Il est prévu que les programmes d'observation de la Terre soient lancés dans le cadre de partenariats, avec pour objectif de mettre en place des systèmes durables. Bien que la détermination d'une stratégie acceptable se soit révélée relativement compliquée, le Directeur général est parvenu, début septembre à convaincre les principaux groupes industriels à travailler ensemble.

Missions futures

Les études de phase-A des quatre missions de base d'exploration de la Terre en cours de préparation ont franchi en fin d'année une première étape importante avec la revue de définition préliminaire. Parallèlement, l'appel à propositions lancé aux chercheurs principaux pour les premières missions de circonstance a permis de recueillir 27 propositions qui font actuellement l'objet d'une évaluation.

Campagnes

La campagne 1998 s'est conclue au début de l'automne par la phase d'acquisition des données de vol de l'expérience CLARE (radar et lidar de nébulosité). Les activités s'orientent désormais vers la préparation de la campagne 1999.

Envisat/Plate-forme polaire

Système Envisat

L'évaluation des réponses à l'avis d'offre de participation (AO) à des projets pilotes et d'exploitation de données scientifiques est aujourd'hui terminée et ses résultats ont été acceptés par les Pays participants au programme. Les chercheurs principaux qui ont été choisis en seront prochainement avertis.

Les activités se concentrent actuellement sur la préparation de la vérification du système, et notamment de celle de l'ensemble du secteur sol, et sur celle de l'étalonnage en vol des instruments, ainsi que sur la validation des produits dérivés de niveau 2.

Activités relatives au satellite

Le programme d'assemblage, intégration et essais (AIT) du modèle d'identification du satellite Envisat s'est poursuivi avec la préparation de ce modèle pour des essais de compatibilité radiofréquence. Une enceinte RF complète a été édifiée dans ce but autour du satellite.

L'AIT du modèle de vol a franchi une étape importante avec l'achèvement des activités d'intégration du compartiment des équipements de la charge utile du modèle de vol dans le porte-charge utile, suivie par l'intégration de trois des instruments du modèle de vol, DORIS, MWR et GOMOS.

Charge utile Envisat

Les modèles de vol des deux instruments GOMOS et RA-2 ont été récemment livrés chez Matra Marconi Space (Bristol GB) pour y être intégrés au modèle de vol du satellite. Un modèle mixte du MIPAS, comprenant l'optique du modèle d'identification et de qualification et des éléments électroniques du modèle de vol, est en cours de livraison. Le modèle de vol du sous-ensemble électronique central de l'ASAR est également prêt à être livré.

Les modèles de vol des instruments non encore livrés subissent leur dernière phase d'intégration et d'essais. Seize des vingt tuiles du modèle de vol de l'antenne de l'ASAR ont déjà été livrées et intégrées à la structure de l'antenne. On remédie actuellement aux défaillances constatées sur certains équipements de l'ensemble optique du modèle de vol du MIPAS. Deux canaux infrarouges du modèle de vol du SCIAMACHY sont en cours de réalignement et l'on recherche les causes d'un problème de lumière parasite constaté sur le modèle de vol du MERIS.

Secteur sol Envisat

L'intégration des installations du système des données de charge utile (PDS) sur la plate-forme de référence se poursuit chez DATAMAT à Rome (I) et une configuration représentative de la station de traitement des données de charge utile (PDHS) est en cours d'installation à l'ESRIN, Frascati (I) en vue de préparer la recette de la version V1 du PDS.

Tous les modules (installations) du PDS sont déjà en place sur la plate-forme de référence, même si certains d'entre eux ne sont représentés que par des logiciels intermédiaires. Cette méthode permet de tester la circulation complète des données et de valider les interfaces.

Le développement et l'intégration du secteur sol des opérations en vol (FOS) progressent selon le plan prévu. Les travaux portent plus particulièrement sur la préparation des premiers essais de vérification du satellite.

Métop

La signature des documents de contrôle des interfaces (ICD) des cinq instruments fournis par la NASA a constitué, au début de l'été dernier, une importante étape dans la poursuite du programme Métop. Les ICD relatifs aux instruments A-DCS et SARP fournis par le CNES peuvent également être considérés comme signés 'de facto', et des progrès significatifs ont été accomplis en ce qui concerne les instruments restants. La consolidation des interfaces et de la configuration d'installation des instruments, ainsi que les progrès accomplis en général dans la conception du satellite et de ses sous-systèmes, a permis de préparer avec succès la 'réunion de consolidation de la conception' organisée au début de l'automne. Les arrangements conclus doivent servir de base aux revues préliminaires de conception (PDR) des unités et sous-systèmes, qui ouvriront elles-mêmes la voie à la PDR du satellite, prévue pour le premier semestre de 1999.

Le consortium industriel Métop a lancé un appel d'offres restreint pour la réalisation de l'instrument GRAS, qui faisait l'objet jusqu'à présent d'un programme de développement technologique dans le cadre de l'EOPP. L'évaluation des offres a

Future missions

By the end of the year, the four ongoing Earth Explorer Core Mission Phase-A studies had reached their first major milestone, the Preliminary Concept Review. Meanwhile, the Call for Proposals by Lead Investigators for the first Earth Explorer Opportunity missions has resulted in twenty-seven proposals, which are now entering the evaluation phase.

Campaigns

The 1998 campaign year concluded with the flight data phase of the Cloud Lidar and Radar Experiment (CLARE) in the early autumn. Activities are now directed towards the 1999 plans.

Envisat / Polar Platform

Envisat system

The evaluation of the Announcement of Opportunity (AO) for scientific data exploitation and pilot projects has been terminated and the results accepted by the Programme Participants. The selected Principal Investigators (PIs) will be notified in the near future.

System activities are presently focusing on the preparation of the system verification, in particular the Ground Segment overall verification, and the preparation of the in-flight calibration of the instruments, as well as the validation of the derived Level-2 products.

Satellite activities

The Envisat satellite engineering-model Assembly, Integration and Test (AIT) programme has continued with the preparation of the complete engineering-model satellite for the radio-frequency compatibility test. For this test, a complete RF enclosure has been built around the satellite.

The flight-model AIT activities have gained momentum with the completion of the integration of the flight-model Payload Equipment Bay (PEB) onto the payload carrier, followed by the successful integration of three flight-model instruments: DORIS, MWR and GOMOS.

Envisat payload

Two flight-model instruments have recently been delivered for integration with the flight-model satellite at Matra Marconi Space (Bristol, UK): GOMOS and RA-2. For MIPAS, a mixed model, including the engineering-qualification-model optics and flight-model electronics units, is being delivered. The flight model of the ASAR Central Electronics Sub-Assembly (CESA) FM is also being readied for delivery.

The flight-model instruments not yet delivered are in their final integration and test phases. The ASAR antenna flight-model tile delivery has progressed well, with 16 out of a total of 20 tiles delivered and integrated on the antenna frame structure. Equipment failures on the MIPAS flight-model optical unit are being fixed, two infrared channels on the SCIAMACHY flight model are being realigned, and a parasitic light problem on the MERIS flight model is being investigated.

Envisat ground segment

Integration of the Payload Data Segment (PDS) facilities on the Reference Platform continues at DATAMAT in Rome (I) and a configuration representative of a Payload Data Handling Station (PDHS) is being installed at ESRIN in Frascati (I) in preparation for PDS V1 version acceptance.

All PDS building blocks (facilities) have been integrated on the Reference Platform, even though some facilities are still intermediate software deliveries. This approach nevertheless allows the testing of the complete data circulation and validation of the interfaces.

The Flight Operation Segment (FOS) development and integration is progressing according to plan, with efforts concentrated on the preparation of the first Satellite Verification Test.

Metop

A major milestone in the Metop development effort was achieved early last summer with the signature of Interface Control Documents (ICDs) for five NASA-provided instruments. Furthermore, the ICDs for the CNES-provided A-DCS and SARP instruments were also signed de facto, and significant progress was made on the remaining ones. The consolidation of instrument interfaces and accommodation, and the general progress in satellite and subsystem design allowed a successful 'design consolidation meeting' to be held in early autumn. The understandings reached will form the basis for the unit/subsystem Preliminary Design Reviews (PDRs), leading up to the satellite PDR in the first half of 1999.

A restricted competitive Invitation to Tender (ITT) was issued by Metop industry for the selection of the consortium for the GRAS instrument, previously managed as a technology development within the EOPP. The tender evaluation resulted in the selection of a consortium led by Saab-Ericsson Space, which had previously won a comparable development contract for an American programme.

The GOME-2 Phase-C/D proposal was received in September from the GOME consortium led by Officine Galileo (I). The joint ESA/Eumetsat evaluation and subsequent negotiations were successfully concluded and resulted in a Contract Proposal which was submitted to ESA's Industrial Policy Committee (IPC) and the Eumetsat Council. The latter endorsed the procurement of two units for Metop-1 and -2. For Metop-3, a competitive evaluation was requested between a recurrent GOME-2 and a Dutch Imaging Spectrometer presently under development for the American EOS-Chem satellite

A joint Metop/Eumetsat/EPS seminar was held in October on commonalties and differences between the ground segments of Envisat and Metop/EPS, with participation from the two projects and from Eumetsat.

Meteosat Second Generation (MSG)

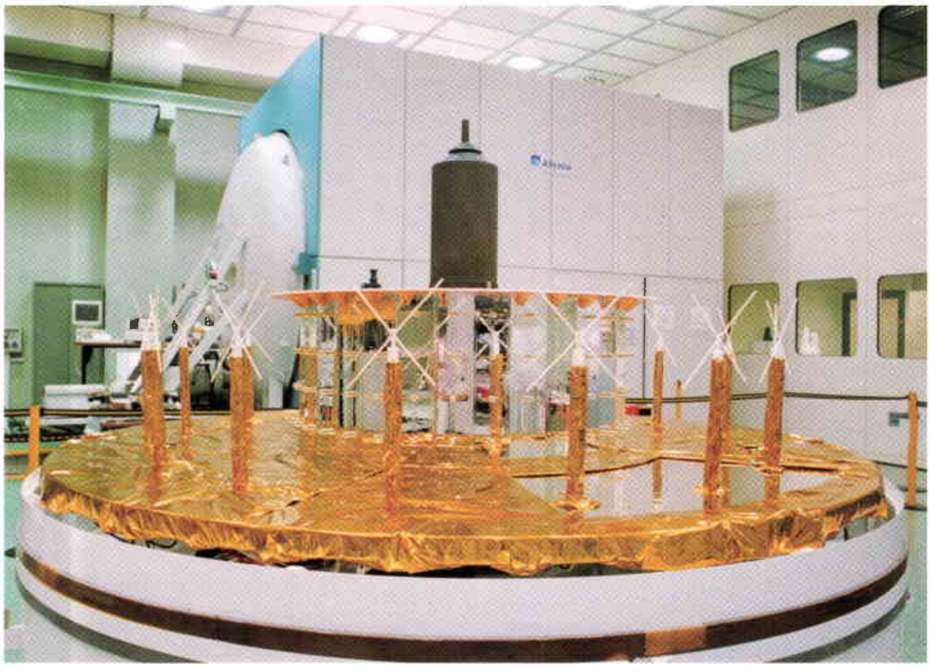
The System Critical Design Review (CDR) was held as planned in October 1998. Some close-out actions remain which primarily relate to yet to be finalised tests at the subsystem and instrument levels.

Testing of the Structural and Thermal Model (STM) was finalised in December. Acoustic testing and shock testing followed the vibration test in Cannes (F).

The development of the MSG-1 spacecraft and the procurement of *abouti au choix d'un consortium dirigé par Saab-Ericsson Space, déjà bénéficiaire d'un contrat semblable pour un programme américain.*

Le consortium GOME, dirigé par Officine Galileo (I), a soumis en septembre une proposition de mise en oeuvre de la phase C/D de GOME-2. L'évaluation, et les négociations ultérieures, conduites par l'ESA et Eumetsat, ont abouti à une proposition de contrat soumise au Comité de la politique industrielle de l'Agence et au Conseil d'Eumetsat. Cette dernière instance a approuvé la fourniture de deux unités de l'instrument pour les satellites Métop-1 et Métop-2. Une évaluation concurrentielle a été requise pour Métop-3 entre une réplique de GOME-2 et un spectromètre imageur néerlandais, réalisé actuellement pour le satellite américain EOS-Chem.

Un séminaire conjoint sur les ressemblances et dissemblances entre les secteurs sols Envisat et Métop/EPS s'est déroulé en octobre, avec la participation de représentants des deux projets et d'Eumetsat.



The MSG 'antenna-farm' engineering model, ready for final testing at Alenia (I)

Modèle technologique du champ d'antennes de MSG prêt pour les derniers essais chez Alenia (I)

Météosat de deuxième génération (MSG)

La revue critique de conception (CDR) du système s'est déroulée comme prévu en octobre 1998. Il reste encore à clore certains essais au niveau des instruments et des sous-systèmes.

L'illustration jointe montre le champ d'antennes du modèle d'identification mis en place pour les derniers essais.

Le programme d'essais du modèle structurel et thermique (STM) s'est achevé en décembre. Les essais de vibrations réalisés à Cannes (F) ont été suivis par des essais acoustiques et de chocs.

La réalisation du satellite MSG-1 et les activités d'approvisionnement des satellites MSG-2 et 3 se poursuivent conformément au calendrier prévu. La réalisation des équipements et des sous-systèmes des modèles d'identification et de vol progresse également. Le développement de l'instrument SEVIRI et du sous-système de communication de la mission demeure sur le chemin critique pour le premier modèle de vol. Le lancement de MSG-1 est toujours prévu en octobre 2000 et celui de MSG-2 en 2002. MSG-3 devrait être livré pour stockage en 2003.

ERS

L'exploitation du système ERS s'est poursuivie sans heurts tout au long de l'année 1998, avec d'excellents résultats des satellites et du secteur sol. ERS-2 sert de satellite principal, tandis que ERS-1 est maintenu en hibernation, comme satellite de secours.

Le déroulement de la mission a été suspendu pendant 30 heures, le 17 novembre, afin de protéger les deux satellites contre la tempête météorique des Léonides. Des mesures spéciales ont été prises pour préserver les instruments sensibles se trouvant à bord. L'équipe d'exploitation au grand complet s'est relayée au sol pour surveiller les satellites et réagir immédiatement en cas de besoin. Aucune anomalie n'a fort heureusement été constatée pendant et après le passage de la tempête.

Le Conseil directeur du Programme d'observation de la Terre a reçu une proposition visant à prolonger l'exploitation du système ERS jusqu'en 2003 en raison de son excellent état de santé. Cette prolongation permettrait d'assurer la poursuite totale de la mission jusqu'à l'entrée en service opérationnelle d'Envisat, et de continuer à recueillir des données relatives au vent et à l'ozone jusqu'à l'entrée en service de Métop-1.

Une série d'activités ont été entreprises et de nouvelles procédures ont été adoptées afin de prolonger aussi longtemps que possible la durée de vie opérationnelle du système ERS :

- *De nouveaux mécanismes de surveillance et d'alerte ont été mis en place.*
- *Le gain d'amplification des signaux provenant des instruments d'ERS-2 a été augmenté afin de compenser le vieillissement de la charge utile.*
- *On étudie actuellement la possibilité de maintenir l'orientation du satellite en n'utilisant qu'un ou deux gyroscopes, épaulé(s) par les capteurs numériques et les roues de réaction. Les premiers résultats obtenus s'avèrent très prometteurs et cette nouvelle solution pourrait être applicable dès la mi-1999.*

MSG-2 and MSG-3 are on schedule. Engineering-model and flight-model production at equipment and subsystem level is in progress. The SEVIRI instrument remains, together with the mission communication subsystem, on a critical path for the first flight model. The launch of MSG-1 remains on schedule for October 2000, with MSG-2 to be launched in 2002. MSG-3 will go into storage in 2003.

ERS

Throughout 1998, ERS system operations continued to run very smoothly, with excellent performance from the satellites and ground segment. ERS-2 served as the primary spacecraft, with the ERS-1 payload in hibernation and available as a back-up.

On 17 November, the mission was interrupted for 30 hours to protect both ERS-1 and ERS-2 from the Leonid meteorites storm. Special measures were taken on-board to protect all of the sensitive spacecraft elements. Extended ground-segment coverage with a complete operations team was set up to monitor the satellites and react immediately in case of problems. Fortunately, no anomalies were detected either during or after the storm.

Based on the good health of the ERS system, a proposal has been submitted to the ESA Earth Observation Programme Board for an extension of operations up to the year 2003. This would permit the continuity of the full mission until Envisat becomes operational, and of the wind and ozone data until METOP-1's entry into operation.

The following procedures and activities have been introduced in order to prolong the ERS system's operational lifetime for as long as possible:
- New monitoring and warning mechanisms have been implemented.
- The signal amplification gains of the ERS-2 instruments have been increased to compensate for payload ageing.
- The feasibility of maintaining satellite attitude using only one or two gyros supported by the digital sensors and reaction wheels is being studied. The initial results are very promising and this new solution should be available by mid-1999.
- A study has been started to find a work-around solution permitting the ERS-1 payload items to be operated again in parallel (since the solar-array failure, the instruments can only be operated individually).

International Space Station Programme

ISS Overall Assembly Sequence

The first International Space Station Element, the Functional Cargo Block (FGB) 'Zarya', was successfully launched from the Baikonur Cosmodrome in Kazakhstan on 20 November. As the first orbiting element, the 20 ton 'Zarya' pressurised spacecraft will provide the initial propulsion and power for the Space Station. The second International Space Station Element, the Node-1 (Unity), with two pressurised mating adapters attached and one stowage rack installed, was successfully launched on 4 December aboard the US Shuttle 'Endeavour' (STS-88). The rendezvous with 'Zarya' took place on 6 December and the two elements were successfully mated during the early hours of 7 December.

Following the 'Zarya' launch, the Heads of Agencies met in Moscow to review the ISS Overall Assembly Sequence. The launch of the Russian Service Module remains scheduled for July 1999 and an additional Shuttle logistics flight (2A.2) has been added to the Assembly Sequence to support the Service Module's launch. An updated Overall Assembly Sequence should be available in spring 1999.

Columbus Laboratory

During recent months, it became apparent that the mass of the Columbus Laboratory had increased to a level that exceeded the specification limits. Actions to reduce it to within specification were initiated and this problem is now nearing satisfactory resolution. In addition, some delays have been encountered with the Data Management System (DMS) software development, and a computer processing problem has been identified, which could result in the system Critical Design Review (CDR) being delayed.

The Electrical Ground Support Equipment (EGSE) acceptance tests have started, and the Electrical Test Model (ETM) testing is now expected to start in February 1999.

Columbus launch barter

Nodes 2 and 3

Manufacturing and welding of the Structural Model primary structure has started. The first radial bulkhead is available and the second is in final machining. Cone welding is complete. Node-2 system analysis is nearing completion, but configuration changes required by NASA are causing secondary structure delays. Node-3 configuration and outfitting updates required by NASA in the ISS Assembly Sequence, Revision D, have been completed, but further changes introduced by NASA are impacting the Node-3 development schedule.

Crew Refrigerator/Freezer Racks

Breadboarding of critical design elements has started, awaiting a decision from NASA on the upload strategy and where the Refrigerator/Freezers will be installed in the Station (Transhab versus Hab Module). NASA has agreed to ESA's present planning and has scheduled an interface meeting for mid-December with crew representatives to agree on a technical solution that can be implemented with reasonable effort.

Cryogenic Freezer Racks

In view of the recently announced delay in the launch of the Cryogenic Freezer, the Executive has decided to postpone the Invitation to Tender (ITT) for Phase-B/C/D by three months, until early 1999.

Cupolas

The Cupola barter negotiations with NASA were successfully concluded in October and the corresponding Implementing Arrangement was finalised. Under this Arrangement, ESA will provide two Cupolas, plus some enhancements to the Columbus module, in exchange for payload launch and return services provided by NASA for five external European payloads as well as an additional launch mass allocation of 150 pounds on the Columbus module launch.

Following the ESA Industrial Policy Committee's (IPC) approval of the contract proposal, the Cupola development effort was initiated in December with Alenia Spazio as the prime contractor.

- *On recherche actuellement de nouvelles solutions permettant de relancer l'exploitation en parallèle de la charge utile d'ERS-1 (Depuis la défaillance des panneaux solaires, les instruments ne peuvent plus être actionnés qu'un par un).*

Programme de Station spatiale internationale

Séquence d'assemblage de l'ISS

Le premier élément de la station spatiale internationale, le module 'Zarya' (FGB), a été lancé avec succès du Cosmodrome de Baïkonour le 20 novembre dernier. En tant que premier élément placé sur orbite, ce cylindre pressurisé de 20 tonnes fournira les moyens de propulsion et l'énergie initialement nécessaires à la station spatiale. Le deuxième module de l'ISS, l'élément de jonction numéro 1 'Unity', équipé de ses deux adaptateurs d'accouplement pressurisés et d'un bâti de stockage, a été lancé le 4 décembre à bord de la Navette spatiale américaine 'Endeavour' (vol STS-88). Le rendez-vous avec 'Zarya' a eu lieu le 6 décembre et les deux éléments ont été réunis aux premières heures du 7 décembre.

A la suite du lancement de 'Zarya', les représentants des différentes agences concernées se sont rencontrés à Moscou pour faire le point sur l'ensemble de la séquence d'assemblage de la station. Le lancement du module de service russe est toujours prévu en juillet 1999, et l'on a ajouté – en soutien – une mission de logistique supplémentaire de la Navette américaine (2A.2) à la séquence d'assemblage. Une séquence d'assemblage révisée devrait être adoptée au printemps 1999.

Laboratoire Columbus

Il est apparu au cours des derniers mois que la masse du laboratoire Columbus avait augmenté jusqu'à excéder les limites spécifiées. On a entrepris d'y remédier et la question est en passe d'être résolue. La réalisation du logiciel du système de gestion des données (DMS) a en outre pris du retard et l'on a constaté un problème de traitement informatique qui risque de retarder la revue critique de conception (CDR) du système.

Les essais de recette des équipements de soutien sol électriques (EGSE) ont débuté et ceux du modèle d'essais électriques (ETM) devaient être lancés en février 1999.

Compensation du lancement de Columbus

Éléments de jonction 2 et 3

La fabrication et le soudage de l'ossature du modèle structurel ont débuté. La première cloison radiale est disponible et l'usinage de la deuxième est en voie d'achèvement. Le soudage des cônes est achevé. L'analyse de l'élément de jonction n°2 au niveau système est presque terminée, mais certaines modifications de configuration demandées par la NASA provoquent des retards dans la réalisation de la structure secondaire. La configuration et l'équipement de l'élément de jonction n°3 sont achevés, ainsi que les mises à jour réclamées par la NASA dans la révision D de la séquence d'assemblage de l'ISS. D'autres modifications introduites par la NASA vont cependant avoir une incidence sur le calendrier de réalisation de cet élément.

Bâtis réfrigérateurs/congélateurs pour l'équipage

Le montage sur table des éléments de conception critique des bâtis réfrigérateurs/congélateurs pour l'équipage a débuté, en attendant que la NASA fixe la procédure d'emport de ces éléments dans l'espace et leur choisisse un lieu d'implantation dans la Station spatiale (Transhab ou module d'habitation). La NASA a approuvé le programme actuel de l'ESA et organisé en décembre une réunion sur les interfaces en présence de représentants des astronautes. Cette réunion devait permettre de se mettre d'accord sur les solutions techniques les plus raisonnables.

Bâtis congélateurs cryogéniques

L'Exécutif a décidé de reporter de trois mois (soit début 1999) l'appel d'offres relatif à la phase B/C/D du programme de congélateurs cryogéniques en raison de l'annonce récente d'un report de la date de lancement de cet élément dans l'espace.

Coupoles

Les négociations entamées avec la NASA sur l'accord de compensation relatif aux coupoles à fournir par l'ESA se sont conclues positivement en octobre et l'Arrangement de mise en oeuvre correspondant a été définitivement adopté. Aux termes de cet Arrangement, l'ESA fournira deux coupoles à la station spatiale et apportera certaines modifications au module Columbus, la NASA assurant en échange l'emport dans l'espace et le retour de cinq charges utiles externes européennes et accordant à Columbus une masse supplémentaire au lancement d'environ 75 kg.

La réalisation des coupoles a débuté en décembre, après l'approbation de la proposition de contrat par le Comité de la politique industrielle et la désignation d'Alenia Spazio comme maître d'oeuvre.

Véhicule de transfert automatique (ATV)

Après examen de scénarios de rechange, et malgré les incertitudes qui pèsent toujours sur la situation économique et financière de la Russie, il a été décidé en octobre de conserver le scénario d'origine consistant à amarrer l'ATV au module de service russe, moyennant quelques modifications techniques mineures à apporter au véhicule de l'ESA. Cette décision a permis de signer, le 25 novembre, le contrat relatif à la phase principale de développement (phase C/D) conclu avec Aerospatiale.

La procédure d'échange de lettres entre les directeurs généraux de la RKA et de l'ESA visant à officialiser l'engagement de haut niveau souscrit par RKA/ RSC-Energia pour l'intégration de l'ATV et la fourniture du matériel russe s'est conclue le 19 novembre par la réception d'une lettre signée par le Directeur général de la RKA. Cet engagement, souscrit en octobre par RKA/RSC-Energia, est conforme à l'ensemble des impératifs financiers et techniques de l'ESA pour les phases de développement et d'exploitation. Une réunion de démarrage portant sur les activités d'intégration de l'ATV a eu lieu en décembre avec les représentants de RSC-Energia, à la suite de l'approbation par l'IPC de la proposition d'approvisionnement correspondante.

X-38/CRV et application des technologies de rentrée

Le protocole relatif à la coopération NASA/ESA au projet X-38/CRV a été signé le 21 novembre.

A la suite de la réorientation des activités relatives au véhicule de transport des équipages (CTV) et de l'approbation

Automated Transfer Vehicle (ATV)

Following-on from the investigation into alternative docking scenarios, and despite the political and economic uncertainties in Russia, it was decided in October to retain the original scenario of docking the ATV to the Russian Service Module, with some limited ATV technical modifications to be implemented. The contract for the main development phase (Phase-C/D) was subsequently signed with Aerospatiale on 25 November.

The signature of the 'Exchange of Letters' by the RSA General Director and ESA's Director General to formalise the RSA/RSC-Energia High-Level Commitment for ATV integration and Russian hardware procurement was completed on 19 November with the receipt of a letter signed by RSA's General Director. This High-Level Commitment, made in October by RSA/RSC-Energia, is compliant with all of ESA's financial and technical requirements for both the development and exploitation phases. A 'kick-off' meeting with RSC-Energia for the ATV integration work took place in December following the IPC's approval of the corresponding Procurement Proposal.

X-38/CRV and Applied Re-entry Technology

The Protocol covering the NASA/ESA X-38/CRV co-operation was signed on 21 November.

Following the reorientation of the Crew Transport Vehicle (CTV) activity, and the approval of a new slice for the Applied Re-entry Technology (ART) Programme, a contract has been prepared, and should be signed in December, to cover industrial activities in co-operation with NASA for the X-38 V201 vehicle.

NASA has invited four US contractors plus one European contractor to observe the ongoing X-38 activities at Johnson Space Center (JSC) in Houston until February 1999. This will allow industry to familiarise itself with the X-38 programme and will facilitate the preparation of industrial proposals for the Operational Crew Rescue Vehicle (CRV). NASA plans to release a draft Request for Proposal (RFP) in December for procurement of the operational CRV, and its final update in February 1999.

Atmospheric Re-entry Demonstrator (ARD)

The Atmospheric Re-entry Demonstrator (ARD) was successfully launched by the Ariane 503 flight on 21 October (see ESA Bulletin No. 96, pages 4-13). All ARD systems performed nominally throughout the mission and all mission objectives were achieved. The ARD reached an altitude of 830 km, splashed down within 4.9 km of its target point in the Pacific Ocean after 1 h 41 min, was recovered some 5 h later and is currently undergoing more detailed technical analysis. Data assessment has commenced and results are expected during the first half of December. The ARD will arrive back in Europe during the second half of January.

Ground-segment development and operations preparation

The results of the definition studies of all identified options for the ground segment, in particular the Operations Control Centres locations, and the status of the operations support study, were presented to the Programme Board in November. No conclusion could be reached at that time and the matter was referred to the ESA Council for a decision in December. The Council resolved that the operations control ground infrastructure and execution function for the European elements of the International Space Station under the overall ESA authority will be located as follows:

- the Operations Control Facility for the Columbus Laboratory, together with the central node of the Communications Network (IGS), at GSOC in Oberpfaffenhofen (D), and
- the Operations Control Facility for the ATV at CNES in Toulouse (F).

ESA will implement the above decision through appropriate contractual arrangements with the agencies responsible for the national facilities.

Concerning the ASI-led study addressing the centralised implementation of the operations support functions at ALTEC, it was agreed to also continue pursuing other implementation options.

Discussions on Common System Operations Costs (CSOC) were held at JSC during October and November and agreements were reached on the approach to common cost estimation.

Utilisation

Promotion

The Second European Symposium on Utilisation of the International Space Station was held at ESTEC (NL) on 16-18 November, and there were a total of 470 participants. The Proceedings will be published by ESA Publications Division in February 1999 as ESA SP-433.

At the Symposium, a Europe-wide Student Competition for the best experiment proposal for the ISS was started. The competition will end with the announcement of the winner and presentation of the awards at the IAF Congress in Amsterdam in autumn 1999.

The International Forum for the Scientific Use of the ISS (IFSUSS) met on 18-19 November with the objective of furthering the co-ordination of research projects between the ISS Partners.

Preparation

The two industrial proposals received in October for Phase-B/C/D of the Technology Exposure Facility (TEF) have been evaluated and a contract has been awarded to a consortium led by Carlo Cavazzi (I).

The External Payload Integration Contract is nearing the completion of Phase-1 (accommodation analysis and definition). The completion of the viewing and thermal analysis is hampered by the absence of a NASA decision concerning the precise location of the European payloads on the Express Pallet.

Hardware development

The procurement and manufacturing of flight hardware for all Standard Payload Outfitting Equipment (SPOE) has been authorised.

The Critical Design Review (CDR) for the Material Science Glovebox (MSG) was held on 12 November and that for the –80°C Freezer (MELFI) on 24 November.

The Preliminary Design Review (PDR) for Hexapod has been initiated.

Astronaut activities

A major event in this context was the successful STS-95 mission from 29 October to 7 November. ESA astronaut Pedro Duque, in his role as Mission Specialist, performed his first flight as a member of the highly publicised STS-95 *d'une nouvelle tranche du Programme d'application des technologies de rentrée, un contrat couvrant les activités industrielles menées en coopération avec la NASA pour le développement du véhicule X-38/V201 a été préparé pour signature en décembre.*

La NASA a invité quatre contractants américains et un contractant européen à venir au Centre spatial Johnson de Houston (JSC) suivre jusqu'en février 1999 les activités liées au X-38 afin de se familiariser avec le programme et faciliter la préparation des propositions industrielles relatives au véhicule de sauvetage des équipages (CRV). La NASA prévoyait de diffuser en décembre un projet d'appel d'offres (RFP) portant sur l'approvisionnement du CRV opérationnel, et de lancer sa version définitive en février 1999.

Démonstrateur de rentrée atmosphérique (ARD)

Le démonstrateur de rentrée atmosphérique (ARD) a participé avec succès au vol Ariane 503, le 21 octobre dernier (voir Bulletin ESA n°96, pages 4-13). L'ensemble de ses systèmes ont fonctionné normalement et tous les objectifs de la mission ont été atteints. Le démonstrateur a atteint une altitude de 830 km, avant de retomber dans l'océan Pacifique une heure et quarante et une minutes plus tard, à moins de 4,9 km du point d'impact prévu. Il a été récupéré au bout de cinq heures et soumis à un examen technique détaillé. Les résultats de l'évaluation des données recueillies devaient être communiqués au cours de la première quinzaine de décembre. Le retour de l'ARD en Europe était prévu au cours de la seconde quinzaine de janvier.

Réalisation du secteur sol et préparation de l'exploitation

Les résultats des différentes études de définition du secteur sol, et notamment celles relatives à l'implantation des Centres de contrôle des opérations ont été présentés en novembre au Comité directeur du programme, en même temps qu'un point sur l'étude relative au soutien des opérations. Le Comité n'est parvenu à aucune conclusion et le dossier a été transmis au Conseil de l'ESA pour décision en décembre. Le Conseil a décidé que les infrastructures de contrôle au sol et la conduite des opérations liées aux éléments européens de la station spatiale internationale seraient réparties de la façon suivante, sous la responsabilité de l'ESA:

- *Installation de contrôle des opérations du laboratoire Columbus et noeud central du réseau de communications (IGS): GSOC, Oberpfaffenhofen (D)*
- *Installation de contrôle des opérations de l'ATV: CNES, Toulouse (F)*

L'ESA conclura avec les agences responsables des installations nationales les arrangements contractuels nécessaires à la mise en oeuvre de ces décisions.

A la suite de l'étude menée sous la direction de l'ASI sur une mise en oeuvre centralisée des fonctions de soutien des opérations chez ALTEC, il a été décidé de conserver également les autres options de mise en oeuvre.

Des discussions portant sur les coûts communs d'exploitation des systèmes (CSOC) ont eu lieu en octobre et en novembre au JSC et des accords ont été conclus sur la démarche à adopter pour parvenir à une estimation commune de ces coûts.

Utilisation

Promotion

Le deuxième symposium européen sur l'utilisation de la Station spatiale internationale s'est déroulé à l'ESTEC (NL) du 16 au 18 novembre, en présence de quelques 470 participants. Les conclusions de cette réunion devaient être publiées en février 1999 par la Division des Publications de l'ESA dans le document ESA SP-433.

A cette occasion a été lancé un concours destiné à récompenser la meilleure proposition d'expérience pour l'ISS imaginée par un étudiant européen. Le nom du vainqueur et les différentes récompenses seront annoncés lors du Congrès de la Fédération internationale d'astronautique organisé à Amsterdam à l'automne 1999.

Une réunion du Forum international sur les utilisations scientifiques de la station spatiale (IFSUSS) a eu lieu les 18 et 19 novembre, avec pour objectif de renforcer la coordination entre les différents projets de recherche des partenaires de l'ISS.

Préparation

Les deux propositions industrielles relative à la phase B/C/D du projet d'Installation d'exposition technologique (TEF) reçues en octobre ont fait l'objet d'une évaluation, et le contrat correspondant a été attribué à un consortium conduit par Carlo Cavazzi (I).

La phase 1 du contrat d'intégration des charges utiles externes (analyse et définition de l'installation) est presque achevée. L'absence de décision de la NASA quant à la localisation précise des charges utiles européennes sur la palette Express ne permet pas de mener à son terme l'analyse thermique et d'exposition.

Réalisation des matériels

L'approvisionnement des matériels de vols destinés à l'ensemble des équipements complémentaires des charges utiles standard (SPOE) a été autorisé.

Les revues de conception critique (PDR) de la boîte à gants pour science des matériaux et du congélateur de laboratoire à - 80°C (MELFI) se sont respectivement déroulées les 12 et 24 novembre.

La revue préliminaire de conception (CDR) de l'Hexapode a été entamée.

Activités des astronautes

La réussite de la mission STS-95, qui s'est déroulée du 29 octobre au 7 novembre, constitue un événement très important dans ce domaine. L'astronaute de l'ESA Pedro Duque a effectué à cette occasion son premier vol dans l'espace, en assumant les responsabilités de spécialiste mission au sein de l'équipage très "médiatisé" de la navette américaine Discovery.

Le Directeur général de l'ESA a également annoncé en octobre les noms des deux derniers astronautes européens, le néerlandais André Kuipers et le belge Frank de Winne. Les deux hommes entameront vers la mi-1999 leur formation au Centre des astronautes européens, afin d'obtenir leur qualification pour de futures missions à bord de la Station spatiale. La première phase de constitution par l'ESA du Corps des astronautes européens est désormais achevée.

A l'issue de sa formation, C.Fuglesang a reçu le 2 octobre, à la 'Cité des Etoiles' (ZPK) (Russie), son certificat de crew aboard the US Space Shuttle 'Discovery'.

Also during October, ESA's Director General announced the names of Europe's newest astronauts, André Kuipers (NL) and Frank De Winne (B). Both astronauts will begin training at the European Astronaut Centre around mid-1999 to qualify for future missions on board the International Space Station. ESA has now completed the first phase of its creation of the single European Astronaut Corps.

On 2 October, following the successful completion of his training, C. Fuglesang received his certificate as 'Soyuz Return Commander' in ZPK (Russia). G. Thiele was assigned to the Shuttle Radar Topography Mission STS-99, scheduled for September 1999, and training for the mission has started.

An agreement has been reached between ESA and CNES concerning the PERSEUS mission, scheduled to start end of February with ESA astronaut J-P. Haigneré on board. ESA is providing logistic, medical and communications support in exchange for crew time and onboard resources during the mission.

Significant progress has been achieved in designing the Columbus System Training with the completion of the definition of the detailed curriculum and the establishment of an Instructor Selection and Employment Plan.

Early deliveries

Data Management System for the Russian Service Module (DMS-R)
By early October, RSC-Energia had successfully tested the entire Service Module application software on the two Fault Tolerant Data Management System (DMS-R) Computers. The ESA-supplied DMS-R hardware and software performed correctly during all of these tests.

European Robotic Arm (ERA)
A likely delay in the launch of the Russian Science Power Platform (SPP), on which ERA is mounted, has been announced. Launch is now expected to take place in July 2001, although this has still to be confirmed. Discussions are continuing with RSA on the implications for ERA's delivery to Russia.

Due to continuing problems with the main joint system, efforts are being made to re-plan the ERA system-level Assembly, Integration and Verification (AIV) schedule.

The integration of the ERA software on the electrical test bench is progressing, but final integration of the Engineering Qualification Model is held up by the late delivery of the joint subsystem. Although efforts are being made to contain this delay, it is expected to impact the ERA Critical Design Review (CDR) planning and the eventual ERA flight-model delivery dates.

Discussions have been held with RSC-Energia on the maintenance approach for ERA, and the operational support aspects of the ESA/RSA co-operation, particularly the sustaining engineering required.

Microgravity

EMIR-1 and EMIR-2
The Advanced Gradient Heating Facility (AGHF), the Advanced Protein Crystallisation Facility (APCF), Biobox, the Facility for Adsorption and Surface Tension (FAST) and the facility for Morphological Transitions in a Model Substance (MOMO) were launched from Kennedy Space Center on STS-95/ Spacehab on 29 October. This launch attracted much media attention due to its also being the second space flight by John Glenn. Scientists from eight European countries had experiments on the flight to study the effects of weightlessness on various materials and processes. ESA astronaut Pedro Duque, in his role as Mission Specialist, was in charge of overseeing the operation of these experiments.

The sounding-rocket Maxus-3 with a totally ESA microgravity payload was successfully launched from Esrange in Kiruna (S) on 24 November. The Maxus rocket performed its trajectory nominally and the scientific payload, comprising three life-science and two fluid-physics experiments, was successfully recovered within 1.5 hours after launch. Mini Texus-6, a smaller sounding rocket carrying an ESA experiment on combustion in microgravity, was also flown successfully, on 3 December.

ESA's twenty-fifth parabolic-flight campaign was successfully conducted in the period 20–30 October. Three flights, each consisting of thirty-one parabolas, were performed using the Airbus A-300 Zero-G aircraft.

Microgravity Facilities for Columbus (MFC)
The Biolab subcontractor Preliminary Design Reviews (PDRs) have almost been completed and the system PDR, started in early October, is expected to be completed by January 1999. The Invitation to Tender (ITT) for Phases B/C/D for the Experiment Preparation Unit (EPU) has been finalised and is planned for release by end-1998.

The Fluid Science Laboratory (FSL) subcontractor PDRs started in October, and the system PDR is expected to start in January and to be completed in April 1999. Technical exchanges are continuing with the Canadian Space Agency (CSA) to investigate the possibility of using their Microgravity Vibration Isolation Mount (MIM) system inside the Laboratory to improve the experiment microgravity environment.

The Phase-C/D contract for the Materials Science Laboratory (MSL) in the US Lab was signed in November. In view of the schedule criticality, the Phase-C/D activities had already been started in April 1998, covered by a Preliminary Authorisation to Proceed.

The final presentations for the two parallel contracts covering Phase-A of the European Physiology Module (EPM) were held in ESTEC (NL) on 2 and 3 September. The ITT for the Phases-B and C/D should be released by the end of 1998. Discussions are underway with NASA concerning the co-location of the EPM with the Human Research Facility (HRF-1).

'Commandant de véhicule Soyouz pour le retour'. G.Thiele a entamé son entraînement, après avoir été désigné au sein de l'équipage de la mission STS-99 de la navette spatiale américaine, consacrée à la topographie par radar.

L'Agence spatiale européenne et le CNES ont conclu un accord sur la mission PERSEUS, dont le lancement est prévu fin février avec la participation de l'astronaute de l'ESA J-P. Haigneré. L'ESA fournira à la mission un soutien dans le domaine des communications ainsi que sur les plans logistique et médical en échange de temps d'équipage et de ressources à bord.

D'importants progrès ont été accomplis dans la mise au point de la formation à l'utilisation du système Columbus, avec la définition détaillée du programme d'études et la réalisation d'un plan de sélection et d'emploi des formateurs.

Livraisons à court terme

Système de gestion de données pour le module de service russe (DMS-R)

RSC-Energia a expérimenté, début octobre, la version complète du logiciel d'application du module de service sur les ordinateurs à double tolérance de panne du système de gestion de données (DMS-R). Le matériel et les logiciels du DMS-R fournis par l'ESA ont fonctionné correctement au cours de ces essais.

Bras télémanipulateur européen (ERA)

Le lancement de la plate-forme russe science et énergie (SPP), sur laquelle doit être installé le bras télémanipulateur européen (ERA), devrait être retardé jusqu'en juillet 2001. L'annonce de ce retard demande cependant confirmation. Des discussions sont en cours avec la RKA sur les implications que ce retard pourraient avoir sur la livraison de l'ERA à la Russie.

Les difficultés persistantes rencontrées par le système principal commun pourraient amener une révision du calendrier d'assemblage, d'intégration et de vérification (AIV) de l'ensemble du système ERA.

L'intégration du logiciel de l'ERA sur le banc d'essais électrique se poursuit, mais le retard enregistré dans la livraison du sous-système commun retentit sur l'intégration définitive du modèle de qualification et d'identification (EQM). On s'efforce actuellement de réduire ce retard, mais celui-ci devrait néanmoins avoir des conséquences sur le calendrier de la revue critique de conception (CDR) du bras télémanipulateur et sur les dates de livraison possibles de son modèle de vol.

L'ESA et RSC-Energia ont discuté de la stratégie de maintenance ainsi que du soutien opérationnel, et notamment du soutien technique continu, prévus pour l'ERA dans le cadre de la coopération ESA/RKA.

Microgravité

EMIR-1 et EMIR-2

Le four à gradient de haute technologie (AGHF), l'installation de cristallisation des protéines de pointe (APCF), le Biobox, l'installation d'études de l'adsorption et de la tension de surface (FAST) et l'installation d'études morphologiques sur des substances modèles (MOMO) ont participé à la mission STS-95/Spacehab lancée du Centre spatial Kennedy le 29 octobre. Les média ont accordé une place particulière à ce vol car c'était le second voyage dans l'espace de John Glenn. Mais cette mission a également permis d'emporter dans l'espace des expériences préparées par des chercheurs originaires de huit pays européens et destinées à étudier les effets de l'impesanteur sur différents matériaux et processus. L'astronaute de l'ESA Pedro Duque a supervisé le fonctionnement de ces expériences en sa qualité de spécialiste mission.

La fusée-sonde Maxus-3, emportant à son bord une charge utile d'expériences en microgravité entièrement préparées par l'ESA, a été lancée le 24 novembre de la base de l'Esrange, à Kiruna (S). La fusée a suivi la trajectoire prévue et la charge utile scientifique, comprenant trois expériences en sciences de la vie et deux expériences de physique des fluides, a été récupérée avec succès une heure et demie après le lancement. Mini Texus-6, une petite fusée sonde emportant une expérience de l'ESA sur la combustion en microgravité, a été lancée le 3 décembre.

La 25 ème campagne de vols paraboliques de l'ESA s'est déroulée du 20 au 30 octobre. L'Airbus A-300 Zéro-G affecté à cette campagne a effectué à cette occasion trois vols comportant chacun 31 paraboles.

Installations de recherche en microgravité pour Columbus (MFC)

Les revues préliminaires de conception (PDR) du Biolab sont pratiquement achevées au niveau des sous-traitants et celle lancée début octobre au niveau système devait être terminée en janvier 1999. L'appel d'offres relatif aux phases B/C/D de l'unité de préparation des expériences (EPU) a été rédigé et devait être diffusé fin 1998.

Les revues préliminaires de conception (PDR) du Laboratoire de science des fluides (FSL) ont débuté en octobre au niveau des sous-traitants et celle au niveau système devait être lancée en janvier pour se terminer en avril 1999. L'ESA et l'Agence spatiale canadienne (ASC) poursuivent actuellement des recherches techniques sur les possibilités d'utilisation dans le laboratoire européen le dispositif antivibrations (MIM) mis au point par l'ASC afin d'améliorer l'environnement des expériences en microgravité.

Le contrat de phase C/D du Laboratoire de sciences des matériaux destiné au Laboratoire américain a été signé en novembre. Compte tenu du calendrier très serré, les activités industrielles entrant dans le cadre de cette phase avaient débuté en avril 1998, couvertes par une autorisation préliminaire d'engagement des travaux.

La présentation finale des deux contrats parallèles de phase A du Module de physiologie européen (EPM) s'est déroulée à l'ESTEC (NL) les 2 et 3 septembre. L'appel d'offres relatif aux phases B et C/D devait être lancé fin 1998. On examine actuellement avec la NASA la possibilité d'une co-implantation de l'EPM et de l'installation de recherche sur l'homme (HRF-1) esa

In Brief

ESA Signs Materials Science Laboratory Contract

The contract for the development and delivery of ESA's Materials Science Laboratory (MSL) for the International Space Station was signed on 24 November 1998 at ESA Headquarters by Mr J. Feustel-Büechl, ESA Director of Manned Space Flight and Microgravity, and Drs S. Graul and E. Wolff for the MSL prime contractor Dornier GmbH.

MSL is a multi-user facility being developed under ESA's Microgravity Facilities for Columbus (MFC) Programme. MSL is mainly intended to support high temperature research in the fields of metallurgy, crystal growth, and thermophysical properties measurement. The high degree of modularity and flexibility of MSL, as well as the wide range of advanced diagnostics including the measurement of Seebeck voltages and sample resistance as an adaptation from the highly successful French Mephisto programme, have led to a cooperative agreement between NASA and ESA for the utilisation of MSL.

As part of the NASA-ESA cooperation, MSL will be integrated into the first Materials Science Research Rack (MSRR-1) provided by NASA and will be accommodated in the US laboratory of the Space Station. Both Europe and NASA will each be allocated 50% of experiment resources for the utilisation of MSL. The cooperation agreement, initially limited to two years, is expected to be extended for an on-orbit period of five years.

One novel feature of MSL is the possibility to exchange 'Furnace Inserts' in orbit. A Furnace Insert is an arrangement of heating and cooling zones specifically adapted to certain groups of experiments. The flexibility offered by this capability is further enhanced by the possibility to mount experiment-dedicated electronics in MSL. At present, ESA intends to include two Furnace Inserts in the MSL development, namely the Low Gradient Furnace (LGF) and the Solidification and Quenching Furnace (SQF). NASA will also develop two Furnace Inserts called the Quench Module Insert (QMI) and the Diffusion Module Insert (DMI). Additional Furnace Inserts are under consideration by NASA as well as by European agencies, such as the Floating Zone Furnace with Rotating Magnetic Field (FMF) currently planned by the German Space Agency.

The industrial consortium led by Dornier GmbH includes fourteen subcontractors: SEP (F) with support by Soterem (F), Ratier-Figeac (F) and Mechanex (CH); Threde (D) with support by ETEL (CH), EREMS (F) and Kayser Italia (I); DASA-DSS (D), Verhaert (B), Ferrari (I), HTS (CH), the University of Freiberg (D), and ARDE (US) as a specialised supplier. esa

MSL contract signing at ESA HQ on 24 November 1998. Seated from left to right: Dr S. Gaul, Dornier GmbH; Mr J. Feustel-Büechl, ESA Director of Manned Spaceflight and Microgravity; Dr E. Wolff, Dornier GmbH

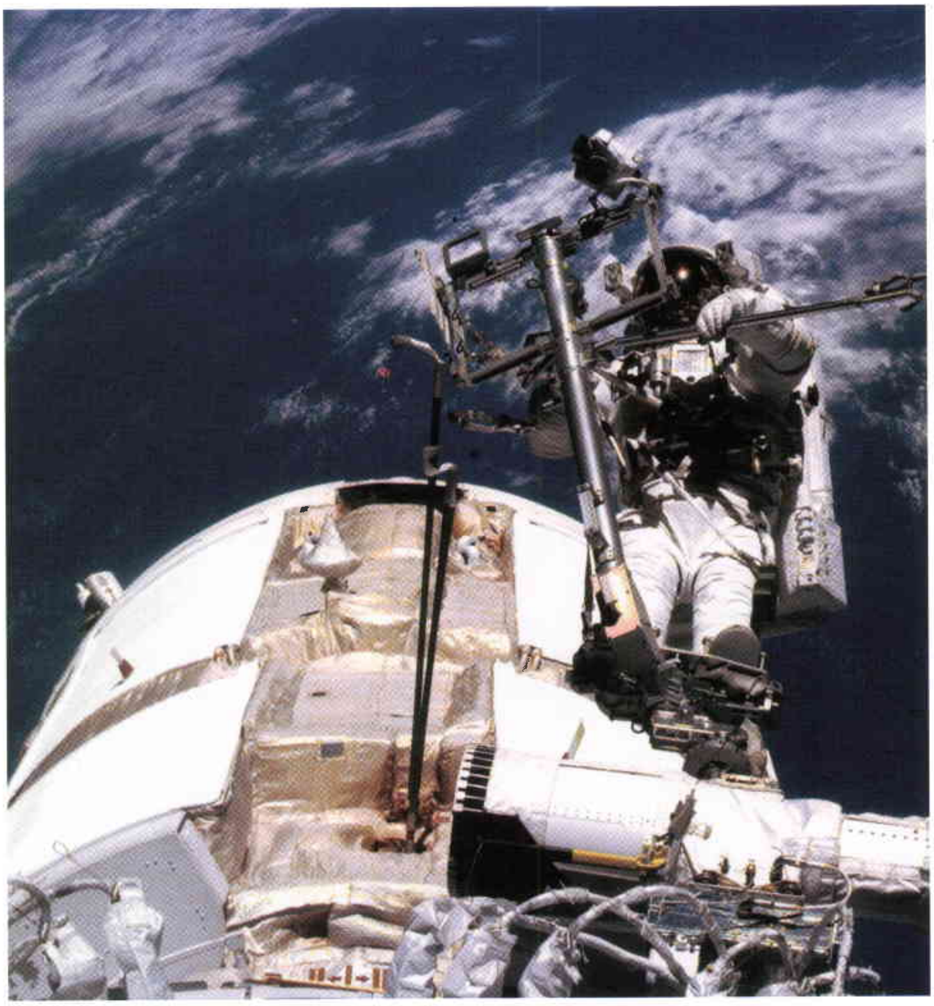
'Unity' Joins 'Zarya'

Unity, the second element of the new International Space Station (ISS), was launched on Friday 4 December aboard the Space Shuttle Endeavour from the Kennedy Space Center in Florida, less than two weeks after the first element, Zarya, was placed in orbit by a Russian Proton launcher from the Baikonur Cosmodrome in Kazakhstan (on 20 November 1998).

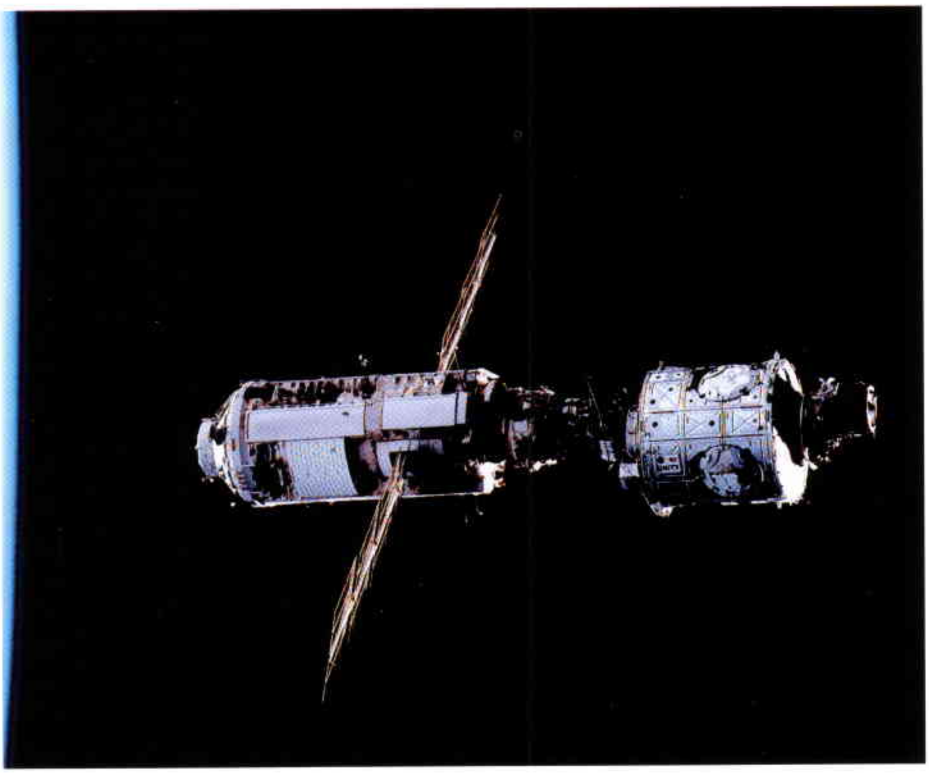
In a historic moment, Mission Commander Robert Cabana and Russian Cosmonaut/Mission Specialist Sergei Krikalev swung open the hatch between Endeavour and the first element of the ISS on 10 December 1998. The STS-88 astronauts completed the first steps in the orbital construction of the ISS by connecting Zarya and Unity during three space walks totalling 21 hours and 22 minutes. The US-made connecting module, Unity, has six docking ports and will serve as the basic building block to which all future US modules will be attached. Krikalev will return to the Space Station in early 2000 when the first of three crews moves into the new station.

In all, more than 100 elements totalling 460 tonnes of structures, modules, equipment and supplies will be assembled during 45 missions by the year 2004. Europe, as one of the five Partners (together with the United States, Russia, Japan and Canada), will take part in 19 of the 45 planned assembly flights. In addition to supplying technical and scientific equipment, ESA is contributing two major elements: the multi-purpose Columbus laboratory and the Automated Transfer Vehicle – a vehicle to be launched by Ariane-5 to transport supplies to the ISS.

For further information, visit:
http:/www.estec.esa.nl/spaceflight esa



Astronaut James Newman on the Shuttle's Remote Manipulator System arm whilst deploying an antenna on Zarya (courtesy NASA)



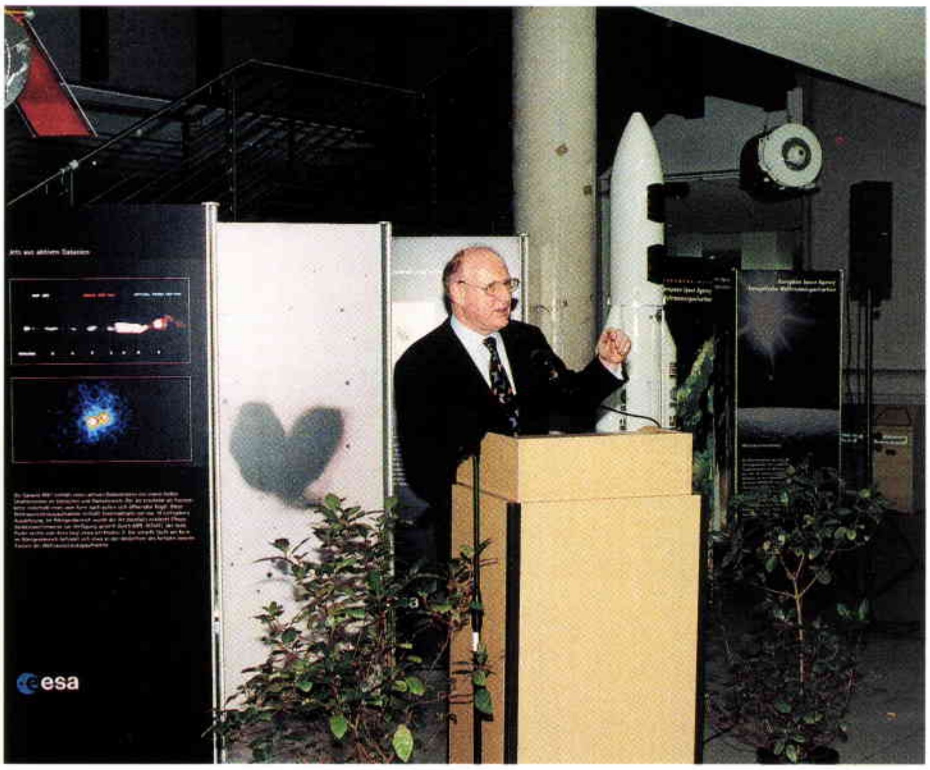
The mated Zarya (left) and Unity (right) modules backdropped against the blackness of space over Earth's horizon (left edge of photo) shortly after undocking from Endeavour's cargo bay (courtesy NASA)

Announcement of Opportunity for Technology

As a trial case for testing new ways of ESA-industry partnerships in technology, an 'Announcement of Opportunity for Technology' was issued and evaluated during the 3rd quarter of 1998. The objective set for this AO was to solicit European companies to propose technological developments of near-to-market space products of their own choice, in order to gain a better positioning with respect to worldwide competition. Focusing on small- and medium-sized enterprises (SMEs) and equipment suppliers, companies usually associated with a role as European prime-contractor were excluded from this Announcement of Opportunity.

The overall budget amounted to 2.5 million ECU, of which 20% was reserved for SMEs. ESA's contribution was limited to 150 000 ECU per proposal, to be complemented by company co-funding at least equal to the ESA contribution. In response to this AO, 55 companies submitted 75 proposals, from which 21 proposals were selected for contract award. A second AO is currently planned for 1999.

Kick-off of the first contract awarded under the 'Announcement of Opportunity for Technology' at ESTEC. Seated from left to right: M. Stanghini, Operating Marketing Manager for FIAR Space; H. Kappler, ESA's Director of Industrial Matters and Technology Programmes; N.E. Jensen, Head of ESA Technology & Systems Studies Department. Standing from left to right: P. de Boer, ESA Contracts Department ; F. Ronchi and L. Nebuloni, FIAR Space; and S. Benetti, ESA Contracts Department



Martin Huber, Head of ESA's Space Science Department, during the opening ceremony for 'ESA 2000' in Jena (photo: P. Scheere)

ESA 2000 Exhibition Opens in Jena

On 4 November 1998, Dr. Martin Huber, Head of ESA's Space Science Department and Prof. Georg Machnik, Rector of the University of Jena, opened the 'ESA 2000' space science exhibition in the foyer of the Friedrich-Schiller University Jena in Thuringia, Germany. Following the opening ceremony, Dr. Frank Jansen, from the Astrophysical Institute of Potsdam, Germany and ESA's consultant for the exhibition, invited the visitors to a tour of the numerous stands and models depicting Europe's past, present and future space endeavours.

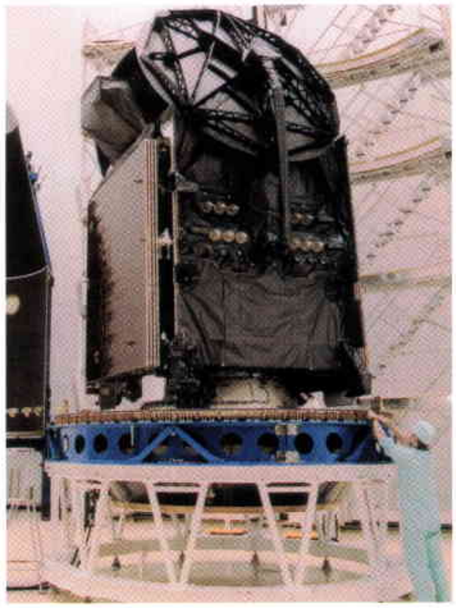
ESA 2000 was opened in Jena during the celebration week '450 Jahre Hohe Schule Jena, 1548-1998'. In his opening address, Dr. Bernard Vogel, Prime Minister of the Federal State of Thuringia, recounted Jena's colourful intellectual and political history during the last 450 years.

ESA 2000 will be on display at the following locations during 1999: Planetarium Bochum, Deutsche Roentgen Museum Remscheid, Wissenschafts-zentrum Bonn, and Zeiss-Grossplanetarium Berlin.

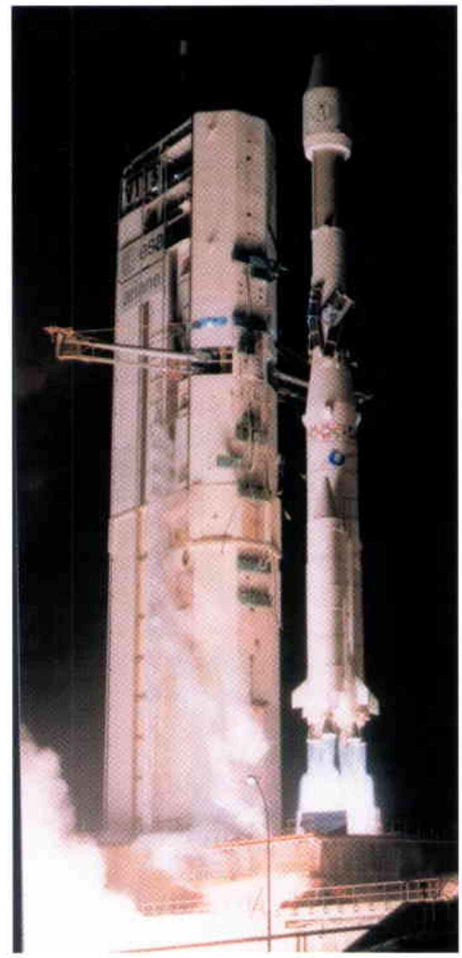
Ariane Launches V114 & V115

The 114th Ariane launch (V114) took place successfully on Saturday 5 December 1998. An Ariane 42L launcher (equipped with 2 liquid strap-on boosters) lifting-off from the Guiana Space Centre – the European spaceport in Kourou, French Guiana – placed into orbit the Mexican telecommunications satellite SATMEX 5. The satellite will provide telecommunications services from Canada to Tierra del Fuego, Argentina.

The 115th Ariane launch (V115) followed on Monday 21 December. The same type launcher placed the direct-to-home television services satellite PAS 6B into geostationary transfer orbit. The spacecraft separated from the launch vehicle 21 minutes into the flight. Satellite controllers in Sydney, Australia, received the first signals 67 minutes after launch, confirming normal operation. With 32 active Ku-band transponders, PAS-6B is planned to provide direct-to-home television services for 15 years for South America from its orbital slot of 43 deg W longitude. It is one of the most powerful satellites in PanAmSat's fleet with 10 kW total power. Three more PAS launches are scheduled in 1999.



The PAS-6B satellite being readied for launch in Kourou



Flight V115: an Ariane 42L launcher takes to the skies on 21 December at 22:08 from Europe's spaceport in Kourou carrying the PanAmSat PAS 6B satellite.

Scientific Research Opportunities with Meteosat Second Generation

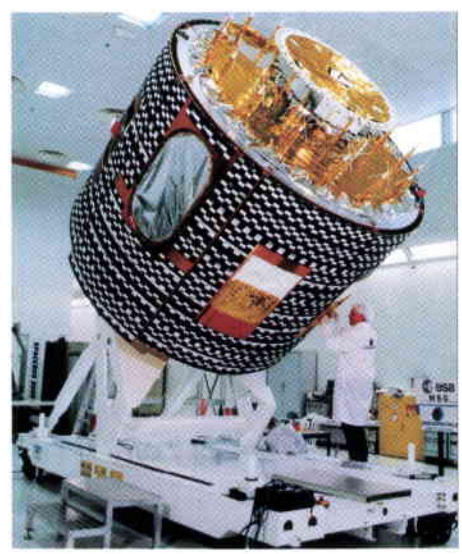
At the beginning of February this year, ESA and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) jointly opened a Research Announcement of Opportunity (RAO) for the scientific use of data from the Meteosat Second Generation (MSG) satellite system.

MSG is a meteorological geostationary satellite system developed by ESA and Eumetsat, the latter representing the European operational meteorological user community. The programme foresees a series of three satellites providing observations over a period of at least 12 years following the launch of the first satellite, MSG-1, planned for October 2000 on an Ariane launcher.

The main instrument of MSG, the SEVIRI imager, will provide about ten times more information than current Meteosat satellites. It will offer new and, in some cases, unique capabilities to characterise clouds, surfaces and the stability of the lower atmosphere, with improved thermal infra-red calibration and radiometric performances. MSG will also carry a Geostationary Earth Radiation Budget (GERB) instrument that will observe the radiative fluxes reflected and emitted by the Earth.

The objective of the joint RAO is to demonstrate the capability of the MSG system to foster innovative research in areas such as hydrology and land surface processes, atmospheric, oceanographic and climate research. This Announcement will also trigger the demonstration of innovative MSG products beyond traditional imagery and weather forecasts, by European and African users, and will contribute to improved calibration and validation.

The selected investigators will be invited to present their results in workshops or conferences jointly organised by Eumetsat and ESA. The first workshop will take place in mid 2000, i.e. before the launch of the first satellite, in order to present the research plans and coordinate the work.



The Research Announcement of Opportunity is coordinated entirely through electronic means. Proposals for research will be collected via an Internet server operated by ESA under the web address <http://msg.esa-ao.org>.

Le septième cours d'été de 1'ECSL: Brest 1998

Partie intégrante de la mission de développement de la connaissance du droit de l'espace que l'ECSL s'est fixé voici déjà neuf ans, le cours d'été de l'ECSL* s'est tenu cette année à Brest, dans l'enceinte de l'Université de Bretagne Occidentale.

Pour sa septième édition, le cours d'été de l'ECSL a, une fois encore, réuni dans un même forum une quarantaine d'étudiants en provenance dix neuf universités réparties sur les territoires de huit Etats membres, ainsi qu'une vingtaine d'enseignants issus des milieux académiques, de l'industrie et d'organisations internationales, parmi lesquelles figure bien sûr l'Agence.

Au fil de deux semaines de cours intensifs, les étudiants ont été initiés aux multiples domaines du droit de l'espace et des activités spatiales.

Comme chaque année, afin de garantir une cohérence de l'enseignement dispensé, les cours ont été répartis en cinq modules dont le contenu se définit comme suit:

- Tout d'abord, une introduction se concentrant sur les Traités et Principes des Nations Unies relatifs à l'espace extra-atmosphérique. Les autres sources du droit de l'espace, telles les législations nationales, font aussi partie de ce module.
- Les télécommunications font, quant à elles, l'objet d'une double analyse:

Premièrement, une analyse institutionnelle comprenant une étude du rôle de l'ITU, ainsi que celle du phénomène de privatisation des organisations internationales de télécommunications comme Inmarsat ou Intelsat.

Deuxièmement, une étude des problèmes juridiques découlant de la mise en oeuvre des dernières évolutions en matière de distributions de programmes télévisés.

- L'ESA se voit également consacré un module. Son histoire, sa politique industrielle, sa structure et son mode de fonctionnement, ses activités de lancement, les pratiques et procédures d'approvisionnement, ainsi que ses relations avec la Communauté Européenne font l'objet d'autant de cours donnés par des membres du personnel de l'Agence.
- Le troisième module aborde les questions liées à la coopération internationale dans le domaine des activités spatiales, notamment au niveau de la station spatiale internationale.
- Enfin, un dernier groupe de cours s'intéresse aux conséquences de la commercialisation des activités spatiales ainsi qu'aux nouvelles initiatives dans le domaine. Ce module couvre des domaines aussi variés que les assurances, la télédétection, la navigation par satellite ou encore le règlement des litiges.

Outre cet ensemble de cours, les étudiants se sont également vus soumettre un cas pratique relatif à une appropriation indirecte d'une orbite moyenne via la mise en oeuvre du droit des brevets. Répartis en groupes de travail chargés de défendre chacun un intérêt particulier, les étudiants ont été amenés à faire valoir leurs points de vue à l'occasion d'une simulation de conférence internationale qui clôtura le programme académique.

Les loisirs n'ont pas été oubliés. Les organisateurs ont émaillé le séjour d'intermèdes tant culturels que ludiques. Ainsi, les étudiants se sont vus proposés, entre autres, une visite du musée des télécommunications de Plomeur-Boudou, une randonnée à cheval et une croisière au son du bignou... De quoi satisfaire les goûts les plus éclectiques.

T. Herman
ECSL Executive Secretary

*H. Tuinder, "Europe's First Space Law and Policy Summer Course", ESA Bulletin 73, 1993, pp. 77-79
V. Kayser & R. Roelandt, "The ECSL Summer Course on Space Law and Policy - An Example of ESA's Role in Space Law Teaching", ESA Bulletin 81, 1995, pp. 59-62

The Earth Explorer Missions – Further Evolutions

Introduction
For the post 2000 era, two general classes of mission are being proposed by the Agency:

- Earth Explorer Missions: research/demonstration missions with the emphasis on advancing understanding of the different Earth system processes. The demonstration of specific new observing techniques would also fall under this category.
- Earth Watch Missions: pre-operational missions addressing the requirements of specific Earth observation application areas. The responsibility for this type of mission would eventually be transferred to operational (European) entities and the private sector.

Within this overall context two complementary types of Earth Explorer Missions are envisaged, namely:

- Earth Explorer Core Missions: larger research/demonstration missions led by ESA
- Earth Explorer Opportunity Missions: smaller research/demonstration missions not necessarily ESA led.

This article is concerned with both types of *Earth Explorer Missions* and specifically with developments since the Granada User Consultation Meeting in May 1996 after which four candidate *Earth Explorer Core Missions* were selected for Phase-A study.

More information on the nature of these missions and the scientific context of the Earth Explorer element of the Agency's *Living Planet Programme* can be found in ESA SP-1227 (*"Earth Explorers: The Science and Research Element of ESA's Living Planet Programme"*) published in October 1998.

The Earth Explorer Core Missions
The four candidate *Earth Explorer Core Missions* selected for Phase-A study after the Granada User Consultation Meeting were as follows (not in any order of priority):

(a) *A Land-Surface Processes and Interactions Mission* – intended to observe surface characteristics associated with land-surface processes and land/atmosphere interactions at local scales; to advance the understanding of these interactions on a global scale by extrapolating through space and time using process models; to enhance the capability to model and hence to advance the capability to manage our environment and its resources.

(b) *A Gravity Field and Steady-State Ocean Circulation Mission* – intended to advance work in the areas of steady-state ocean circulation, physics of the Earth's interior and levelling systems (based on GPS); to provide the unique data set required to formulate global and regional models of the Earth's gravity field and the geoid (its reference equipotential surface) to high spatial resolution and accuracy.

(c) *An Atmospheric Dynamics Mission* – intended to contribute to the correction of a major deficiency in the current (meteorological) operational observing network as well as the study of the Earth's global energy balance (i.e. global circulation and related features such as the El Niño and the Southern Oscillation); to provide global observations of three-dimensional wind fields.

(d) *An Earth Radiation Mission* – intended to advance the understanding of radiative processes in maintaining the present climate and in governing the amplitude and evolution of large-scale climate anomalies; to provide global observations of cloud and aerosol fields (including both characteristics and distribution in the vertical) coupled with observations of radiative fields in synergy with other data.

Phase-A studies in support of each of these candidate *Earth Explorer Core Missions* have been initiated and Mission Advisory Groups have been set up to produce Reports for Mission Selection.

The four Phase-A studies are scheduled to be completed later this year and the four Reports for Mission Selection should be available in August 1999. These Reports will not only summarise the results of the Phase-A studies but will also contain updated (relative to the Reports for Assessment: ESA SP-1196/Vols. 1-9) scientific arguments in support of the four missions. The latter will include the results of various scientific studies initiated in support of the four missions as well as other relevant scientific developments.

The Reports will be presented to the scientific community during a Consultative Workshop which will be held in Granada, Spain, on 12 to 14 October 1999. This Workshop is open to the whole research community and will largely follow the format of 'Granada I'. Each of the four missions will be presented in turn and, in addition to seeking clarifications, participants will be invited to comment on the strengths and weaknesses of the four candidate missions. More information on arrangements for this meeting (including registration) can be found on the Agency's Earth Explorer web site

<http://www.estec.esa.nl/explorer/>.

Following this meeting, the evaluation of the four missions will be initiated under the auspices of the Earth Sciences Advisory Committee (ESAC). It will be this Committee's responsibility to decide on behalf of the scientific community which two of the four missions to recommend for full implementation to the Programme Board for Earth Observation.

The Earth Explorer Opportunity Missions

On Monday 13 July 1998, the first Call for Proposals for *Earth Explorer Opportunity Missions* was issued for small missions intended to conduct research in the field of Earth Observation and/or to demonstrate the potential of new innovative Earth Observation observational techniques/ technologies of relevance to both the scientific and the applications communities. The deadline for submissions was 1 December 1998.

In response, some 27 Full Proposals were received. These are currently being evaluated scientifically and technically under the auspices of the Earth Sciences Advisory Committee (ESAC). The Committee is scheduled to complete its deliberations and submit its findings, coupled with specific recommendations on which proposals to implement, early in April 1999.

As far as research is concerned, proposals may contribute to any of the objectives underlying the Earth Explorer element of the Agency's *Living Planet Programme* (ESA SP-1227). These are organised under four themes, namely:

- Theme 1 - Earth Interior
- Theme 2 - Physical Climate
- Theme 3 - Geosphere/Biosphere
- Theme 4 - Atmosphere and Marine Environment: Anthropogenic Impact

Furthermore, for the purposes of this Call, proposals could be for small missions fully funded and led by ESA, for co-operative ESA-led missions with other space entities, or for instrument or other provisions to the programme of another space entity. All were acceptable and all could include the demonstration of techniques/ technologies as well as research. More information may be found in ESA SP-1226, *The Living Planet Programme: Earth Explorers: Call for Earth Explorer Opportunity Missions,* or on the Agency's Earth Explorer web site

<http://www.estec.esa.nl/explorer/>.

All of the ESA SP's referenced above can be purchased from ESA Publications Division: see order form inside back cover or visit the Publication's Bookshop website *<http://esapub.esa.int>*

Alpbach Summer School 1998

The Alpbach Summer School 1998, co-organised by the Austrian Federal Ministry for Science and Transport, the Austrian Space Agency, ESA and the national space authorities of its Member States, was successfully held from 21-30 July 1998.

51 students from Austria, the Czech Republic, France, Germany, Ireland, the Netherlands, Spain, Sweden, Switzerland, the United Kingdom and Australia converged on Alpbach (A) to learn more about Planet Earth and further develop their space-related studies. The aim of the Summer School is to offer advanced training and working experience to European students, on a subject which is not usually part of the academic curricula, in an atmosphere conducive to informal discussions between lecturers, tutors and students.

The topic for 1998 'Our Solid and Liquid Planet' was concerned with the application of satellites for an improved understanding of the Earth/atmosphere system and for monitoring the global environment. For careful management of the Earth's biological, fossil and mineral resources, and in order to preserve the long-term habitability of our planet, it is necessary to understand the complex processes of the Earth system. Earth observation from space is an important way to provide key data for these tasks.

20 lecturers from among the ESA Member States provided an overview of the wide range of satellite applications. Two specific application areas were covered in detail:

- The global energy and water cycle
- The dynamics of the solid Earth.

The Alpbach Summer School students were challenged to design future satellite missions for these two applications, which they brilliantly accomplished, presenting the following mission studies at the end of the session:

- SPLASH (Satellite System for Processes in Land Surface Hydrology)
- DEMETER (Deep Earth Measurement Through Extreme Resolution Gravity Gradiometry)
- GRANDMA (Gravity and Magnetometry).

The study results demonstrate the serious enthusiasm of the students in the field of aerospace sciences and will most likely prove to be the backbone of many future space science missions.

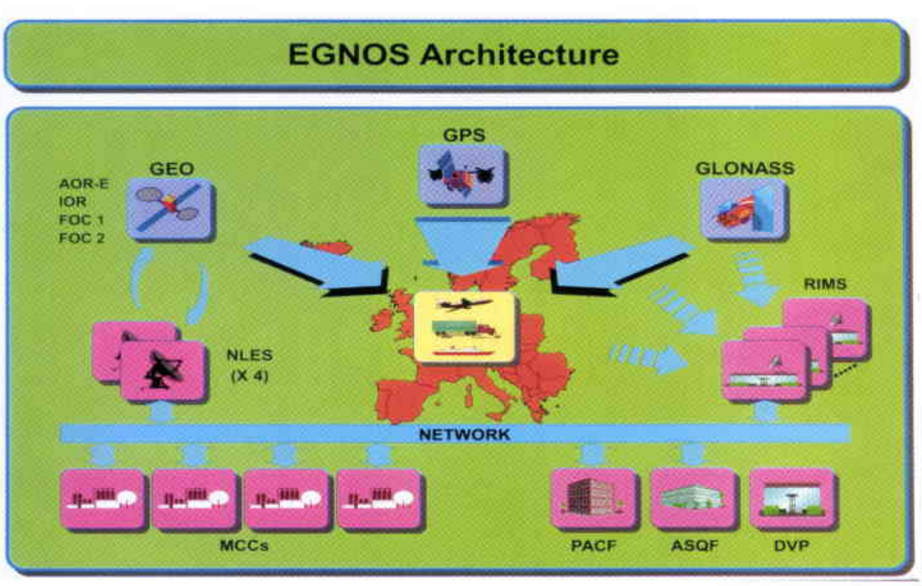
Klaus Pseiner
Managing Director, Austrian Space Agency

EGNOS Bilateral Agreements Signed

On Thursday 21 January 1999, ESA's Director General, Antonio Rodotà, signed eight Bilateral Agreements with Air Traffic Service Providers, Air Traffic Management Service Providers and other Agencies: AENA (ES), ANA & EP (P), CNES & DNA (Fr), DFS (D), ENAV (I), NATS (UK), NMA (N) and Swisscontrol (CH). These Agreements establish the terms of cooperation between the parties in support of the European Geostationary Navigation Overlay Service (EGNOS), a system intended to provide GPS/GLONASS (GPS-Global Positioning System, GLONASS-Global Navigation Satellite System) satellite-based augmentation services to aviation, maritime and land users, thereby significantly enhancing safety-critical applications.

EGNOS is being designed to serve the needs of all modes of transport in the European region. Its built-in expansion capabilities will also allow the propagation of the EGNOS technology and expertise to the other regions of the world (Africa, South America, Pacific region, etc).

EGNOS is being implemented by ESA, in cooperation with the European Commission (EC) and Eurocontrol in the context of a more global European effort in the field of satellite navigation, and will be interoperable with similar systems under development in the US (WAAS: Wide Area Augmentation System) and in Japan (MSAS: Multi-Transport Satellite Augmentation System).



ESA has taken a leading role in preparing the future European contribution to a Global Navigation Satellite System (GNSS 1 & 2), capable of meeting the strategic, industrial and technical objectives laid down by European states. The direct involvement and contributions of other agencies in this programme introduces an important operational/commercial thrust and opens new avenues and opportunities for ESA's Application Programmes.

EGNOS, planned to be operational in early 2002, will have installations of varying degrees of complexity in the eight countries involved in the Bilateral Agreements, as well as outside Europe. The implementation is entrusted to an industrial team led by Alcatel.

STS-95 Crew on Tour

ESA astronaut Pedro Duque accompanied his fellow crew members of the Space Shuttle Discovery STS-95 mission on a whirlwind tour of his home country, Spain, and ESA establishments (EAC, ESRIN, ESAHQ and ESTEC) from 11-21 January before continuing on to Japan. The well-received crew sparked European public and media interest and appreciation for on-going space endeavours, especially related to the International Space Station and manned spaceflight in general.

ESA staff members were also appreciative for the opportunity to see and talk to the crew. At ESTEC, NASA astronauts Curt Brown (Commander), Steve Lindsay (Pilot), Steve Robinson (Mission Specialist) and the popular, 77 year-old, John Glenn (Payload Specialist), as well as our own Pedro Duque gave an entertaining yet informative presentation of their 9-day mission of last October, followed by questions from the audience.

A total of 31 experiments were carried out during STS-95, including European experiments from Belgium, UK, France, Germany, Italy, Spain, Sweden and Switzerland. The mission was also a final test for some of the ESA science facilities and experiments designed to explore the effects of weightlessness on various materials and substances which may be flown in Europe's Columbus laboratory of the ISS.

Top
Mr D. Dale, ESA Director of Technical and Operational Support, receives a souvenir of the mission from Shuttle Commander Curt Brown during the STS-95 presentation at ESTEC

Centre
Each of the STS-95 astronauts was presented with a gift to commemorate their visit to The Netherlands. Pictured here (from left to right) are: Pedro Duque, ESA Astronaut; Kathy Laurini, NASA Resident at ESTEC, Jörg Feustel-Büechl, ESA Director of Manned Spaceflight and Microgravity; and John Glenn, STS-95 Payload Specialist

Bottom
The STS-95 crew at ESTEC (from left to right): Pedro Duque, Steve Robinson, Steve Lindsay, Curt Brown and John Glenn

ESA Astronaut Umberto Guidoni, First European on the ISS

ESA astronaut Umberto Guidoni will become the first European to travel to the International Space Station (ISS). The announcement was made by ESA Director General Antonio Rodotà, together with NASA Administrator Daniel S. Goldin and Italian Space Agency (ASI) President Sergio De Julio, on 9 February in Rome, Italy.

Guidoni, an astrophysicist of Italian nationality, will fly on Shuttle mission STS-102, currently scheduled for April 2000. For the first time, the Shuttle will transport material in a specially-designed Multipurpose Logistics Module (MPLM) mounted in its cargo bay. The module, Leonardo, is the first of three such carriers scheduled for launch to the ISS. The modules are being built by ASI under an ASI-NASA agreement which includes a flight opportunity for an Italian astronaut.

STS-102's cargo – laboratory racks filled with equipment, experiments and supplies – will be used to outfit the US laboratory module, which will have been attached to the ISS one month earlier. Once docked, the crew will use the Shuttle's robotic arm to lift Leonardo from the cargo bay and attach it to another of the Space Station's ports. The astronauts will then unload its contents. Leonardo will then be placed back in the Shuttle's cargo bay and returned to Earth.

For additional information, see the following web pages:

- Umberto Guidoni: <http://www.estec.esa.int/spaceflight/astronaut/eacpr/bios/cv-ug.htm>
- ESA astronauts: <http://www.estec.esa.int/spaceflight/astronaut>
- International Space Station: <http://www.estec.esa.int/spaceflight>
- Multipurpose Logistics Module (MPLM): <http://www.alespazio.it/mplm.htm>

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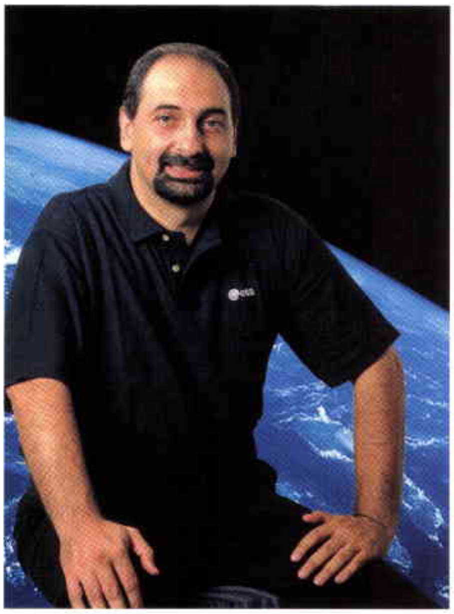


Umberto Guidoni will be making his second spaceflight. His first was as a payload specialist on the Shuttle's 16-day Tethered Satellite System (STS-75/TSS-1R) mission in February-March 1996. Originally recruited by ASI as an astronaut in 1989, he joined ESA's single European Astronaut Corps (EAC) in August 1998. He is currently based at NASA's Johnson Space Center in Houston, Texas, where he is working in the Robotics Branch on graphical user interface displays for the Space Station's Remote Manipulator System, a new-generation robotic arm being built by Canada

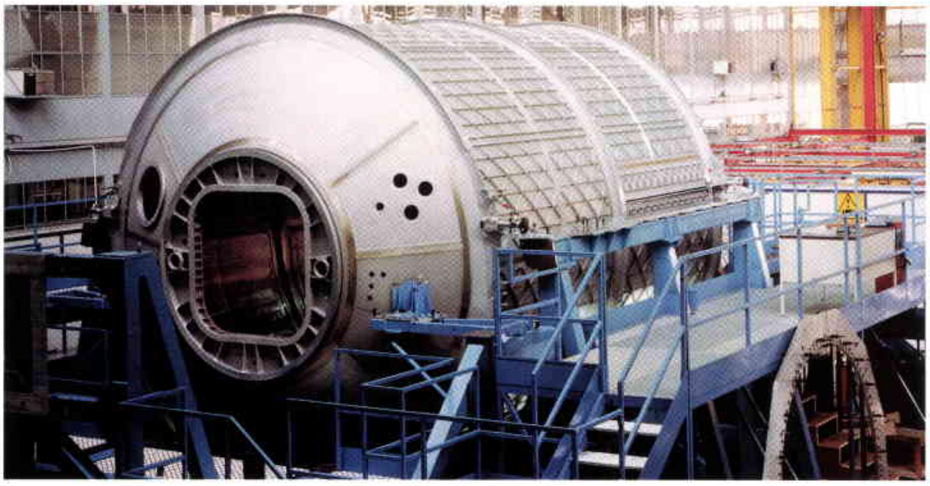
Cupola Contract for the International Space Station Signed

Following successful completion of negotiations, the Cupola contract for the International Space Station (ISS) was signed on 8 February in Turin, Italy, by ESA and Alenia Aerospazio (I). The Cupola programme results from a bilateral agreement between NASA and ESA under which ESA is to provide two Cupolas for the ISS in exchange for Shuttle transportation of European equipment and experiments.

The Cupola is a kind of Space Station control tower – an observation module – in the form of a windowed dome, that will allow two crew members to manoeuvre the robotic arm (Space Station Remote Manipulator System - SSRMS), thereby facilitating the assembly and attachment of the various Station elements. The Cupola will accommodate command/control workstations and other hardware to observe the Earth and Orbiter/ISS activities. The Cupola will also offer unquestionable psychological benefits by providing a pressurised observation area for the crew to have a clear view of the Station, the stars and Mother Earth.

The two Cupola units stipulated in the contract will be launched on the Shuttle and positioned on the Nodes – the interconnecting elements of the Station – by the SSRMS. The first unit is currently planned to be attached to Node 1 (Unity) in early 2003 and the second to Node 3 later that same year.

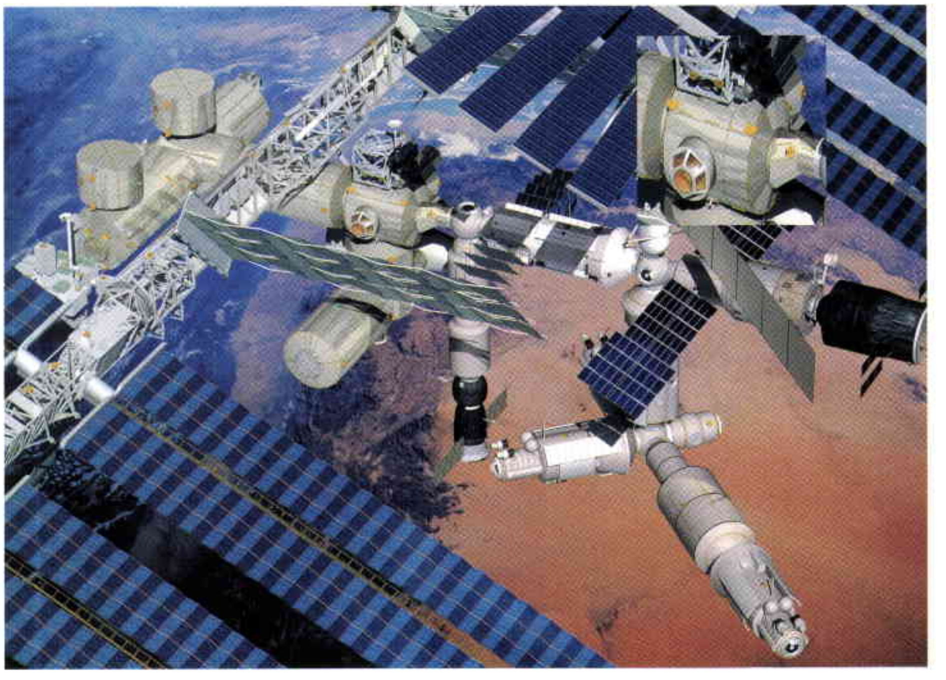
ESA has assigned the programme to Alenia Aerospazio. As prime contractor, Alenia Aerospazio will coordinate an industrial team of six other European companies: CASA (E), APCO (CH), Saab Ericsson and Lindholmen (S), Verhaert (B) and Daimler Chrysler Aerospace/DASA (D).



The MPLM modules as well as Europe's Columbus laboratory (to be added to the Space Station in 2003) have been derived from the European-designed laboratory Spacelab, which flew on 22 Shuttle flights over a period of 15 years (1983 to 1998)

At the signing, Giuseppe Viriglio, Head of Alenia Aerospazio Space Division, declared *"The acquisition of the Cupola programme further strengthens Alenia Aerospazio's leadership in orbiting infrastructures. What is more, it places the company in the unique position of being the second industry after prime contractor Boeing for the design and construction of systems for the International Space Station".*

Jörg Feustel-Büechl, Director of ESA's Manned Spaceflight and Microgravity Directorate, stated *"The signing of the Cupola contract reinforces the already strong position of Italy and Alenia in the International Space Station. It is a logical additional task which takes advantage of their competence, built up since the beginning of our ESA manned space ventures, which started in 1973 with the Spacelab project. The Cupolas are another two elements of the International Space Station which will be built in Europe, thereby enriching its role in this vast international programme. This contract will hopefully encourage, and help to ensure, the anticipated significant participation of Italy in ESA's future operational Exploitation Programme phase of the International Space Station".* esa



The Cupola is an aluminium structure about 2 m in diameter and 1.5 m high. It has one skylight and six lateral windows protected by special shutters that can be opened and closed

ESA and CNES Sign Frame Contract for the Mutual Supply of Network Services

Under this Frame Contract, signed on 29 January 1999, ESA and CNES will provide reciprocal TT&C services for spacecraft through the interconnection of their ground operation networks. ESA and CNES will take advantage of each other's TT&C networks with the aim of reducing costs and improving the quality of the respective services. The contract itself is non-exclusive and each individual support service will be the subject of a short standardised service programme contract. All main terms and conditions, including the values of the several standard services needed for support, are defined in the Frame Contract, thus enabling the Parties to request support at short notice and without complex negotiations.

The signature of this Frame Contract has to be seen in a wider context in which three Agencies, i.e. ESA, CNES and DLR, will interconnect their ground operations networks. esa

At the signing of the new ESA/CNES Frame Contract are, seated from left to right: Mr G. Brachet, CNES' Director General, Mr A. Rodotà, ESA's Director General; standing behind, from left to right: Mr H. Weber, ESA Contracts Department, Mr K-E. Reuter, ESA's Head of Cabinet

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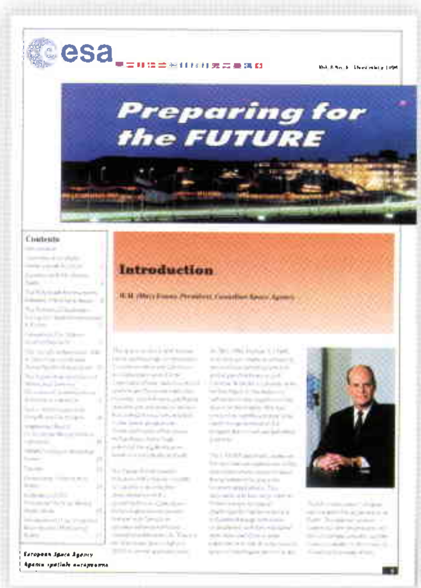

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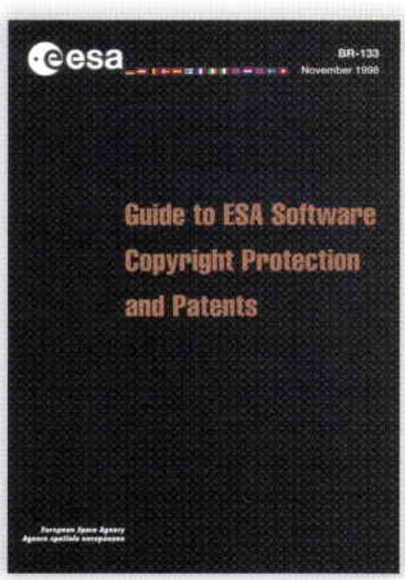

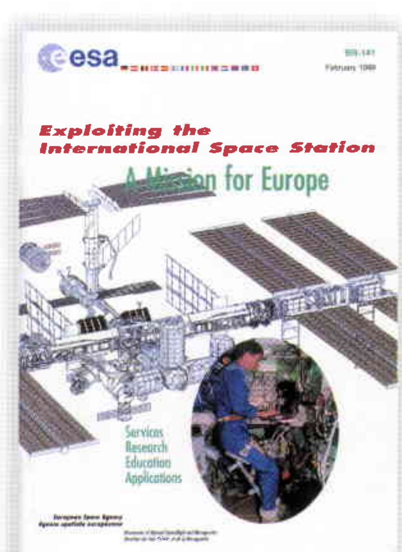

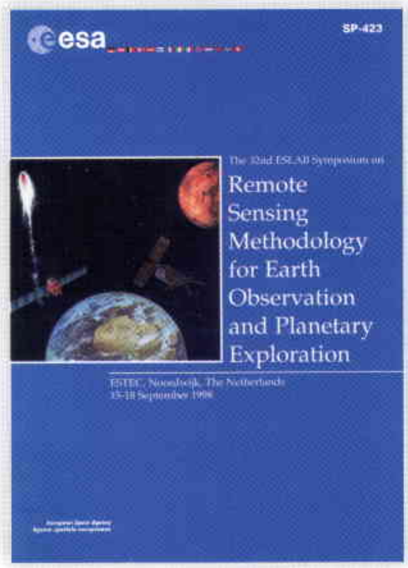

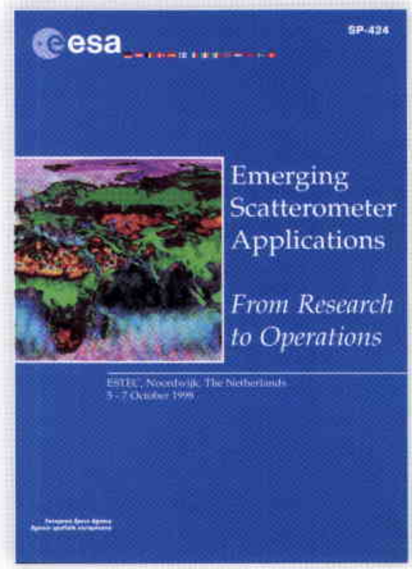

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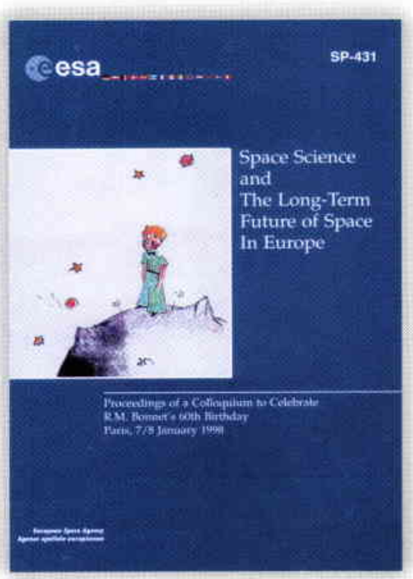

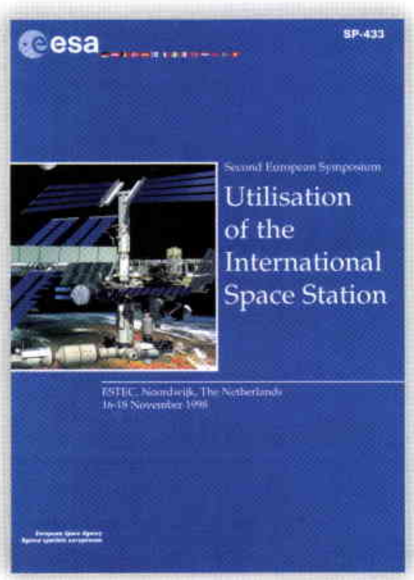

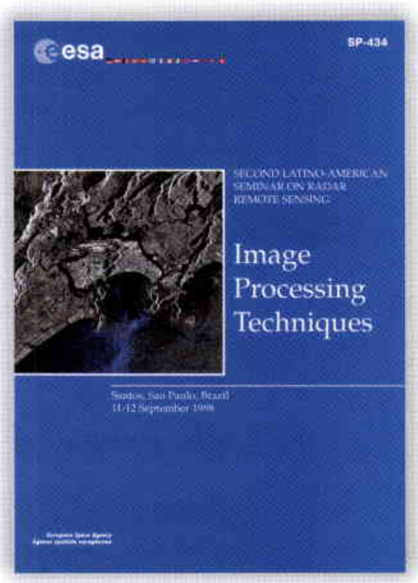

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