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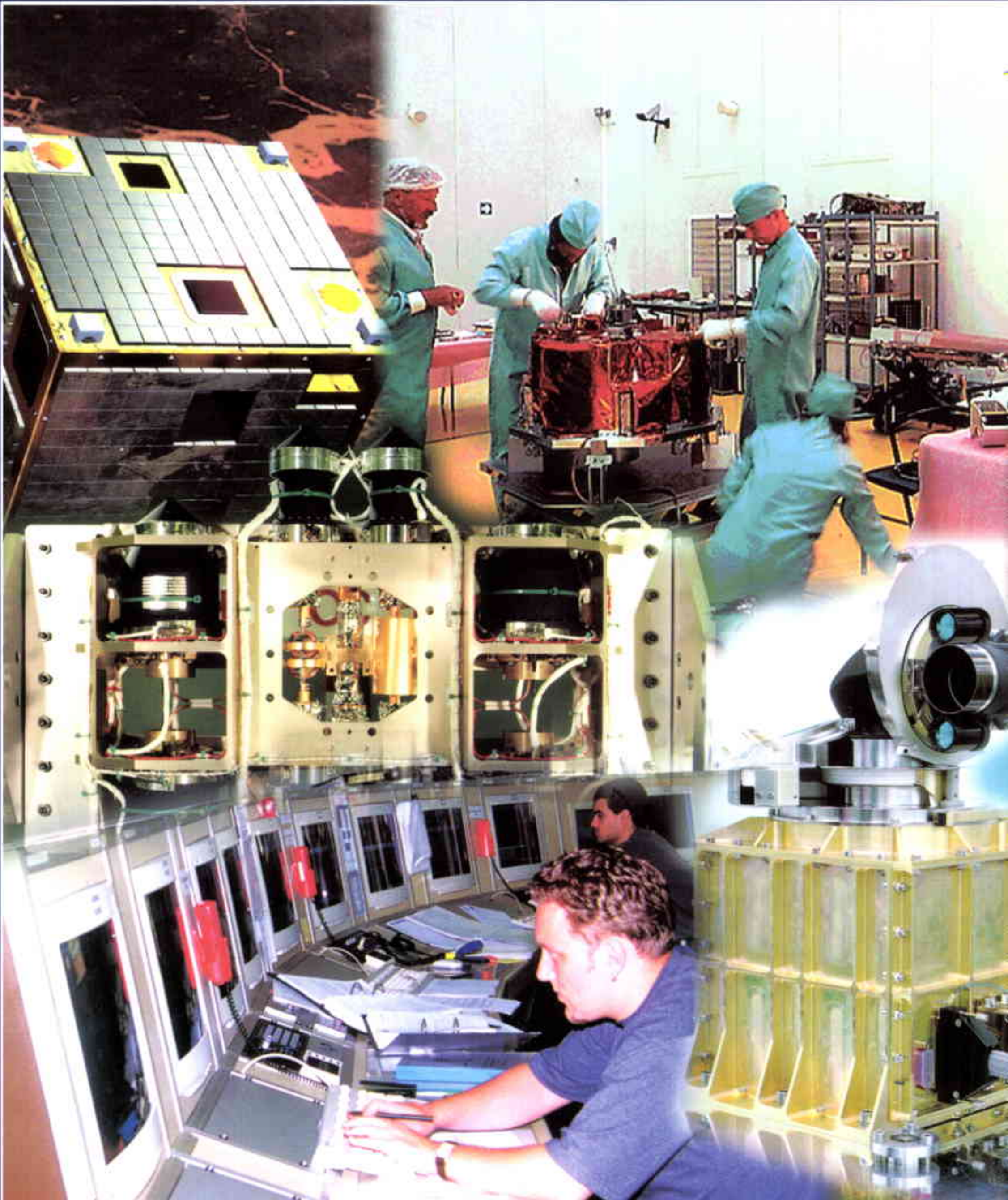

European Space Agency
Agence spatiale européenne

european space agency

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

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

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

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

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: H. Parr

Director General: A. Rodotà.

agence spatiale européenne

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

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

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

L'Agence est dirigée par un Conseil, composé de représentants des Etats membres. Le Directeur général est le fonctionnaire exécutif supérieur de l'Agence et la représente dans tous ses actes.

Le SIEGE de l'Agence est à Paris.

Les principaux Etablissements de l'Agence sont:

LE CENTRE EUROPEEN DE RECHERCHE ET DE TECHNOLOGIE SPATIALES (ESTEC), Noordwijk, Pays-Bas.

LE CENTRE EUROPEEN D'OPERATIONS SPATIALES (ESOC), Darmstadt, Allemagne.

ESRIN, Frascati, Italie.

Président du Conseil: H. Parr

Directeur général: A. Rodotà.

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European Space Agency
Agence spatiale européenne

Towards New Horizons
— The ESA Council Meeting in Brussels

Introduction
At the invitation of Mr Yvan Ylieff, the Belgian Minister for Science Policy and Chairman of ESA's Council at Ministerial Level, the most recent meeting of the ESA Council took place in Brussels on 23 and 24 June. Key agenda items at this Meeting, which represented a critical step in the preparations for the next full Council Meeting at Ministerial Level, were the discussions on greater coordination between ESA and the European Community and the starting of new ESA programmes in the fields of launcher development, Earth observation and satellite navigation.

The Meeting was preceded by a ceremony to mark the 25th Anniversary of the 1973 European Space Conference, which also took place in Brussels, under the Chairmanship of the then Belgian Minister for Scientific Policy, Mr Charles Hanin, and which laid the foundations for the formation of the European Space Agency. During this celebration, the Ministers present expressed their recognition of the range and the extent of the achievements of ESA's space programmes over the past 25 years and the Agency's successes in space science, in satellite communications, in Earth observation and with Ariane – successes that have placed Europe among the World's leading players in space. They also reaffirmed their continuing loyalty to the future role of ESA as the focal point for Europe's space efforts.

Decisions taken in Brussels
The first of the Resolutions to be adopted by the June Council (ESA/C/CXXXVI/Res. 1) is a reflection of the need to strengthen further the synergy and increase the complementarity between ESA and the European Community in their respective spheres of competence in the space domain, thereby enhancing the efficiency of government investment in space systems and technology for the benefit of European users and industry. This *Resolution on the Reinforcement of the Synergy between the European Space Agency and the European Community* had been endorsed a day earlier, on 22 June, by the European Union's Research Ministers meeting in Luxembourg under the chairmanship of John Battle, the UK Minister of State for Science, Energy and Industry. It opens a new era of cooperation between the two organisations. It calls for the further strengthening of relations and encourages more initiatives at strategic level for developing a common vision, particularly in the fields of telecommunications, navigation and Earth observation, to enhance the effectiveness of public investment in these programmes for the benefit of both users and European industry.

In a second Resolution (ESA/C/CXXXVI/Res. 2), Council sanctioned exceptional measures that should allow the Agency to deal more effectively with the financial risks associated with its programmes. In adopting this *Resolution on Modifications to the Financial Regulations Required for the Purposes of Setting Up an Accompaniment Fund*, the Council also welcomed the measures taken by the Director General to adapt the Agency to the new realities, inviting him to continue to pursue his efforts for increased efficiency in conducting Europe's space programmes and strengthening support to European industry in order to further enhance its world-wide competitiveness and market share.

The third Resolution adopted in Brussels (ES/C/CXXXVI/Res. 3) was the *Resolution on Immediate Measures and Preparatory Steps towards the Council Meeting at Ministerial Level Related to the Agency's New Programmes and its Evolution.*

This Resolution contains five elements:
Chapter I:
- *Towards the establishment of an overall European space policy*, whereby the Delegations and the Director General will strive jointly to formulate a coordinated European Space Policy for presentation to the next Council Meeting at Ministerial Level.

Chapter II:

- *Evolution of the European Space Agency*, relating to the improvement of ESA's overall efficiency in terms of improved decision-making processes, further savings in internal costs, the use of performance indicators, and the containment of costs at completion of new programmes.

Chapter III:

- *Efficient use of public resources in Europe*, covering the elaboration of guidelines for reciprocal use of ESA and national facilities for national and ESA programmes, and enhancement of European expertise by establishing conditions for mobility of staff between national centres, ESA and other institutions.

Chapter IV:

- *Programmes of ESA*, sanctioning the start of four new activities in the areas of space transportation, Earth observation and satellite navigation, namely:
  - the first step in the development of a more powerful version of Ariane-5, Ariane-5 Plus, to ensure its continued competitiveness on the international launcher market
  - the first step in preparing the development of a small launcher known as VEGA
  - the definition and start-up of activities related to the Living Planet Programme in Earth Observation
  - the initiation of the first step of the Global Navigation Satellite System (GNSS-2), leading to the choice of the best system and associated technology for a European initiative in the context of a strong European coordination.

Chapter V:

- *Mandate of the Council Working Group for the Preparation of the Council at Ministerial Level,* which invites the Council Working Group to continue the preparations, focusing its analysis on the areas described in Chapters I to IV.

The texts of the various Resolutions are reproduced in full in the following pages. esa

Celebration of 25th Anniversary of the 1973 European Space Conference

Panel Session focussing on ESA's achievements, including some of the Delegates who had attended the 1973 European Space Conference: from left to right: Mr Yvan Ylieff, Mr John Battle, Mr Antonio Rodotà, Mr Hugo Parr, Mr Michel Bignier, Prof. Massimo Trella, Mr Jan Stiernstedt, Mr Peter Creola and Mr Charles Hanin

Mr John Battle, UK Minister of State for Science, Energy and Industry and Chairman of the European Union's Research Council, addressing the assembled guests and representatives of the media during the opening of the 25th Anniversary Celebration, at the UGC Cinema in Brussels

Mr Michel Bignier (centre), former Director of ESA's Spacelab Programme, discussing Spacelab's role as a key to future European and trans-Atlantic cooperation

Rounding off of the Panel Session by Mr Charles Hanin, former Belgian Minister of Scientific Policy, and Chairman of the 1973 European Space Conference

Brussels Participants

Minister Yvan Ylieff, Chairman of the ESA Council at Ministerial Level, and Representatives of the ESA Member States who participated in the Brussels 25th Anniversary Celebration, gathered in the foyer of the Hotel Metropole, with a model of Ariane-5 as a backdrop

The 136th Council Meeting in Session

The Brussels Council Meeting in session in the Salon Excelsior of the Hotel Metropole

From left to right:
Mr Daniel Sacotte, ESA's Director of Administration,
Mr Antonio Rodotà, ESA's Director General,
Mr Hugo Parr, Chairman of ESA Council, and
Mr Karl-Egon Reuter, Head of the ESA Cabinet

ESA/C/CXXXVI/Rés.1 (Final)

agence spatiale européenne

RESOLUTION SUR LE RENFORCEMENT DE LA SYNERGIE ENTRE L'AGENCE SPATIALE EUROPEENNE ET LA COMMUNAUTE EUROPEENNE

(adoptée le 23 juin 1998)

Le Conseil de l'ASE,

VU l'évolution de la recherche et de la technologie spatiales et de leurs applications,

SOULIGNANT que les technologies spatiales ouvrent de nouveaux marchés, ce qui accroît la valeur économique des activités spatiales, tandis que leurs incidences politiques, culturelles et sociales demeurent un facteur prépondérant, et RECONNAISSANT que lesdites technologies spatiales assurent le soutien des politiques publiques concernant l'environnement, la société de l'information et les transports et contribuent à la création de nouveaux gisements d'emplois et à une meilleure qualité de vie,

CONSTATANT l'intensification de la concurrence internationale et la nécessité de mettre l'industrie européenne sur un pied d'égalité avec ses concurrents internationaux,

SOULIGNANT les succès déjà obtenus dans le domaine des sciences, des lanceurs, des applications satellitaires et des vols habités et RECONNAISSANT les progrès enregistrés en matière de coopération entre différents acteurs de l'Europe spatiale, notamment l'Agence spatiale européenne (ASE), la Communauté européenne, les autorités spatiales nationales, l'industrie, la communauté scientifique

ESA/C/CXXXVI/Res. 1 (Final)

european space agency

RESOLUTION ON THE REINFORCEMENT OF THE SYNERGY BETWEEN THE EUROPEAN SPACE AGENCY AND THE EUROPEAN COMMUNITY

(Adopted on 23 June 1998)

The Council of ESA,

HAVING REGARD to the evolution of space research and technology and their applications,

STRESSING that space technologies are opening new markets, increasing the economic value of space activities, while their political, cultural and social implications remain a dominant factor; and RECOGNISING that such space technologies are underpinning public policies towards the environment, the information society and transport and contributing to the creation of new job opportunities and to a better quality of life,

CONSIDERING the increasing international competition and the necessity to place European industry on an equal footing compared to international competitors,

STRESSING the achievements already made in the fields of science, launchers, satellite applications and human spaceflight; and RECOGNISING the progress already made in the cooperation between a number of different actors in the European space sector, in particular the European Space Agency (ESA), the European Community, the national space authorities, industry, the research

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et les opérateurs, ainsi que les avantages qui en découlent pour les utilisateurs européens et l'industrie européenne,

RECONNAISSANT que ladite coopération doit être fondée sur la complémentarité des intérêts de l'ASE (qui est notamment chargée d'élaborer et de mettre en œuvre une politique spatiale européenne à long terme, des activités et des programmes dans le domaine spatial et la politique industrielle adaptée à son programme) et de ceux de la Communauté européenne (qui a des compétences juridiques, économiques et sociales ayant trait à la réglementation des marchés liés à l'espace) en ce qui concerne les politiques de la Communauté relatives à l'environnement, aux transports et à la société de l'information, dont la mise en œuvre bénéficiera de l'utilisation de systèmes spatiaux,

ESTIMANT que cette coopération incitera l'industrie européenne à investir dans les projets spatiaux ayant des perspectives commerciales,

PRENANT NOTE de la Communication sur l'espace de la Commission européenne (COM(96)0617-C4-0042/97) et de la Résolution correspondante du Parlement européen en date du 13 janvier 1998, ainsi que de l'initiative prise par la Commission d'élaborer des plans d'action concrets dans certains secteurs spatiaux et des Conclusions du Conseil de l'Union européenne des 22 septembre 1997, 27 juin 1997 et 17 mars 1998 qui s'y rapportent,

RAPPELANT la Résolution du Conseil de l'ASE siégeant au niveau ministériel du 20 octobre 1995 (ESA/C-M/CXXII/Rés. 2 (final)),

VU la Position commune adoptée au sujet du cinquième programme cadre, qui assure la coordination des applications liées aux technologies spatiales au sein des programmes spécifiques,

RAPPELANT la coopération fructueuse établie au fil des ans entre l'ASE et la Communauté, community and operators, and the benefits attached to it for European users and European industry,

RECOGNISING that such cooperation should be based on the complementarity of the interests of ESA (which is in particular responsible for elaborating and implementing a long term European space policy, activities and programmes in the space field and the industrial policy appropriate to its programme) and those of the European Community (which has competences in legal, economic and social fields which affect the regulation of space-related markets) with respect to Community policies in environment, transport and the information society whose implementation will benefit from the use of space systems,

BELIEVING that this co-operation will be a factor of encouragement to European industry to invest in space endeavours with a commercial potential,

NOTING the Communication on Space of the European Commission (COM(96)0617-C4-0042/97) and the associated European Parliament's Resolution dated 13 January 1998, the Commission's initiative to elaborate concrete action plans in certain space sectors, and the related Conclusions of the Council of the European Union of 22 September 1997, 27 June 1997 and 17 March 1998,

RECALLING the Resolution by the ESA Council at ministerial level on 20 October 1995 (ESA/C-MICXXII/Res.2 (Final)),

HAVING REGARD to the Common Position on the Fifth Framework Programme which provides for the co-ordination of space technology-related applications within the specific programmes,

RECALLING the fruitful cooperation developed over the years between ESA and the Community, CONVAINCUS de la nécessité de doter l'Europe d'une vision et d'un cadre de référence communs permettant aux différents acteurs du secteur spatial susvisés de coordonner leurs actions,

NOTANT qu'à l'occasion de la célébration du vingt-cinquième anniversaire de la Conférence spatiale européenne de 1973, qui a eu lieu le 23 juin 1998, les ministres des Etats membres de l'ASE responsables des activités spatiales ont souligné l'importance que revêt le renforcement de la synergie entre l'ASE et la Communauté européenne,

1. CONVIENT de la nécessité de renforcer encore la synergie et d'accroître la complémentarité entre la Communauté européenne et l'ASE dans le respect de leurs compétences respectives afin d'améliorer l'efficacité des investissements publics dans les technologies et systèmes spatiaux au bénéfice des utilisateurs, de l'industrie et des politiques européennes en la matière ;

2. SOULIGNE que l'objectif ci-dessus sera activement poursuivi, notamment dans le domaine des applications bénéficiant des technologies et systèmes spatiaux pour lesquelles la Commission a établi ou se propose d'établir un plan d'action, à savoir les télécommunications, la navigation et l'observation de la Terre ;

3. CONVIENT, dans ces domaines, de prendre en compte, dans toute la mesure du possible, les intérêts des Etats qui sont membres de la Communauté européenne sans être membres de l'ASE, d'inviter la Communauté européenne à faire de même vis-à-vis des Etats qui sont membres de l'ASE sans être membres de la Communauté européenne et de mettre tout en œuvre pour que lesdits Etats ne soient pas désavantagés par rapport à ceux qui sont membres des deux organisations ;

CONVINCED OF the need to provide Europe with a common vision and framework of reference on the basis of which the different actors involved in the space sector referred to above will be able to coordinate their actions,

NOTING that at the occasion of the celebration of the twenty fifth anniversary of the 1973 European Space Conference held on 23 June 1998, Ministers of ESA Member States responsible for space activities have stressed the importance of reinforcing the synergy between ESA and the European Community,

1. AGREES on the need to further strengthen the synergy and increase the complementarity between the European Community and ESA, in respect of their respective competences, so as to enhance the efficiency of government investments in space systems and technologies for the benefit of the users, industry and related European policies.

2. STRESSES that the above objective will be pursued actively, in particular in the fields of applications benefiting from space technologies and systems where the Commission has produced, or intends to produce, an action plan, i.e. telecommunications, navigation and Earth observation.

3. AGREES to take into account in these areas to the maximum extent possible the interests of the States which are Members of the European Community but not Members of ESA and to invite the European Community to take reciprocal account of the interests of the States which are Members of ESA but not Members of the European Community and to make every effort to ensure that such States are not disadvantaged as compared to States which are Members of both organisations.

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4. INVITE le Directeur général à associer la Commission aux applications spatiales précitées, à la définition et à la mise en œuvre des programmes et activités de l'ASE et aux discussions avec les autres acteurs du secteur spatial afin de tirer le meilleur part des activités conduites par l'ASE et la Communauté en soutien des objectifs de tous les Etats membres dans le domaine spatial.

5. ENCOURAGE le Directeur général à engager la mise en œuvre de mesures pratiques visant à promouvoir la synergie entre les activités de l'ASE et de la Communauté européenne en évitant les doublons inutiles et en mettant l'accent sur les domaines spécifiques d'applications précités et INVITE le Directeur général à prendre des initiatives appropriées afin d'obtenir les décisions nécessaires du Conseil.

4. CALLS ON the Director General to involve the Commission in the space applications referred to above, in the definition and implementation of the ESA programmes and activities and in the dialogue with the other actors in the space sector, so as to maximise the benefits of ESA and Community activities in support of the objectives of all Member States in the space fields.

5 ENCOURAGES the Director General to start implementing practical measures to promote synergy between the activities of the ESA and the European Community while avoiding unnecessary duplication, focusing on the specific fields of applications referred to above and CALLS ON the Director General to take appropriate initiatives with a view to obtaining necessary decisions from the Council.

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agence spatiale européenne

RÉSOLUTION
SUR LES MODIFICATIONS A APPORTER AU RÈGLEMENT FINANCIER EN VUE DE CONSTITUER UN FONDS D'ACCOMPAGNEMENT

(adoptée le 24 juin 1998)

Le Conseil,

CONSTATANT que le système financier en vigueur à l'Agence peut induire une certaine sous-consommation budgétaire d'ordre structurel,

DÉSIREUX d'apporter les correctifs qui s'imposent pour limiter au maximum ce phénomène,

VU la proposition du Directeur Général relative à la constitution d'un fonds d'accompagnement (ESA/C(98)65, rév. 1).

APPRÉCIANT les efforts déployés par le Directeur Général pour améliorer la gestion financière de l'Agence au bénéfice des États Membres,

VU la possibilité d'améliorer la planification des contributions qui résulterait de la constitution d'un fonds d'accompagnement destiné à la mise en place d'une gestion centralisée des risques budgétaires, respectant l'indépendance de chacun des programmes facultatifs,

RESOLUTION

ON MODIFICATIONS TO THE FINANCIAL REGULATIONS REQUIRED FOR THE PURPOSES OF SETTING UP AN ACCOMPANIMENT FUND

(adopted on 24 June 1998)

Council,

NOTING the propensity of the financial system currently operative at the Agency to induce a certain structural underspending of budgets,

WISHING to take the corrective action necessary to limit that phenomenon as far as possible,

HAVING REGARD to the Director General's proposal to set up an accompaniment fund (ESA/C(98)65, rev. 1),

APPRECIATING the efforts being made by the Director General to improve the Agency's financial management for the benefit of its Member States,

HAVING REGARD to the potential for improved planning of contributions that would be created by an accompaniment fund serving to introduce centralised management of budget risks, respecting the independence of each of the optional programmes,

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VU la recommandation formulée par le Comité administratif et financier lors de sa réunion des 28 et 29 mai 1998,

VU l'Article XI.5.f et l'Annexe II à la Convention,

1. DÉCIDE de constituer, conformément à la proposition du Directeur général précitée, un fonds d'accompagnement qui respecte pleinement les règles régissant les programmes facultatifs et en particulier leur autonomie juridique et budgétaire, garantissant ainsi la neutralité du fonds vis-à-vis du coût à achèvement de chacun des programmes facultatifs,

2. APPROUVE les modifications correspondantes du Règlement Financier présentées en Annexe à la présente Résolution.

3. DÉCIDE que les crédits inscrits au titre des disponibilités produites par la gestion centralisée des risques sous le Grand-titre 9 des programmes facultatifs des budgets 1999 et 2000 ne pourront faire l'objet d'un déblocage avant la fin de l'exercice budgétaire 2000, les crédits bloqués sous le Grand-titre 9 des programmes en 1999 étant automatiquement reportés sur l'exercice 2000.

4. LIMITE à deux ans la possibilité offerte par le système actuel de consentir une avance à titre temporaire et DÉCIDE que les procédures feront l'objet d'un réexamen approfondi à la fin d'une période de deux ans.

5. FIXE au premier janvier 1999 la date d'entrée en vigueur du fonds d'accompagnement.

6. CHARGE le Directeur général d'élaborer pour la prochaine session du Conseil au niveau ministériel une proposition visant à assurer une meilleure adéquation entre les demandes de budgets de l'ASE et les besoins des programmes.

HAVING REGARD to the recommendation made by the Administrative and Finance Committee at its meeting of 28 and 29 May 1998,

HAVING REGARD to Article XI.5.f of the Convention and Annex II thereto,

1. DECIDES to set up an accompaniment fund in accordance with the Director General's above-mentioned proposal, fully respecting the rules governing the optional programmes and in particular their legal and budgetary autonomy, thus warranting the neutrality of the fund as far as the cost at completion of each optional programme are concerned.

2. APPROVES the corresponding modifications to the Financial Regulations as set out in the Annex to this Resolution.

3. DECIDES that the payment appropriations representing amounts made available by centralised risk management under General Heading 9 in the 1999 and 2000 budgets for optional programmes may not be unblocked before the end of the financial year 2000, those blocked under General Heading 9 in the 1999 budgets being carried forward automatically to the 2000 budgets.

4. LIMITS to two years the possibility of a temporary advance which is offered by the present system and DECIDES that at the end of a two-year period a complete review of the procedures will be organized.

5. DECIDES that the accompaniment fund shall become operative on 1 January 1999.

6. REQUESTS the Director general to prepare for the next meeting of Council at ministerial level a proposal aiming at better matching the budget requests of ESA to the needs of the programmes.

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Article 37

Fonds d'accompagnement

37/1 Un fonds d'accompagnement mettant en œuvre une gestion centralisée des risques budgétaires pour les programmes facultatifs et n'ayant aucune incidence sur leur coût à achèvement est inscrit au budget de chaque exercice financier, comme suit :

37/1.1 Le fonds d'accompagnement comporte une fraction des crédits de paiement qui sont déduits des budgets des programmes facultatifs du fait de l'incertitude de leur utilisation au cours de l'exercice. Cette fraction est calculée en déterminant un pourcentage correspondant à la probabilité d'utilisation.

37/1.2 Les recettes de ce fonds d'accompagnement sont constituées par les prélèvements effectués sur les budgets des programmes contributeurs et font l'objet d'un suivi comptable par État participant et par programme.

37/2 Le fonds d'accompagnement est approuvé par le Conseil après recommandation par l'AFC.

37/3 Les crédits de ce fonds sont bloqués. Les contributions sont appelées conformément à l'Article 25/1 et les fonds sont gérés dans une trésorerie distincte.

37/4 Dans le cas où des crédits additionnels et la trésorerie correspondante sont nécessaires à la poursuite d'un programme au cours de l'exercice, l'AFC peut, sur proposition du Directeur général, décider le déblocage de crédits du fonds d'accompagnement et recommander leur transfert au budget du programme ainsi que le transfert des fonds correspondants de la trésorerie distincte à la trésorerie générale. Ce transfert est alors soumis à l'approbation du Conseil ou du Conseil directeur de programme compétent.

Les crédits additionnels transférés au budget du programme concerné ne dépasseront pas le montant de la réduction initiale de ce budget.

37/5 Les intérêts reçus seront crédités au fonds d'accompagnement par État participant et par programme.

Article 37

Accompaniment Fund

37/1 An accompaniment fund, implementing a central management of budget risks for optional programmes, and being neutral regarding their costs at completion, shall be established for each financial year as follows:

37/1.1 The accompaniment fund shall comprise a proportion of the payment appropriations by which optional programme budgets have been reduced to take account of the uncertainty of take-up within the financial year; this proportion shall be calculated by applying a percentage corresponding to the probable level of take-up.

37/1.2 The income of this accompaniment fund shall consist of amounts levied from the budgets of the contributing programmes and the accounts recording it shall be monitored by Participating State and by programme.

37/2 The accompaniment fund shall be approved by Council after recommendation by the AFC.

37/3 The appropriations in the fund shall be blocked. Contributions shall be called up in accordance with Article 25/1 and funds shall be managed in a separate treasury.

37/4 If additional appropriations and the related treasury are necessary for continuation of a programme during the financial year the AFC may, on a proposal from the Director General, decide the unblocking of appropriations from the accompaniment fund and recommend its transfer to the programme budget and the related funds from the separate treasury to the general treasury. On this basis, Council or the relevant Programme Board shall approve this transfer.

The additional appropriations transferred to the programme budget concerned shall not exceed the amount by which that budget was initially reduced.

37/5 Interest received shall be credited to the accompaniment fund per participating State per programme.

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37/6 Les crédits non utilisés à la fin de l'exercice sont annulés. En ce qui concerne le solde, chaque État décidera à titre individuel de l'utilisation qui sera faite de sa part.

37/7 L'Exécutif suit la situation du fonds d'accompagnement afin de garantir le bon déroulement et la neutralité du système et remet à l'AFC un rapport de situation de fin d'année qui montre la situation de chaque État par programme, c'est-à-dire les contributions versées au fonds diminuées des contributions calculées sur la base des barèmes utilisés pour les crédits de paiement additionnels qui sont transférés du fonds d'accompagnement aux budgets. Ce rapport est approuvé par l'AFC dans le cadre de l'exercice de report. Au terme d'une période de deux ans, l'AFC procédera au réexamen approfondi des résultats du système et remettra au Conseil, pour décision, ses conclusions et recommandations quant à la poursuite du système.

37/8 A la fin d'un programme facultatif, le total des montants versés au fonds d'accompagnement sera égal au total des montants prélevés sur ce fonds.

37/6 Appropriations not used by the end of the financial year shall be cancelled. As far as the balance is concerned, each State will decide on an individual basis on the use of its share.

37/7 The Executive shall monitor the accompaniment fund in order to guarantee the proper execution and the neutrality of the system and provide the AFC with an end-of-year status report showing the situation of each individual State per programme, i. e. contributions paid into the fund less contributions for additional payment appropriations transferred from the accompaniment fund to budgets calculated according to the relevant scales. This report shall be approved by the AFC in the framework of the carry-forward exercise. After a two-year period of activity, the AFC will review in depth the results of the system and will give to Council, for decision, its conclusions and recommendations in view of the continuation of the system.

37/8 At the end of an optional programme, the sum of the inputs made to the accompaniment fund will be equal to the sum of its outputs.

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agence spatiale européenne

RÉSOLUTION

SUR LES MESURES À PRENDRE DANS L'IMMÉDIAT ET SUR LES PRÉPARATIFS À METTRE EN ŒUVRE EN VUE DE LA SESSION DU CONSEIL AU NIVEAU MINISTÉRIEL RELATIVE AUX NOUVEAUX PROGRAMMES ET À L'ÉVOLUTION DE L'AGENCE

(adoptée le 24 juin 1998)

Le Conseil,

CONVAINCU que la préservation de la dynamique nécessaire à la réussite de la prochaine session du Conseil au niveau ministériel appelle des mesures immédiates consistant à adapter l'ASE aux défis du futur et à lancer des programmes axés sur le marché et les utilisateurs,

DÉTERMINÉ à appuyer pleinement l'action menée par le Directeur général pour accroître l'efficacité de l'Agence,

VU la Résolution sur le renforcement de la synergie entre l'Agence spatiale européenne et la Communauté européenne (ESA/C/CXXXVI/Rés. 1(Final)), adoptée le 23 juin 1998,

RESOLUTION ON IMMEDIATE MEASURES AND PREPARATORY STEPS TOWARDS THE COUNCIL MEETING AT MINISTERIAL LEVEL RELATED TO THE AGENCY'S NEW PROGRAMMES AND ITS EVOLUTION

(adopted on 24 June 1998)

The Council,

CONVINCED that in order to maintain the momentum necessary for the success of the next Council meeting at ministerial level, steps should be taken immediately in adapting ESA to the future challenges and in initiating market and user driven programmes,

DETERMINED to provide the Director General with full support in his efforts to increase the efficiency of the Agency,

HAVING REGARD to the Resolution on the reinforcement of the synergy between the European Space Agency and the European Community (ESA/C/CXXXVI/Res. 1(Final)) adopted on 23 June 1998,

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Chapitre premier

Vers l'établissement d'une politique spatiale européenne d'ensemble

1. APPUIE le Directeur général dans les consultations qu'il mène auprès de la Communauté européenne, des autorités spatiales nationales des Etats membres, des utilisateurs, des opérateurs et de l'industrie en vue de proposer au Conseil, lors de sa session au niveau ministériel, une politique spatiale européenne coordonnée et la stratégie correspondante, fondées sur la Convention de l'ASE, de nature à garantir des perspectives intéressantes à l'ensemble des Etats membres, à répondre aux besoins des utilisateurs et à mettre en place un programme de technologie bien harmonisé.

2. APPUIE le Directeur général dans sa volonté de sensibiliser davantage le public aux bienfaits des activités spatiales et d'attirer les jeunes vers ce type d'activité.

Chapitre II

Evolution de l'Agence spatiale européenne

1. APPUIE le Directeur général dans son action visant à adapter les méthodes, les procédures et la structure internes de l'Agence aux nouveaux défis ; INVITE le Directeur général à analyser de façon plus approfondie et à proposer, en tant que de besoin, des solutions de nature à améliorer les procédures budgétaires et l'efficacité des processus décisionnels ainsi que les modifications à apporter en conséquence à la structure interne de l'Agence.

2. CHARGE le Directeur général de continuer à améliorer l'efficacité interne de l'Agence en réalisant pendant la période 1999-2001 des économies supplémentaires d'un montant total actuellement fixé à 56 MECU (c.e. mi-1998) sur le budget général (activités de base) et les programmes

Chapter I

Towards the establishment of an overall European Space Policy

1. SUPPORTS the Director General in his action of consulting the European Community, the national space authorities of Member States, users, operators and industry with a view to propose to the Council at Ministerial Level, a coordinated European space policy and corresponding strategy, based on the ESA Convention, for ensuring attractive opportunities for all Member States, for responding to user needs and for building up a well harmonised technology programme.

2. SUPPORTS the Director General in his willingness to increase the public awareness of space benefits and attract the young generation towards space activities.

Chapter II

Evolution of the European Space Agency

1. SUPPORTS the Director General in his action to adapt the Agency's internal methods, procedures and structure to the new challenges; INVITES the Director General to further analyse and propose, if and where necessary, means for improving the budgetary procedures and the efficiency of decision making processes, as well as consequential changes to the internal structure of the Agency.

2. INSTRUCTS the Director General to further improve the internal efficiency of the Agency by achieving additional savings of an aggregate amount of currently 56 MECU (mid-1998 e.c.), for the period 1999-2001, in General Budget (basic activities) and optional programmes through a decrease in internal costs without affecting essential activities,

facultatifs, par une réduction des coûts internes sans affecter les activités essentielles.

3. INVITE le Directeur général à continuer d'élaborer et à proposer d'ici la session du Conseil d'octobre un petit nombre d'indicateurs de performance de haut niveau associés chacun à des objectifs de façon à assurer au Conseil la transparence des progrès accomplis en matière d'efficacité.

4. INSISTE pour que le Directeur général propose d'ici fin 1998 des mesures propres à maintenir le coût à achèvement des nouveaux programmes facultatifs dans la limite des 100 % de l'enveloppe visée dans les Déclarations respectives, tout en étant conscient du fait que les modifications du contenu technique d'un programme ou les retards ou modifications enregistrés par un partenaire international dans sa part d'un programme mené en coopération peuvent appeler des mesures visant à adapter le contenu technique du programme ou son enveloppe et ses contributions financières.

Chapitre III
Utilisation efficace des ressources publiques en Europe

SOULIGNE l'importance d'utiliser efficacement les ressources publiques investies dans les activités spatiales en Europe ; SE FÉLICITE des mesures déjà prises à cet égard par le Directeur général ; INVITE ce dernier à soumettre au Conseil, en consultant comme il se doit l'ensemble des parties concernées, des propositions :

- visant à améliorer l'utilisation des installations et ressources publiques existant en Europe, conformément aux principes figurant à l'Article VI de la Convention, en élaborant des directives applicables à l'utilisation des installations et ressources de l'ASE pour les programmes nationaux et des installations et ressources nationales pour les programmes de l'ASE ;

3. INVITES the Director General to further develop and propose by the October Council a small number of high-level performance indicators and targets for each indicator in order to make efficiency improvements transparent to Council.

4. INSISTS that measures are proposed by the Director General by the end of 1998 with a view of keeping the cost at completion of the new optional programmes within the 100% of the envelope referred to in the respective Declarations, conscious of the fact that modifications proposed in the technical content of the programme, as well as delays, and/or modifications incurred by an international partner in his portion of a cooperative programme may call for measures to adapt the technical content of the programme or the financial envelope and financial contributions.

Chapter III

Efficient use of public resources in Europe

UNDERLINES the importance of an efficient use of public resources for space activities in Europe; WELCOMES the steps already taken by the Director General in this respect; INVITES him in due consultation with all parties involved to make proposals to the Council for:

- a better use of existing public facilities and resources in Europe, in line with the policies defined in Article VI of the Convention, by elaborating guidelines for the use of ESA facilities and resources for national programmes and of national facilities and resources for ESA programmes;

- enhancing the overall competencies in Europe by defining the conditions for increasing the mobility of staff of national Centres, ESA and other entities.

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- visant à accroître les compétences d'ensemble de l'Europe en définissant les conditions propres à accroître la mobilité du personnel des centres nationaux, de l'ASE et d'autres entités.

Chapitre IV

Programmes de l'ASE

1. Lanceurs

SE FÉLICITE de la souscription et de l'entrée en vigueur ce jour :

- de la Déclaration additionnelle relative au programme Ariane 5 Plus (ESA/PB-ARIANE/CLXXI/Déc.1 (Final)) (Etape 1), prévoyant une sous-enveloppe financière ferme de 135 MECU aux conditions économiques de 1997. Le barème de contributions ci-après rend compte des souscriptions reçues ce jour :

Etat participant	Programme Ariane-5 Plus Etape 1 %
Belgique	5,0
France	45,0
Allemagne	24,5 **
Italie	[3,0] *
Pays-Bas	4,0
Espagne	[3,0] *
Suède	3,0
TOTAL	81,5

** Ce montant représente une contribution ferme de 33,1 MECU aux c.e. de 1997
* Montant à confirmer dans un délai de 1 mois, à l'issue de procédures internes

Chapter IV

Programmes of ESA

1. **Launchers**

WELCOMES the subscription and the entry into force on this day of the:

- Additional Declaration on the first step of the Ariane 5 Plus programme (ESA/PB-ARIANE/CLXXI/Dec.1(Final)), with a firm financial sub-envelope of 135 MECU at 1997 economic conditions; the following table of contributions records the subscriptions received today:

Participating State	Ariane-5 Plus Programme Step 1 %
Belgium	5.0
France	45.0
Germany	24.5 **
Italy	[3.0] *
Netherlands	4.0
Spain	[3.0] *
Sweden	3.0
TOTAL	81.5

* Subject to confirmation following internal procedures, within a period of one month

** This amount reflects a fixed contribution of 33.1 MECUs at 1997 economic conditions

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- de la Déclaration relative au programme de développement d'un petit lanceur (ESA/PB-ARIANE/CLXXI/Déc. 2 (Final)) (Etape 1), prévoyant une sous-enveloppe financière ferme de 60 MECU aux conditions économiques de 1997. Le barème de contributions ci-après rend compte des souscriptions reçues ce jour :

Etat participant	Programme de développement d'un petit lanceur (Etape 1) %
Belgique	5,0
France	8,3
Italie	55,0
Pays-Bas	[2,0] *
Espagne	[2,0] *
TOTAL	68,3

* Montant à confirmer dans un délai de 1 mois, à l'issue de procédures internes

- Declaration on the first step of a Small Launcher Development programme (ESA/PB-ARIANE/CLXXI/Dec.2 (Final)), with a firm financial sub-envelope of 60 MECU at 1997 economic conditions. The following table of contributions records the subscriptions received today:

Participating State	Small Launcher Development programme Step 1 %
Belgium	5.0
France	8.3
Italy	55.0
Netherlands	[2.0] *
Spain	[2.0] *
TOTAL	68.3

* Subject to confirmation following internal procedures, within a period of one month

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2. Observation de la Terre

SE FÉLICITE de la souscription et de l'entrée en vigueur ce jour de l'extension de programme arrêtée dans le cadre de la Déclaration relative à l'EOPP (ESA/PB-RS/XXXVI/Déc. 1, rév. 11 (Final)), qui prévoit une enveloppe financière de 30 MECU aux conditions économiques de 1997 pour les années 1999-2000 à titre de mesure transitoire visant à définir et lancer réellement le programme-enveloppe d'observation de la Terre. Le barème de contributions ci-après rend compte des souscriptions reçues ce jour :

Etat participant	Extension 1999-2000 %
Danemark	1,0
Finlande	1,1
France	12,5
Allemagne	20,0
Italie	12,7
Pays-Bas	3,8
Norvège	1,0
Suède	2,7
Suisse	4,0
Royaume-Uni	[20,0] *
Canada	[1,7] *
TOTAL	58,8

* Montant à confirmer dans un délai de 1 mois, à l'issue de procédures internes

2. **Earth Observation**

WELCOMES the subscription and the entry into force on this day of the programme extension within the EOPP Declaration (ESA/PB-RS/XXXVI/Dec.1, Rev. 11 (final)) covering 1999 and 2000 with a financial envelope of 30 MECU at 1997 economic conditions as a transitional measure for the definition and proper start-up of the Earth Observation Envelope Programme. The following table of contributions records the subscriptions received today:

Participating State	Extension 1999-2000 %
Denmark	1.0
Finland	1.1
France	12.5
Germany	20.0
Italy	12.7
Netherlands	3.8
Norway	1.0
Sweden	2.7
Switzerland	4.0
United Kingdom	[20.0] *
Canada	[1.7] *
TOTAL	58.8

* Subject to confirmation following internal procedures, within a period of one month

3. Navigation

SE FÉLICITE de l'approbation par les Etats participant au programme ARTES-9 des Appendices A9 et B9 révisés figurant dans le document ESA/JCB(98)26, rév. 1, ainsi que de la souscription et de l'entrée en vigueur ce jour d'une sous-enveloppe financière additionnelle visant à financer les activités de l'étape 1 du GNSS-2 afin de renforcer les activités préparatoires conduisant au choix de la meilleure option possible pour une contribution européenne au GNSS conformément au calendrier défini dans le cadre de la politique correspondante de l'Union européenne. Le barème de contributions ci-après rend compte des souscriptions reçues ce jour :

Etat participant	GNSS-2 (Etape 1) MECU
Autriche	0,2
France	6,0
Allemagne	9,5
Italie	7,1
Pays-Bas	0,2
Norvège	0,2
Espagne	3,0
Suède	1,5
Suisse	1,5
Royaume-Uni	[7,5] *
Canada	0,2
TOTAL	29,4

* Montant à confirmer dans un délai de 1 mois, à l'issue de procédures internes

3. **Navigation**

WELCOMES the approval by States participating in the ARTES 9 programme of the revised Appendices A9 and B9 contained in document ESA/JCB(98)26, rev.1, as well as the subscription and entry into force on this day of an additional financial sub-envelope to fund activities of Step 1 of GNSS-2 in order to reinforce the preparatory activities leading to the choice of the best option for a European contribution to GNSS in accordance with the calendar defined in the relevant European Union policy. The following table of contributions records the subscriptions received today:

Participating State	GNSS-2 Step 1 MECU
Austria	0.2
France	6.0
Germany	9.5
Italy	7.1
Netherlands	0.2
Norway	0.2
Spain	3.0
Sweden	1.5
Switzerland	1.5
United Kingdom	[7.5] *
Canada	0.2
TOTAL	29.4

* Subject to confirmation following internal procedures, within a period of one month

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4. SOULIGNE l'importance de respecter les équilibres appropriés entre l'ensemble des activités de l'ASE, à savoir l'équilibre entre science, applications et infrastructures, l'équilibre entre développement, utilisation et technologie et l'équilibre entre les intérêts de chacun des Etats membres, et SOULIGNE l'importance du programme scientifique et du programme de technologie de base en tant qu'activités fondamentales de l'ASE.

5. SOULIGNE combien il est important pour les programmes futurs d'apporter une réponse adéquate aux besoins des utilisateurs, d'offrir à chacun des Etats membres des avantages suffisamment intéressants au niveau des programmes de l'ASE, de faire le meilleur usage possible des ressources tant publiques que privées disponibles en Europe pour les investissements dans le secteur spatial et de tirer parti des systèmes de cofinancement prévoyant le partage des risques et des bénéfices entre partenaires en contrepartie d'un élargissement des débouchés commerciaux.

6. SOULIGNE l'importance du rôle de l'industrie dans le domaine des applications spatiales et INVITE le Directeur général à préciser clairement, dans chacune des propositions de programme, le degré de participation de l'industrie et la forme que cette participation prendra (partenariat ou cofinancement, par exemple).

4. UNDERLINES the importance of the appropriate balances among the overall activities of ESA, namely the balance between science, applications and infrastructure activities, the balance between development, utilisation and technology activities and the balance between the interests of each Member State, and STRESSES the importance of the scientific and basic technology programmes as the foundation of ESA.

5. UNDERLINES the importance for future programmes to provide an adequate response to user needs, to ensure sufficiently attractive benefit to each Member State in ESA programmes, to make best possible use of public and private resources available in Europe for space investment and to take benefit from co-funding schemes sharing risks and benefits among partners in return for increased market opportunities.

6. UNDERLINES the importance of the role of industry in the field of space applications and INVITES the Director General to clearly identify in each programme proposal the participation of industry and the way in which this is achieved e.g. through partnership, co-funding or other.

Chapter V

Mandate of the Council Working Group for the preparation of the Council at Ministerial level

INVITES the Council Working group, within its mandate for preparing the Council at Ministerial Level (ESA/C/CXXXII/Res.1 adopted on 21 October 1997), to focus its analysis on the following areas:

1. the better use of public resources for space activities in Europe;
2. the definition and implementation of a co-ordinated European space strategy;
3. the improvement of the decision making process;

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Chapitre V

Mandat du Groupe de travail du Conseil chargé de préparer la session du Conseil au niveau ministériel

INVITE le Groupe de travail du Conseil, dans le cadre du mandat qui lui a été confié pour préparer la session du Conseil au niveau ministériel (Résolution ESA/C/CXXXII/Rés. 1, adoptée le 21 octobre 1997), à centrer son analyse sur les points suivants :

1. utilisation plus efficace des ressources publiques investies dans les activités spatiales en Europe ;
2. définition et mise en œuvre d'une stratégie spatiale européenne coordonnée ;
3. amélioration du processus décisionnel ;
4. état d'avancement de la mise en œuvre de la Résolution sur la politique industrielle de l'Agence, adoptée le 4 mars 1997, et évolution ultérieure;
5. décisions de programmes et autres thèmes se rapportant à la session du Conseil au niveau ministériel.

4. the progress achieved in the implementation of the Resolution on the European Space Agency's industrial policy adopted on 4 March 1997 and its further development;
5. programme decisions and other topics related to the Council meeting at Ministerial Level.

25th Anniversary Dinner

Mr Yvan Ylieff, Belgian Minister for Science Policy and host for the 136th Meeting, invited the Council Delegates and other participants to a celebratory Dinner on the evening of 23 June in the 'Centre Belge de la Bande Dessinée' in Brussels

Mr Yvan Ylieff addressing his assembled dinner guests

The Post-Council Press Conference

Following the highly successful outcome of the 136th Council, Mr Yvan Ylieff (centre), the Belgian Minister for Science Policy, Mr Hugo Parr (right), Chairman of the ESA Council, and Mr Antonio Rodotà (left), ESA's Director General, held a Press Conference at the Hotel Metropole, which was attended by more than 40 representatives of the international press, television and other media

RENDEZVOUS WITH THE NEW MILLENNIUM

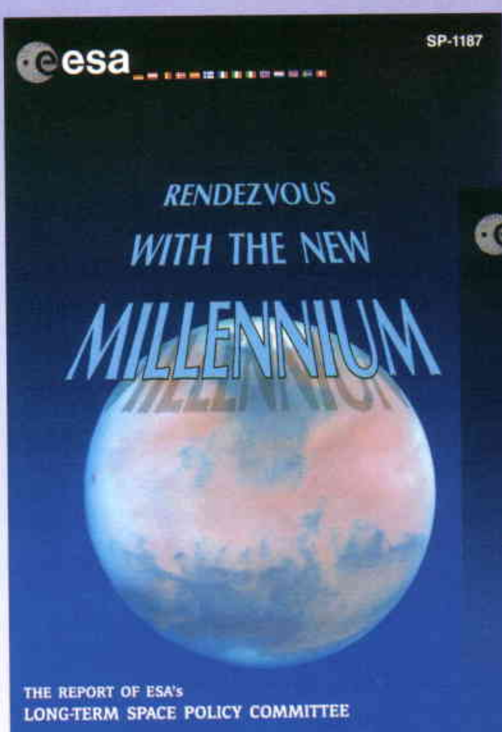
The Report of ESA's Long-Term Space Policy Committee

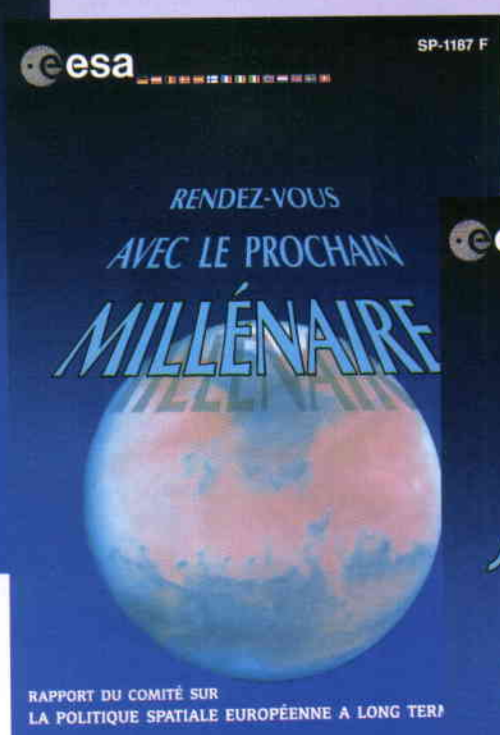
With 30 years of space activities behind us, we can now look forward to the next millennium on far more solid ground than the early pioneers ... At present, most space activities go from study phase to launch in about 10 years. The near-future is therefore already accounted for, and the major options for the next 20 years are also known. But what about the decades beyond that, and how will the world change over the next 50 years?

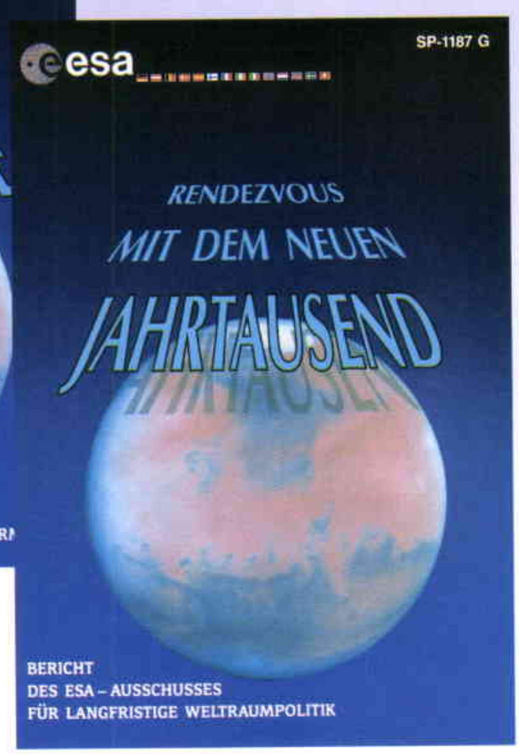
To identify a strategic vision for European space activities in the next century — one that will respond both to the challenges and threats facing humanity in the future — the ESA Council created a Long-Term Space Policy Committee (LSPC) in June 1993. The Commitee's task was to prepare a report on European space policy after the year 2000.

The LSPC chose to take a 50-year perspective in order to go beyond the mere extrapolation of current trends while still keeping in mind the present technological and financial constraints. The Committee analysed in depth the themes that it deemed to be of importance and collected the thoughts of recognised experts in relevant domains.

Its work has culminated in this report, *Rendezvous with the New Millennium*, which was presented to the ESA Council Meeting at Ministerial Level in Toulouse. The Ministers welcomed and endorsed the report: they expressed their satisfaction with the perspectives taken and have invited the Committee to continue to reflect on the long-term space policy for Europe.







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The Single European Astronaut Corps

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The International Space Station will be used as a multi-disciplinary research institute in space for fundamental and applied science, as a test-bed for new technologies, a platform for the observation of the Earth and the Universe, and as a stepping stone to further exploration and exploitation of space by mankind. The permanent presence of a crew on board will be one of its most important features. The first crew members will be aboard shortly after the arrival of the Russian Service Module, which means approximately eight months after the first Station element is put into orbit.

The roles of the Station astronauts will cover system operations as well as utilisation activities. In the system operations domain, the astronauts will work, under the authority of the Station Commander, with specific responsibilities not only for the systems provided by the space agency by which they are employed, but also for other systems across the whole Station. In the context of the utilisation activities, they will conduct scientific and applications-oriented experiments on board, with the active involvement of the experimenters concerned on Earth, as far as the specific nature of each experiment allows.

The need for astronauts

Whereas robotic and telescience activities in space are considered by most people as highly justified, the rationale for sending astronauts into space is often put into question by the media and public opinion. However, sending men and women to work on a space station — be it the current Russian station Mir or the imminent International Space Station — is not an end in itself, but a response to clear and objective considerations.

Mankind owes the unique place that it occupies among the living species on Earth to two essential types of 'built-in tools': the human brain and the human hand. It is this combination of high cognitive and manipulative skills that has enabled man to continuously improve his own living conditions and adapt himself to external changes in the natural, social and economic environment. No robot offers a similar combination of high intelligence, adaptability, mobility, dexterity and tactile skills. These capabilities are of particular value when it comes to activities which have never been done before and for which no standard reaction pattern can be conceived in advance.

The car industry and chemical plants are good examples of areas where robotic systems can perform well-defined routine tasks to support man in his day-to-day work, or even take over certain dangerous or monotonous activities. Less visible are the considerable efforts expended by human workers on the preparation, maintenance and repair of these robots. Moreover, robotic systems soon reach their inherent limitations when it comes to evaluating results and deciding what to do next, particularly when confronted with new or non-nominal situations.

An essential aspect of ground-based scientific research is the ability to modify experiment procedures, and even to reorient the line of research, as a function of the results achieved in earlier steps. This is all the more true for space-based research tasks. The presence of a crew onboard a space station allows us to cope with unexpected hardware failures, to change the technical configurations and operational parameters of experiments, to carry out manipulations that cannot be programmed in advance, to react directly to intermediate experimental results, and to cope intelligently with any unforeseen or unforeseeable behaviour, be it of the experiments or of the subsystems of the space station itself. That is why complex space systems, like the US Space Shuttle, the European Spacelab, the Russian space station Mir, and even the Hubble Space Telescope, would be unthinkable without at least the temporary presence of astronauts. In addition, the astronauts themselves, who are regularly exchanged on a space station, offer a ready supply of test subjects for studying human physiology in space.

European astronauts for the International Space Station

Europe is one of the five International Partners in the cooperative International Space Station Programme. According to the objectives of international cooperation and the rules set forth in the Intergovernmental Agreement (IGA) and the NASA/ESA Memorandum of Understanding signed in Washington on 29 January 1998, ESA as the agency representing the European International Partner, has the right to provide personnel from the time it begins to share common system operations responsibilities. This means that ESA will provide one astronaut for a three-month stay on board the Station every 8 months (on average), after the launch of the Columbus Laboratory. An ESA astronaut will also participate in the in-orbit assembly and system verification of the Columbus Laboratory.

Figure 1. The first three ESA astronauts selected in 1977: from left to right: Ulf Merbold, Claude Nicollier and Wubbo Ockels

ESA is also negotiating with the other International Partners a number of additional flight opportunities for European astronauts before assembly of the whole Station is complete. The goal here is to increase ESA's operational experience in general, and to establish a solid Astronaut Corps at the level needed to meet the Agency's rights and obligations in terms of operations and utilisation. Consequently, the NASA/ESA Memorandum of Understanding Enabling Early Utilisation Opportunities of the International Space Station, signed on 18 March 1997, provides two Space Shuttle flight opportunities for ESA astronauts to be accommodated in the Station programme prior to the in-orbit assembly and verification of Columbus. A further step in the preparation of European astronauts for their future tasks will be ESA astronaut Pedro Duque's flight on the STS-95 Shuttle mission, scheduled for launch in October 1998.

In addition, the experience already gained by European astronauts is being made available to support the development of the various elements of the European participation in the International Space Station.

History and future of national and ESA astronauts

For historical reasons, there has not so far been a unified European approach to astronaut recruitment and employment. ESA had selected its first three astronauts (U. Merbold, C. Nicollier, W. Ockels) in 1977 with a view to their employment in the framework of Spacelab, as part of the US Space Shuttle programme. The ESA Astronaut Corps was later significantly enlarged in 1992 in preparation for the future missions related to the Columbus and Hermes programmes. When these programmes did not materialise, or at least not to the extent expected, not only was the size of the ESA Astronaut Corps frozen, but astronaut departures for personal reasons were not compensated by new recruitment.

In parallel with the ESA Astronaut Corps, three European countries – France, Germany and Italy – had each built up an astronaut corps of their own. In addition, astronauts from the United Kingdom, Austria and Belgium have also participated in manned space missions.

With no European manned space vehicles yet available, all of these ESA and national European astronauts have participated in missions on either American (Space Shuttle) or Soviet/Russian (Salyut and Mir) facilities (Table 1). With the coming of the International Space Station, the situation will change radically. On the one hand, Europe as a full partner in the International Space Station Programme will, with the Columbus Laboratory, be the owner of its own 'real estate' in space and will therefore have its own rights to participate in Station operations and utilisation, including astronaut activities. On the other hand, the planned ending of Spacelab and Mir operations leaves limited opportunities for additional mission arrangements for astronauts outside the framework of the International Space Station. It was for this reason that ESA, in December

Table 1. European astronauts in space

Name	Space Agency	Home Country	Mission Designation	Year
S. JÄHN		Germany	Soyuz-31	1978
J.-L. CHRETIEN	CNES	France	Salyut-7	1982
U. MERBOLD	ESA	Germany	STS-9/Spacelab-1	1983
P. BAUDRY	CNES	France	STS-18	1985
R. FURRER	DFVLR	Germany	STS-22/Spacelab D-1	1985
E. MESSERSCHMID	DFVLR	Germany	STS-22/Spacelab D-1	1985
W. OCKELS	ESA	Netherlands	STS-22/Spacelab D-1	1985
J.-L. CHRETIEN	CNES	France	Mir/Aragatz	1988
H. SHARMAN	Juno Consortium	United Kingdom	Mir/Juno	1991
F. VIEHBÖCK	ASA	Austria	Mir/Austromir	1991
U. MERBOLD	ESA	Germany	STS-42/Spacelab IML-1	1992
K. D. FLADE	DLR	Germany	Mir/Mir-92	1992
D. FRIMOUT	SPPS	Belgium	STS-45/ATLAS-1	1992
M. TOGNINI	CNES	France	Mir/Antares	1992
C. NICOLLIER	ESA	Switzerland	STS-46/TSS-1, Eureca-1	1992
F. MALERBA	ASI	Italy	STS-46/TSS-1, Eureca-1	1992
H. SCHLEGEL	DLR	Germany	STS-55/Spacelab D-2	1993
H. U. WALTER	DLR	Germany	STS-55/Spacelab D-2	1993
C. NICOLLIER	ESA	Switzerland	STS-55/Spacelab D-2	1993
J.-P. HAIGNERE	CNES	France	Mir/Altair	1993
C. NICOLLIER	ESA	Switzerland	STS-61/Hubble servicing	1993
U. MERBOLD	ESA	Germany	Mir/Euromir-94	1994
J.-F. CLERVOY	ESA	France	STS-66/Atlas-3	1994
T. REITER	ESA	Germany	Mir/Euromir-95	1995
U. GUIDONI	ASI	Italy	STS-75/TSS-1R	1996
M. CHELI	ESA	Italy	STS-75/TSS-1R	1996
C. NICOLLIER	ESA	Switzerland	STS-75/TSS-1R	1996
C. ANDRE-DESHAYS	CNES	France	Mir/Cassiopeia	1996
J.-J. FAVIER	CNES	France	STS-78/LMS-1	1996
R. EWALD	DLR	Germany	Mir/Mir-97	1997
J.-F. CLERVOY	ESA	France	STS-84 to Mir	1997
J.-L. CHRETIEN	CNES	France	STS-86 to Mir	1997
L. EYHARTS	CNES	France	Mir/Pegase	1998
Mission Assignments:				
M. TOGNINI	CNES	France	STS-93	1998
P. DUQUE	ESA	Spain	STS-95	1998
J.-P. HAIGNERE	CNES	France	Mir-99	1999
C. NICOLLIER	ESA	Switzerland	STS-104	2000

1997, launched an initiative to revisit the existing European astronaut policy and to adapt it to the requirements and constraints of the International Space Station era.

European mission opportunities and astronaut needs

The starting point for the elaboration of a new astronaut policy was the analysis of the expected missions for European astronauts. On the basis of the planned involvement of ESA astronauts in the International Space Station operations and utilisation scenario, and the existing bilateral arrangements between European national agencies and NASA or RKA for missions by national astronauts, the number of expected mission opportunities for European (from ESA Member State) astronauts has been evaluated (Fig. 2).

In the context of the International Space Station, more mission-specialist and onboard-engineer positions will become available. Especially during the assembly and initial utilisation phase, covering the period between end-1998 and end-2002 when only a limited number of utilisation flights appear in the launch manifest, system operations are expected to have priority over scientific missions, thus requiring a higher mission-specialist or onboard-engineer profile.

The basic duties for the European astronauts during this early period are to prepare for and to participate in space flights and to accompany the development programme for the European contribution to the International Space Station. This will lead to a deep involvement through collateral duties, providing familiarisation with

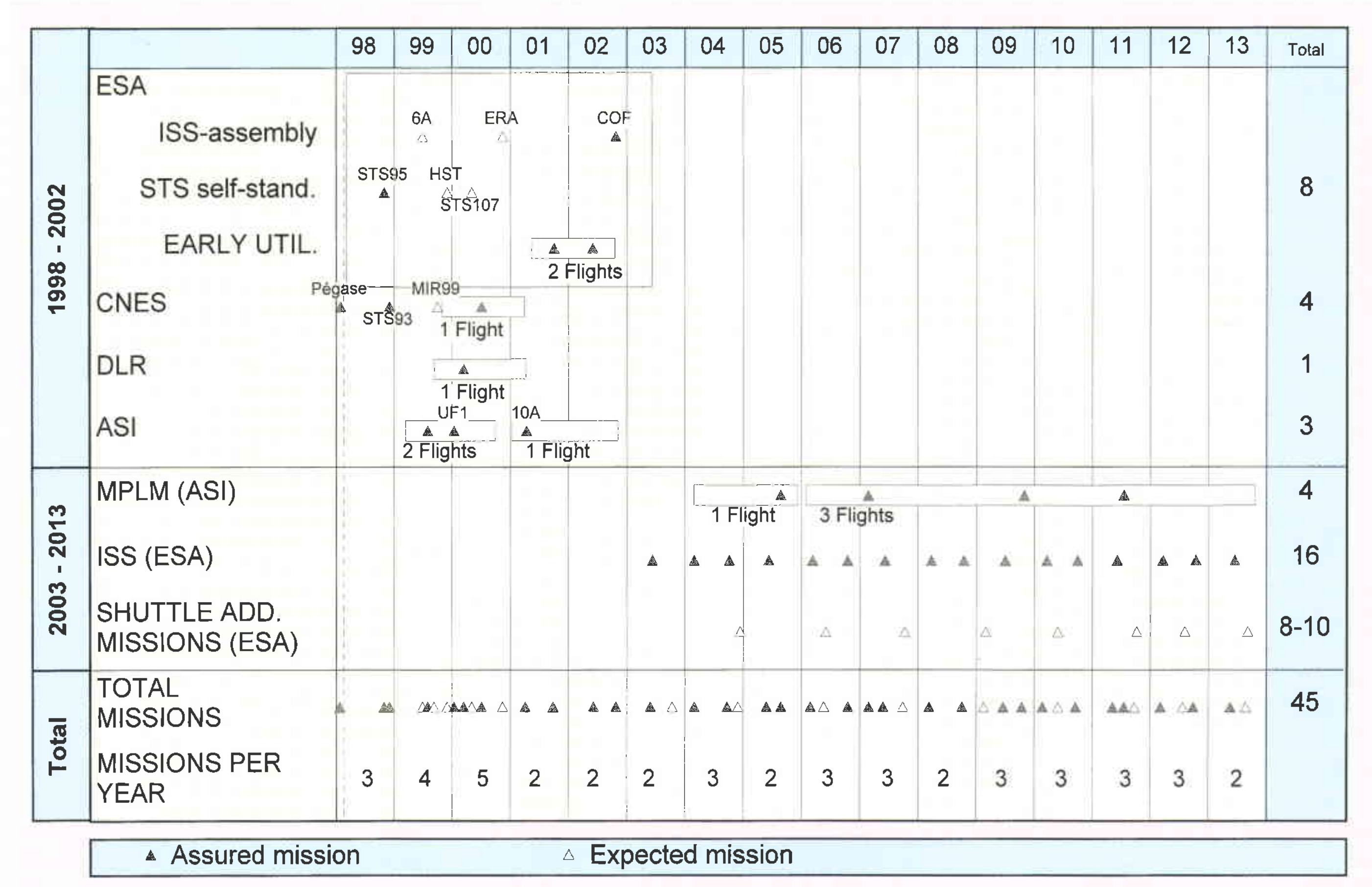
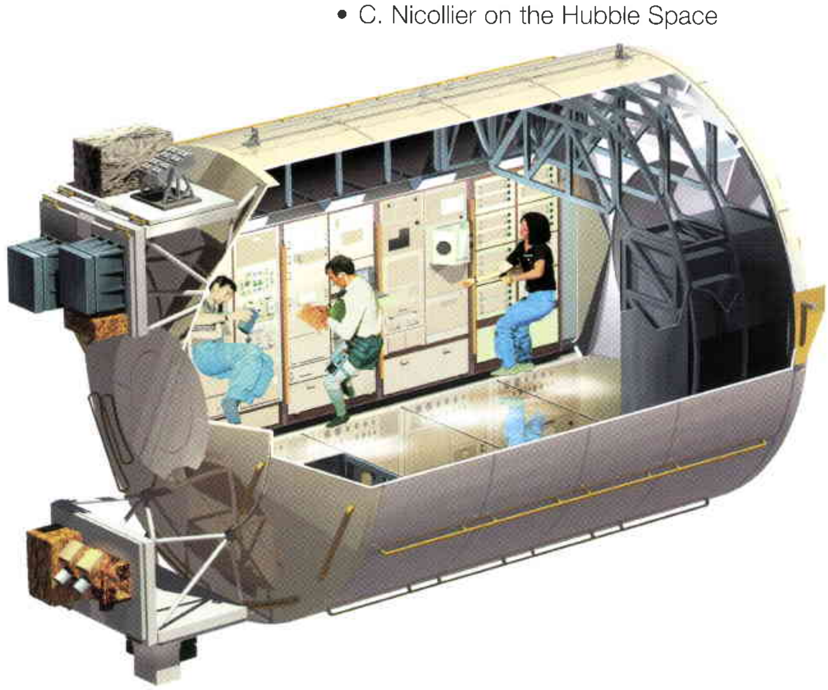


Figure 2. Summary of European mission opportunities

the programme on the one hand, and support to the engineering teams on the other.

The following potential European missions have therefore been identified for the period from mid-1998 until end-2002:

– 1998: 2 missions:
  - P. Duque on STS-95
  - M. Tognini on STS-93
– 1999: 3 missions:
  - J.-F. Clervoy on assembly flight 4-A
  - J.-P. Haigneré on Mir-99
  - C. Nicollier on the Hubble Space Telescope servicing mission
– 1999-2002: 10 missions:
  - 4 flights by European astronauts as Shuttle Mission Specialists
  - ESA mission (to be confirmed) in the context of the European Robotic Arm (ERA)
  - 2 ESA Early Utilisation Flights
  - 2 Shuttle flights for ASI astronauts in the framework of the NASA/ASI arrangements on the MPLM
  - 1 ESA mission for activation of the Columbus Laboratory.



This tally results in a total of 15 ESA and national missions, but other potential missions can also be expected in the same period.

For the period after the Columbus Laboratory's arrival at the Station, i.e. the period of Europe's own utilisation rights, from 2003 until 2013, consolidation of the ESA and national mission opportunities leads to:

– 16 ESA missions for utilisation of the Columbus Laboratory
– 1 Shuttle mission in 2003 – 2004 for an ASI astronaut
– 3 missions for ASI astronauts to the Station from 2005 onwards within the framework of the MPLM arrangements
– a number of Shuttle missions for European newcomer astronauts to prepare for Space Station missions; the exact number depends

on recruitment plans in the period after the Columbus launch, but a first estimate is 8 to 10 missions in the period 2003 – 2013.

A grand total 28 to 30 ESA and national mission opportunities are therefore to be expected in this period. Taking all realistic mission opportunities from 1998 to 2013 into account, this results in approximately 44 mission opportunities for European astronauts over the next 15 years. If one then takes into account the need for back-up astronauts for each of these missions, together with the necessary training and preparation time, these 44 missions would require a total of 26 astronauts to be available by 2000, if the distinction between ESA and national astronauts were to be maintained.

The integration of all European astronauts into a single Astronaut Corps, and the resulting rationalisation of the mission assignments, will allow the same number of missions to be conducted with just 16 astronauts. This assumes an average of 3 European astronaut missions per year, whereby each astronaut has a flight opportunity approximately every 3 years. After 2000, provided there is a stable mission frequency, natural astronaut attrition will have to be compensated for with an average of two new recruits every two years, thereby allowing appropriate crew rotation in terms of skills, ages and national considerations.

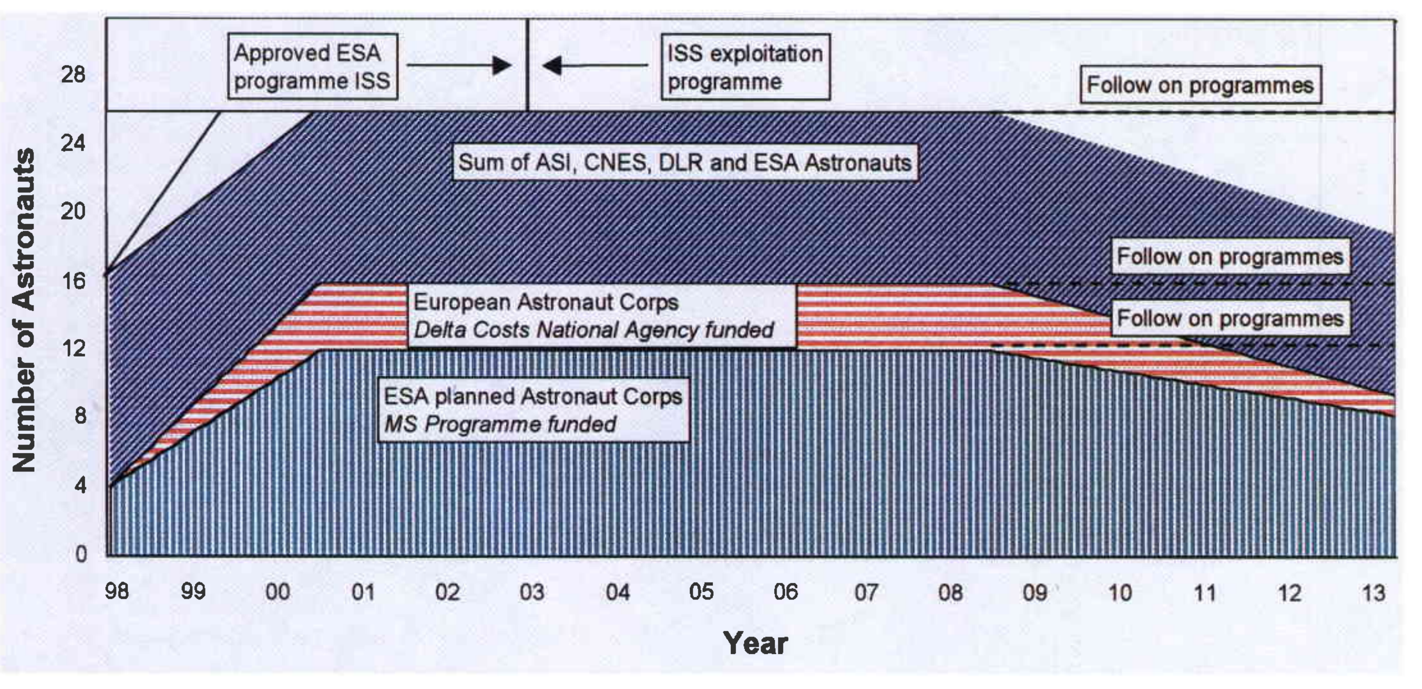
The benefits of a single European Astronaut Corps

The financial savings from having a single European Astronaut Corps result not only from the smaller number of astronauts required to conduct the European missions identified, but also from the associated reductions in management and support personnel and the more efficient use of facilities.

Each International Partner is responsible not only for the training of its own astronauts, but of all astronauts – i.e. including the astronauts from the other International Partners – on the facilities which they contribute to the Space Station. For Europe, this means the Columbus Laboratory, the Automated Transfer Vehicle (ATV) and the European Station payloads. Simulators and training mock-ups for these elements will have to be maintained for the duration of the programme and put under configuration control. Often, they will have to be reconfigured for the next mission increment. One single pool of such facilities will therefore lead to greater efficiency and considerable cost savings. A single Astronaut Corps, with a common home base at the European Astronaut Centre (EAC) in Cologne, will henceforth ensure cost-efficient basic and mission-specific training on the European Station elements (Fig. 3).

This pooling of resources is equally valid in less-visible areas too, such as the medical operations support. To be integrated as a certified crew surgeon in the International Space Station operations involves extensive training and proficiency maintenance, supported by dedicated biomedical engineers. In practice, the various space-medicine organisations in Europe are already actively working together to share resources. However, only long-standing contact between the crew surgeons and the astronauts can guarantee a relationship based on mutual trust, and this can only be achieved by both groups working

Figure 3. The European Astronaut Corps



together at the same home base. The same is true for the Crew Interface Coordinators and support engineers, for whom extensive contact with the astronauts is equally important.

A single home base also provides a stable environment for the astronauts' families and encourages a more uniform level of European astronaut background, proficiency and experience.

Money-wise, the pooling of resources will save several million Euros per year, compared with the current expenditures by ESA and the national agencies for maintaining their separate astronaut teams. In addition, the fact that Europe will speak with one voice to the other International Partners when negotiating astronaut assignments, and the associated costs, must not be underestimated.

Figure 4. The European Astronaut Centre (EAC), near Cologne, in Germany

The ESA initiative for a single European Astronaut Corps

To start the process of revisiting the existing European Astronaut Policy and seeking more economic and efficient use of available resources, ESA's Director General launched an initiative, together with the Heads of Delegations representing the relevant national agencies – ASI (I), CNES (F), and DLR (D) – in December 1997. A small working group, led by ESA's Director of Manned Spaceflight and Microgravity, with representatives from ASI, CNES, DLR and ESA, was convened several times in January and February 1998. It submitted a report to the Directors General of the four Agencies, presenting an analysis of the European resources and a proposal for an agreement between ESA and the national agencies.

The report proposed to:

- set up an integrated single European Astronaut Corps, managed by ESA
- establish the common home base for the European Astronaut Corps at ESA's European Astronaut Centre in Cologne, Germany (Fig. 4).
- develop a plan for discontinuation of the national astronaut programmes and the termination of new recruitment at national level
- complete the integration of national astronauts into the single European Astronaut Corps by mid-2000
- maximise the use of all of the infrastructure and mission opportunities available through ESA
- provide possibilities for utilising astronauts from the European Astronaut Corps for national missions
- establish a regular selection plan for astronauts which enables the adequate representation of all ESA Member States.

This would have numerous benefits for Europe:

- increased cost efficiency
- improved long-term career prospects for the astronauts
- improved flight opportunities
- better implementation of a coherent astronaut mission-assignment policy among the International Partners
- improved European coordination of astronaut activities
- availability of the national astronauts for national programmes
- a better European balance within the Astronaut Corps.

Following the endorsement of this approach by the ESA Manned Space Programme Board in February 1998, the ESA Council in March 1998 approved the Resolution on the Build-up of a Single European Astronaut Corps and adopted the relevant revised policy on European astronauts. In the meantime, the build-up of the European Astronaut Corps has begun.

The implementation of the single European Astronaut Corps

ESA is proceeding with the integration of national astronauts meeting the following criteria:

- age limit of 50 years at the time of recruitment, in order to allow an active career in ESA of at least 10 years
- compliance with ESA medical criteria consistent with the rules applicable to International Space Station cooperation.

ESA is limiting this first recruitment exercise, which began in May 1998, to 7 astronauts from France, Germany and Italy:
- two from France: one French astronaut, J.-F Clervoy, is already in the ESA Corps
- two from Germany: one German astronaut, T. Reiter, is presently in the ESA Corps, but on temporary leave for military duties
- three from Italy: there are presently no Italian astronauts in the ESA Corps.

In addition, ESA intends to select one astronaut, and possibly a second, from other countries in the 1998 to 2000 time frame (Table 2) , based on a reduced short-list established during the 1992 recruitment exercise. Three astronauts from countries others than France, Germany or Italy are presently in the ESA Corps: P. Duque from Spain, C. Fuglesang from Sweden and C. Nicollier from Switzerland.

Table 2. Nominal recruitment plan for the ESA Astronaut Corps

	1998	1999	2000
France	2	1	-
Germany	2	1	-
Italy	3	-	1
Other Countries	-	1 (2)	-

In the period 1999 – 2000, when the integration process has to be completed, the remaining national astronauts, provided they meet the medical criteria, will be progressively integrated into the Corps, leading to a total of 16 astronauts.

Beyond 2000, the normal ESA procedure will apply for further astronaut selections, maintaining a fair balance within the Corps.

National missions

National astronaut missions can be of great importance for the promotion of space activities in a specific country, and it is therefore important to establish a *modus operandi* between the new unified astronaut policy and national needs. National missions are usually based on bilateral agreements between the respective country and the mission-opportunity provider, such as the existing arrangement between NASA and ASI on the MPLM, and the Russian and CNES Mir-99 mission.

One possibility is the secondment of astronauts from the single European Astronaut Corps to the respective national organisation, or the concluding of a specific arrangement between the national organisation and ESA. In the first solution, a European Astronaut Corps member can be seconded to the national organisation from the start of mission-specific training until the end of post-flight activities. In the case of a specific arrangement, the astronaut would continue to be fully embedded in the ESA structure, but the planning and execution of the mission would rest with the national authorities. Depending on the astronaut's profile, activities such as involvement in national public-relations events or sitting on national boards or advisory groups, etc. could also fall into this category.

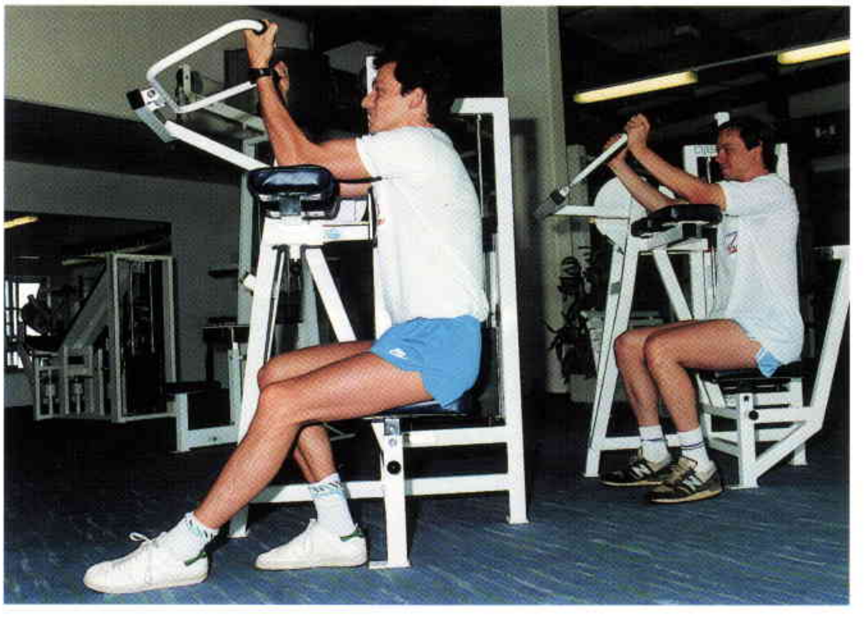


Figure 5. Astronauts Pedro Duque and Christer Fuglesang in training at EAC

Conclusions

The 44 astronaut missions which have been identified as necessary between 1998 and 2013 to support ESA and national activities will mean an average of three astronaut mission opportunities per year. The fact that the total of 16 astronauts needed to support these missions will now be concentrated within a single European Astronaut Corps, with the European Astronaut Centre (EAC) in Cologne-Porz (D) as their common home base, will ensure efficient future use of ESA and national capabilities in Europe, in terms of human resources, facilities and infrastructure. The decision to pursue this revised astronaut policy and to form the single European Astronaut Corps must therefore be seen as a very positive example of the forward-looking space integration process that is currently taking place at the European level.

Space Transport Systems for the 21st Century *

F. Engström
Director of Launchers, ESA, Paris

I was recently asked to talk about "Space Transport Systems for the 21st Century" and my problem was to link this with the theme of the forum, namely "Mobility on Earth". I began by suggesting that "space transport" is an extension of "Mobility on Earth". Indeed, even when in space, we remain captives of the Earth's gravitational field, if we exclude the very few space flights that go beyond our planet's sphere of influence.

In addition, ESA's space activities are largely oriented towards our planet: we observe the Earth from space, we communicate on Earth via space, and we return the results of our scientific probing of the Universe to Earth. Moreover, all of our space activities are prepared on Earth, and any funds we spend on space are spent on Earth. We also evolve in and learn about using and exploiting our near-Earth space environment from here on Earth.

Space: a new environment

Contrary to the often expressed view that "there is nothing in space", this near-Earth space environment is of great interest. The following are just a few of its features:

- It is vast, as its volume extends beyond the orbit of the Moon. Within this volume, and once we have surmounted the initial hurdle of reaching low Earth orbit, we can move at will with relative ease; in fact with much greater ease than when we want to move around on the surface of the Earth.
- It has unlimited and unconstrained access to the full power emitted by the Sun.
- It is free from the crushing force of gravity, so that in space we can build gigantic structures that would be unthinkable on Earth.
- Its perfect and infinite vacuum allows contamination-free fabrication processes.
- It is the perfect black-body heat sink and the ideal environment in which to apply the advances of superconductivity.

We can surely find other unique features, but most importantly:

- It is the vantage point from which our planet can be observed in its entirety, from which global correlations become obvious, and the whole Universe can be probed with unlimited clarity. Space offers a new perspective, which can shape mankind's view of itself, its role and its destiny.

Now that I have made my point about how interesting the space environment is, you might also ask whether we, as a species, should appropriate this environment, which is also very hostile to life because of its vacuum, its radiation, and its extreme thermal gradients? Well, it is interesting to observe that nearly every domain on planet Earth is occupied by life, in the form of viruses, bacteria, plants and animals. Today, we humans already occupy a much larger ecological domain than the one naturally suited to us. Indeed, our expansion on this planet has been due not so much to our natural adaptability, but to our intellect and dexterity, which allow us to cloth and protect our bodies from heat or cold, to extend our range through animal-based or mechanical means of transport, and to recreate cosy conditions even in areas naturally hostile to our presence. In fact, we have expanded our living environment through technology, and I would suggest that there is a very direct link between our technological capabilities and the environments that we can penetrate, exploit and eventually occupy.

As far as space is concerned, we are still at the stage of the early pioneers of the Wild West, with early commercial undertakings and the first settlements on the horizon. However, because space completely surrounds the Earth and is accessible from anywhere on our planet, its exploitation and colonisation will not be the act of people from a single continent as was the case for the American West, but will be a task for the whole of humanity.

The key to the new environment: access to space, the expendable rocket launch vehicle

So, if I am convinced that space will become part of daily life on our planet, how come that

* Based on an invited lecture given at "Forum Engelberg", in Switzerland, on 27 March 1998

we do not yet have colonies in Earth orbit or on the Moon? What are we waiting for? Well, we are still waiting for the right transportation system, and I will try to outline the scope of the problem.

Although it is deceptively close, the only way we can imagine today of reaching near-Earth space and staying in it is to place ourselves in orbit around Earth. This requires imparting a speed of almost 8 km/s to a body at least 100 km above the surface, for which we currently rely on launchers powered by chemical rocket propulsion. The latter generates the thrust required to accelerate the launch vehicle by ejecting a stream of gaseous matter as fast as possible. The most practical solution with the highest performance is provided by the combustion of hydrogen with oxygen. However, both of the propellants must be carried onboard the launcher (usually in liquid form), unlike a car engine, for instance, which can draw its oxygen from our planet's atmosphere.

As a result, the mass fraction of propellants required onboard such a launcher is much closer to 1 than it is for transport systems on Earth. If we take Europe's state-of-the-art Ariane-5 launcher (Fig. 1) as an example, its total take-off mass is, grosso modo, 735 tons. Of these, 7 tons are the payload to be carried into geostationary transfer orbit (corresponding to about 20 tons into low Earth orbit), 643 tons are the propellants needed, and only 85 tons are made up by the tanks that contain the propellants, the rocket engines to produce the required thrust, the avionics to guide the launcher, and all of the other elements that constitute a complete launch vehicle. This hardware is discarded once the propellants have been ejected, and Ariane-5 is therefore classed as an "expendable launcher". For each launch, a complete new vehicle must be constructed, assembled and launched, at a cost of some 140 million ECU.

This is still a high price for putting a few tons of payload into Earth orbit, but it was even more expensive in the past. As a result, incursions into space remain the preserve of an elite of astronauts and scientists and of high-value satellites and probes; today's commercial applications of space are primarily still those that deal in the flow of information and not of material goods.

How come expendable launchers are not cheaper? It is mainly because they are complicated machines that must work under very high stress levels and meet very exacting safety requirements. As a result, the margin between success and failure is very narrow and launchers still fail from time to time, often for seemingly trivial reasons or due to minor oversights.

If we now look to commercial aviation, a large aircraft such as an Airbus 340 costs about as much to purchase as an Ariane-5 launcher. However, the aircraft is capable of logging many thousands of flying hours with extraordinary safety. Its fuel load represents only 30% of its take-off mass and is an easy to handle petroleum product. Its dry mass is a comfortable 50% of the take-off mass, and its engines can run for thousands of hours without a major rebuild.

Clearly, today there is no technical or operational commonality between an aircraft and a rocket launcher. It is therefore hardly surprising that their markets and their marketing logic have so little in common.

Figure 1. Lift-off of the second Ariane-5 test flight from the ELA-3 launch complex at the Guiana Space Centre on 30 October 1997

The future imperative for access to space: reduce the cost!

The question now then is whether aviation and space, which today seemingly have so little in common, could or should come together more closely in the future. There are two trends that might lead to a possible convergence in the longer term: one is the desire to reduce the cost of access to space, and the other is the search for higher speeds in aviation in order to reduce journey times.

As regards the need for reducing the cost of access to space, the main argument of its proponents is that, with the present cost of launching with expendable launchers, applications of space will never blossom beyond those of today and that space will remain a restricted market. If, however, the cost of access to space could be lowered by a factor of 10, or 100 or 1000, then many more uses of space - most of them still to be discovered or invented - might become possible and the market revenue from commercial space activities might reach what now seem impossible orders of magnitude.

In fact, however, the situation is not that clear-cut between the claimed presently excessive high costs and the as much claimed need for so much lower costs in the future. In reality, space is already a very profitable and dynamic market, as evidenced by the recent boom in communications satellites for network applications. In such applications, which will generate turnovers of many billions of dollars, the launch costs represent a very minor element. Nevertheless, there has been fierce competition between the launch providers to win these launch orders, with success dependent on competitive pricing. Even a slight cost advantage is therefore already very important, but we will not have to wait for the hoped for orders of magnitude cost reductions before seeing impressively large space markets.

At ESA, therefore, we are pursuing all promising options for cost reduction. Presently, our two main approaches are firstly to improve what we have to the best of our ability, and secondly to look into novel solutions within a reasonable technology horizon.

Our "improvement activities" are focussed on nurturing our current operational expendable launcher, Ariane-5. We already have an approved Ariane-5 Evolution programme running, and we are proposing an Ariane-5 performance-improvement programme known as "Ariane-5 Plus". Both programmes are aimed at keeping pace with the evolving market needs and reducing the cost per kilogramme of payload put into orbit.

These Ariane-5 improvements, whilst important to maintain a competitive edge in the current and near-term launcher market, will not change the present launch costs by a large factor. Today's expendable launchers have effectively reached a technology plateau in terms of technical implementation and cost per flight. Novel solutions are required if we are to reduce the cost of access to space by an order of magnitude or more and I will now briefly review some of the possibilities, before outlining what ESA has been and will be doing in this context.

Reusable launchers with rocket propulsion
The first option that comes to mind is that of reusing a launcher instead of discarding it after one mission. In the traditional view, such a vehicle would accelerate to orbital velocity, eject its payload, re-enter the atmosphere at orbital speed (28 000 km/h, or about Mach 25), dissipate its kinetic energy in working against drag, and land near the launch base, where it would then be prepared for its next flight. Such a single-stage reusable launcher must therefore carry sufficient propellant to achieve orbital speed with rocket propulsion, and must be resilient enough to survive a full re-entry from Mach 25 intact. In short, structures and engines that are expended today must instead survive a controlled re-entry and remain healthy enough to be reused many times.

This is a very difficult technical problem, the implications of which are nevertheless being investigated world-wide. The most advanced work is being done in the USA, in the form of the Reusable Launch Vehicle (RLV) programme, which includes the X33 as an Advanced Technology Demonstrator to determine whether or not the technologies needed to build a cost-effective operational RLV are available.

Air-breathing propulsion for reusable launchers
Rocket propulsion requires such high propellant mass fractions that a more performant technology needs to be found. The most obvious option is to use atmospheric oxygen for propulsion into orbit, instead of carrying the oxygen inside the launcher. Since the launcher's

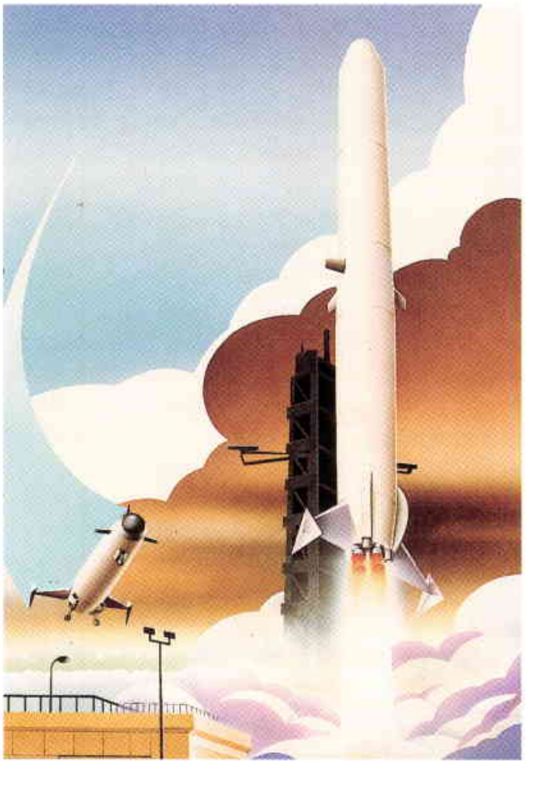


Figure 2. An ESA Future Launching System (FLS) studied, by Aerospatiale leading a team of European companies, in the early 1980s. The reusable first stage would fly back to the launch base, whilst the second stage would be expendable (courtesy of Aerospatiale)

task is to achieve its terminal speed in vacuum, some form of rocket propulsion will always be required and the air-breathing propulsion option would help to achieve the highest possible speed in the atmosphere, before exiting it with rocket propulsion.

However, orbital speed is a very high target compared with present aircraft speeds. Millions of us fly at Mach 0.9 in commercial jets, thousands fly at Mach 2 when in Concorde, and just a select few get to fly at Mach 3.5+ in the world's fastest military aircraft. These speeds are minimal compared with the Mach 25 that must be achieved to stay in orbit. Limiting the contribution of air-breathing propulsion to only the lower Mach numbers as is possible today is therefore not really helpful in making a reusable launcher more feasible.

Novel air-breathing propulsion systems able to reach speeds in the Mach 6 to 12+ range must therefore be defined and developed. Assuming that these efforts meet with success, one can imagine that these systems might also find application in global high-speed aviation.

Atmospheric oxygen collection for reusable launchers

Another possible solution is that of collecting the oxygen required for the rocket-ascent propulsion directly from the atmosphere. This would allow the launcher to take off with reduced weight, loaded only with liquid hydrogen, and then to extract the oxygen that it needs from the Earth's atmosphere. Once the required amount has been collected, the launcher would switch over to rocket propulsion and accelerate to orbital speed.

Staging for reusable launchers

All of today's launchers have several stages, allowing them to jettison structural mass as soon as the propellant that it contains has been consumed and the thrust from its engines exploited. The launcher then becomes lighter and the remaining rocket engines have a smaller mass to accelerate. Staging is currently the most efficient means of accessing space with rocket propulsion and it might therefore be of interest to apply staging in reusable launchers also.

For example, the first stage could be a rocket propulsion stage that accelerates the second (upper) stage to about Mach 6. The second stage then fires its engines until orbital velocity, while the first stage dives back into the atmosphere, decelerates to subsonic speed and flies back on turbojets to its launch base, where it can be reused. This approach introduces some additional operational complexity, but the problem of reuse is simplified.

We can also imagine a scenario in which the first stage reaches orbital altitude, but its velocity is short of orbital, and so it ejects its upper stage with payload and immediately re-enters the atmosphere to land again at its launch base after having made one circuit around the Earth, or at a base down range of the launch site.

With staging, we are also free to implement expendable or reusable second stages. When the second stage is expended, we are relieved of the problem of re-entry and we can have a more robust second stage with a higher payload capability than if it were reusable.

Many technical solutions and combinations thereof can be visualised and are possible. However, the fundamental question is, and will remain, will the chosen technology or system be able to reduce the cost of access to space by one or two orders of magnitude?

Staging also opens up options for implementing air-breathing propulsion for space launching in an elegant manner. For example, a TSTO (two stage to orbit) launcher of which the first stage is air-breathing allows one to separate the air-breathing and the rocket-propulsion cycles. Also, the high-speed propulsion system developed for the air-breathing first stage could well be of interest to the global aviation community.

ESA's approach to lowering launch costs in the longer term

I would like to turn now specifically to what has been done so far in ESA on launcher reusability, and our plans for the future. Reusable launchers are feasible technically, but it is has yet to be proved that they are economic. For many years, we have had a very small level of study activity on reusable launchers. In the early 1980s, we concluded that only partial reusability would make economic sense in the foreseeable future (Fig. 2). We also concluded at that time that the next generation of European launcher, Ariane-5 – the development programme for which began in the mid-1980s – should be expendable but optimised for cost efficiency.

In the late-1980s and early 1990s, we investigated whether the Ariane-5 architecture would be suitable for reusability, by replacing the two solid boosters with reusable liquid-propellant boosters. We concluded, however, that this approach would not be cost-effective in practice (Fig. 3).

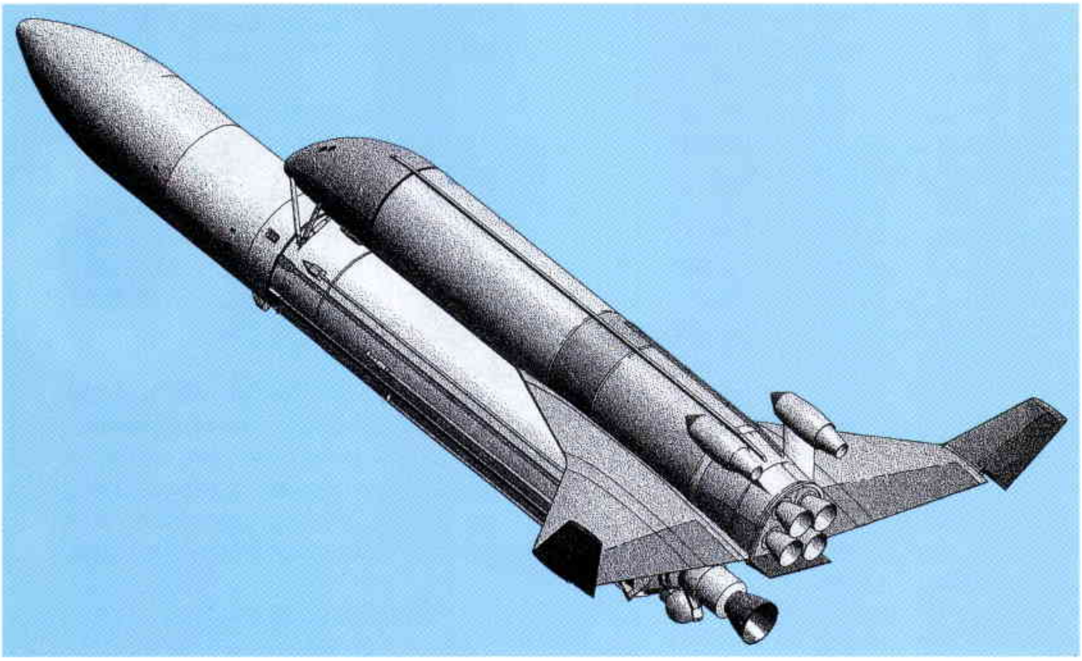


Figure 3. An ESA Reusable Rocket Launcher (RRL), studied by Aerospatiale in the early 1990s, with a reusable first stage powered by the Russian RD170 liquid oxygen/kerosene engine (courtesy of Aerospatiale)

At around the same time, the USA was undertaking the National Aerospace Plane (NASP) programme, and we tried to understand whether the air-breathing approach proposed for NASP was credible. We found this not to be an option for Europe (Fig. 4). On this same occasion, we also brought the United Kingdom's Hotol and Germany's Sänger proponents together in order to assess the respective merits of these two approaches. It turned out that neither was optimum, as the respective launcher architectures had been selected somewhat prematurely without having explored all possible alternatives.

We also knew that answers regarding the true potential of reusability will never be obtained from endless theoretical studies, but will come from practical work on mastering the new technologies needed. Therefore, in parallel with these study activities, we have proposed, at each Council Meeting at Ministerial Level since the meeting in Rome in January 1985, the implementation of a dedicated programme to explore whether the technological performance levels needed for launcher reusability could be achieved. This finally led to the investigative programme FESTIP (Future European Space Transportation Investigations Programme) coming into effect in February 1994.

FESTIP was initially approved for a first slice of three years (1994-1996) to cover concept definition and technology work. For the concept definition work, we set ourselves the goal of being prepared for a decision on the

Figure 4. An ESA Winged Launcher Configuration (WLC) studied, by DASA leading a team of European companies, in the late 1980s. It has a supersonic combustion ramjet air-breathing propulsion system (courtesy of British Aerospace)

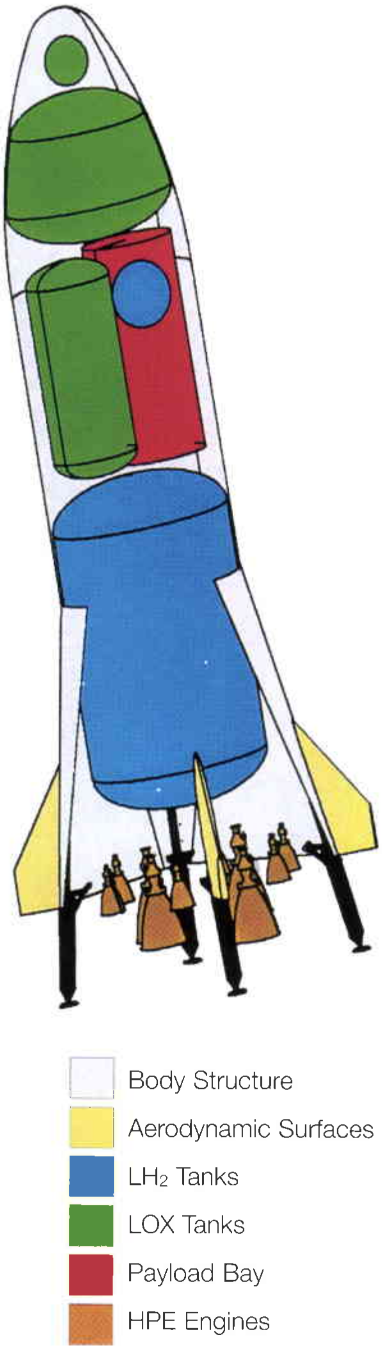
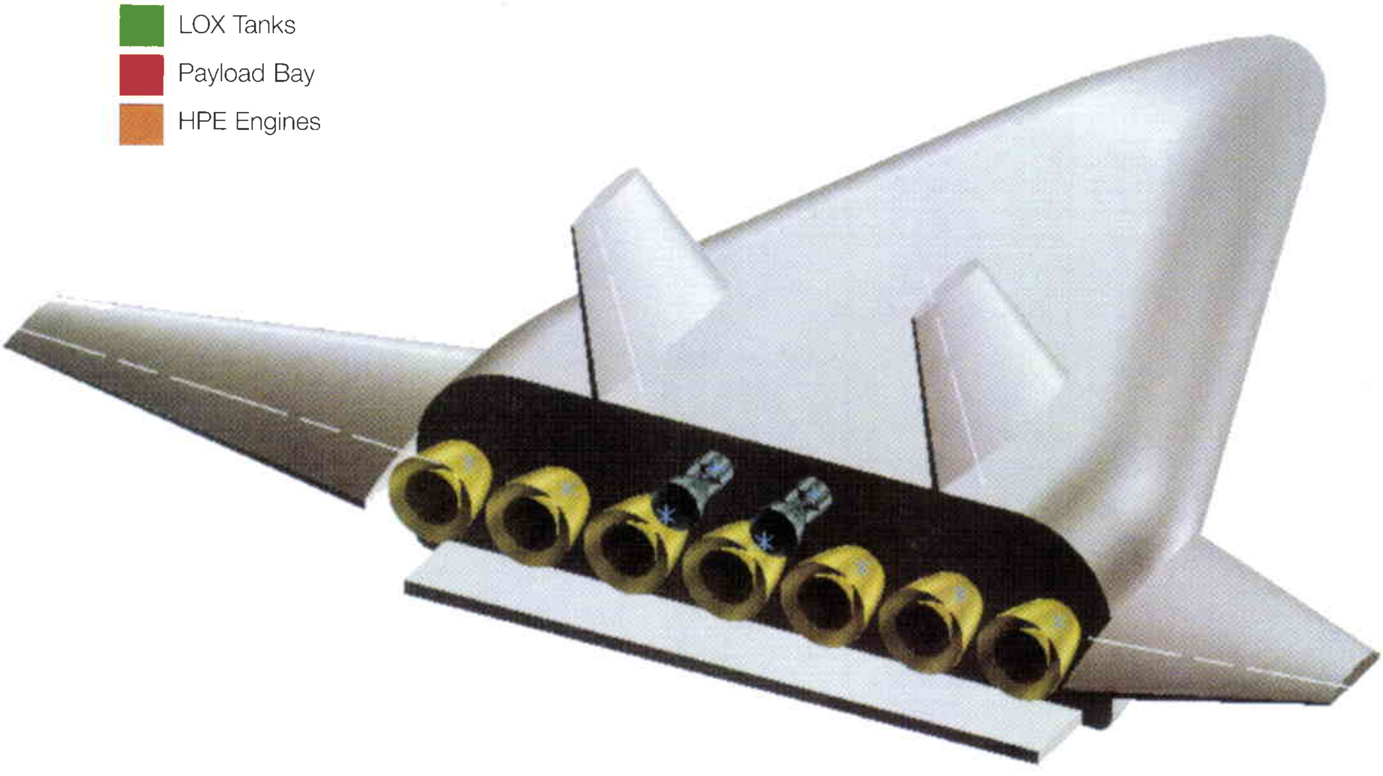


Figure 5a. An ESA Single-Stage-to-Orbit Reusable Rocket Launcher studied in the context of FESTIP, by DASA leading a team of European companies, and designed for vertical take-off and landing

possible development of a first-generation reusable launcher in 2005. We wanted to establish which reusable-launcher concepts might be feasible with the technologies that could be developed by then. We first concluded that air-breathing propulsion could only be envisaged to the extent that its technology was not too ambitious with respect to the overall state of the art in aviation. We then defined single- (Fig. 5) and two-stage (Fig. 6) to orbit reusable rocket launchers, which are either fully reused or their main parts at least are recovered for reuse. We concluded that recurrent launch costs could be reduced by a factor of 3 with respect to expendable launchers, but at the price of a significant investment in advanced technologies, mainly in the field of materials, structures and reusable rocket propulsion.

The FESTIP first slice was supplemented by the 1997-1998 extension, which will conclude the investigative work. Beyond 1998, ESA proposes the execution of a dedicated Future Launchers Technologies Programme (FLTP), which will draw upon the full competence of the European launcher industry. One important feature of the FLTP will be our proposal to design, build and fly a European Experimental Test Vehicle (Fig. 7), which will provide European industry with its first hands-on experience in practical launcher stage reuse operations. The large jumps in technology and gaps in experience between Ariane and any first-generation reusable launcher make such a learning phase a prerequisite. Only when we have learned the basics of reuse, will we truly

Figure 5b. An ESA Single-Stage-to-Orbit Reusable Rocket Launcher studied in the context of FESTIP, by DASA leading a team of European companies, and designed as a lifting body for vertical take-off and horizontal landing



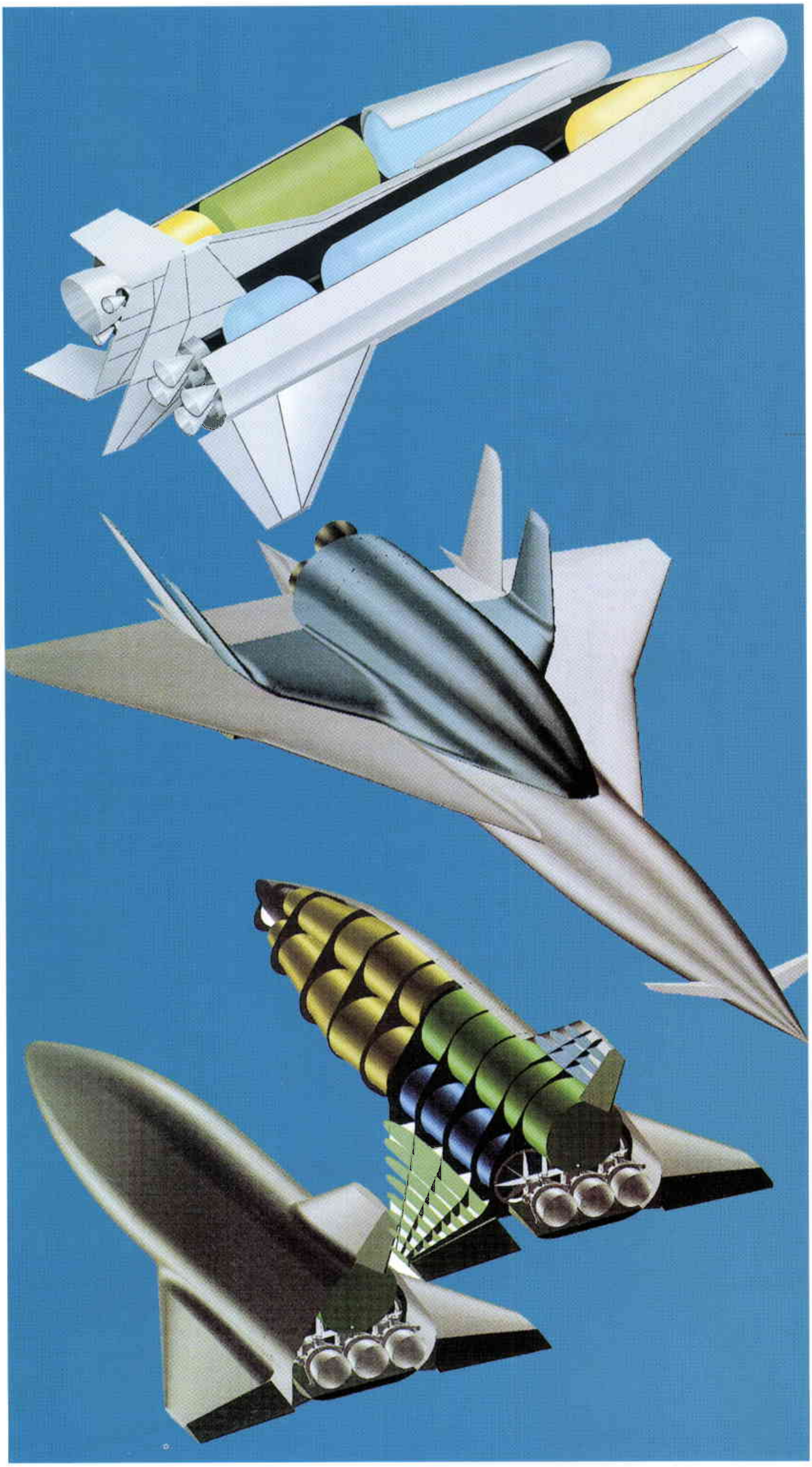


Figure 6a. An ESA Two-Stage-to-Orbit Reusable Rocket Launcher studied in the context of FESTIP, by DASA leading a team of European companies, and designed for vertical take-off and horizontal landing

Figure 6b. An ESA Two-Stage-to-Orbit Reusable Rocket Launcher studied in the context of FESTIP, by DASA leading a team of European companies, and designed for horizontal take-off and landing, with the first stage propelled to Mach 4 by air-breathing propulsion

Figure 6c. An ESA Sub-Orbital Reusable Rocket Launcher studied in the context of FESTIP, by DASA leading a team of European companies, and designed for horizontal take-off and landing. The sub-orbital stage would attain orbital altitude (but not reach orbital velocity) and eject its payload equipped with an upper stage. The reusable Sub-Orbital Launcher would then land down range and be transported back to the launch site for its next flight

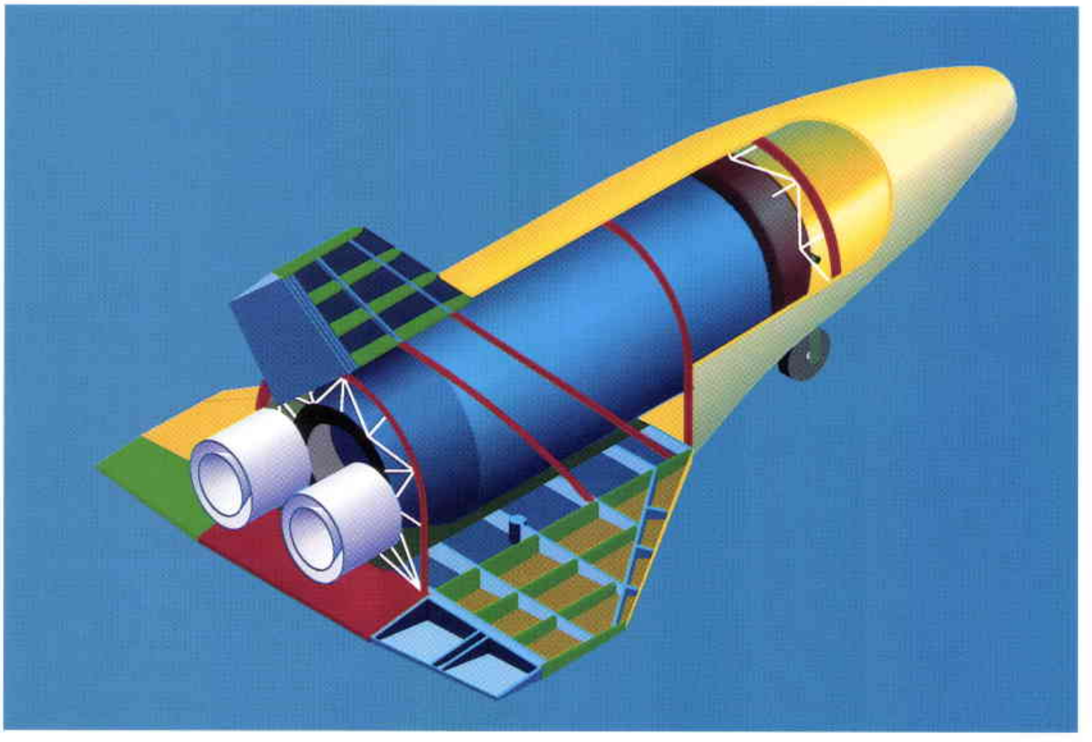


Figure 7. The European Experimental Test Vehicle (EXTV) studied in the context of FESTIP, by DASA leading a team of European companies. The version shown is designed for vertical take-off and horizontal landing

be ready to decide whether or not to apply that knowledge to operational developments.

The long term: synergy between access to space and global aviation?

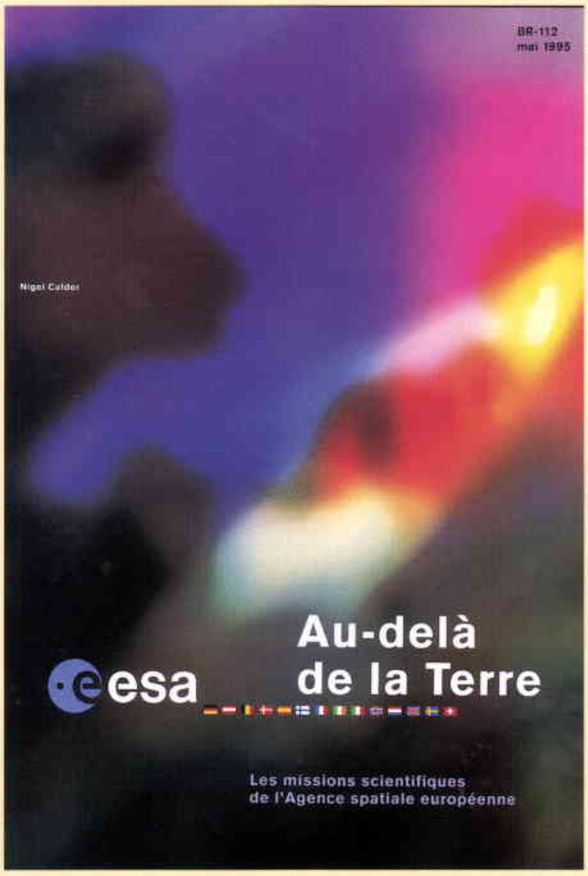
It is likely that launcher reusability developments will also significantly influence the way in which global aviation is viewed in the future. Work on the so-called "high-speed commercial transport", which aims to reduce the travel times for global flights by a straightforward extrapolation of subsonic aviation, has been in progress for some considerable time. However, supersonic cruising flight poses rapidly increasing thermal problems as the speed increases, and the sonic-boom problem still makes approval of supersonic flight over populated land masses unlikely.

The alternative that could emerge thanks to reusable launchers is that of reaching an antipodean point on Earth in one hop through space, referred to as a "boost glide". It relies on the fact that one could fully load a reusable launcher with propellant and have it reach orbital velocity, or load less propellant but more payload and have it hop halfway around the planet. To be fully effective, such a form of global travel would call for chemical propulsion with higher performance than pure rocket propulsion, but propulsive performance levels less than those already achieved by today's turbojets for subsonic transport would already be more than adequate.

Finally, since we seem to be performance-limited by chemical propulsion, are there alternatives? In fact, the only other possible near-term solution for reaction propulsion is that of nuclear thermal propulsion, in which a fission reactor (gigawatt class) is used to heat the working fluid. Although such a solution might be of use on the Moon, for instance, and would be ideal for rapid planetary-transfer missions, it seems unlikely that Europe would undertake such a development in earnest in the near term unless there were very compelling reasons for doing so.

Conclusion

I would like to conclude with a statement of faith. Within our present technology horizon, we know along which lines we must proceed in order to make access to space cheaper, more flexible and safer than it is today. The progress that can be expected is significant enough for the work to be undertaken. Since a successful outcome is likely, but not yet certain and therefore not commercially attractive, we will still be dependent on dedicated short-term funding from far-sighted Governments in order to make progress. I believe that the proposed ESA Future Launchers Technologies Programme (FLTP) is a step in the right direction in this respect and will contribute to unleashing the true potential of space, to the long-term benefit of Europe, its citizens and its Industry.



Au-delà de la Terre

Les missions scientifiques de l'Agence spatiale européenne (ESA)

de Nigel Calder

'Au-delà de notre ciel teinté de bleu par l'atmosphère terrestre s'étend l'Univers, ce vide spatial noir ponctué de planètes, d'étoiles et de galaxies. C'est le royaume des chercheurs spatiaux.'

Nigel Calder, écrivain très connu en Grande-Bretagne pour la qualité de ses écrits scientifiques, brosse ici un tableau complet et vivant du programme de recherche spatiale de l'ESA, en nous donnant un avant-goût des projets que l'Agence compte mettre en oeuvre au XXI^{e} siècle.

La vigueur et la diversité de cette recherche s'imposent au lecteur. *Au-delà de la Terre* présente douze missions différentes, en mettant l'accent sur les raisons humaines et scientifiques qui sous-tendent l'immense travail à la clé de la recherche spatiale. La description proprement dite des missions est accompagnée de détails techniques apparaissant sous forme de tableaux et d'illustrations.

Cet ouvrage traite principalement du programme scientifique actuel de l'Agence : Horizon 2000. Les quatre grandes missions dites pierres angulaires — Soho et Cluster, XMM, Rosetta, First — ainsi que les différentes missions de taille moyenne y sont exposées. La première partie du document porte sur les engins spatiaux chargés d'explorer les environs de la Terre, le Soleil et d'autres destinations du système solaire, la deuxième étant consacrée aux télescopes d'astronomie sur orbite terrestre. Dans l'un et l'autre cas, l'auteur donne un aperçu du contexte historique et international dans lequel s'inscrivent les missions.

La troisième partie du document projette le lecteur dans la deuxième décennie du XXI^{e} siècle et traite plus particulièrement des trois grandes missions du programme Horizon 2000 Plus de l'ESA, qui couvre la période 2006-2016. Explorer la mystérieuse planète Mercure, exploiter les avantages de l'interférométrie pour atteindre un degré de précision inégalé dans le domaine de l'observation astronomique, partir à la recherche des ondes gravitationnelles — tels sont les trois projets majeurs de l'Agence pour cette période, conciliant les nécessités de la planification à long terme et le caractère imprévisible de la recherche.

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A Different Approach to Project Procurement

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This article introduces the projects that are described in the following two articles in this ESA Bulletin, namely the Mars Express and the SMART-1 missions. Both are test cases for new approaches in technology development and project management which are being introduced into ESA's Science Programme. The overall aim is to reduce the cost of missions, but at the same time maintain the high scientific quality that has been achieved in past.

Background

The European science community is, in the main, a strong supporter of the ESA Science Programme and recognises its value and its ability to launch and operate World-class scientific missions. In recent years, however, there has been increasing concern that space missions take too long to implement and generally are too expensive. More tangibly, the budget for missions has been decreasing to a level at which missions of high scientific value are becoming more and more difficult to support, unless cheaper procurement approaches are identified and adopted. Other factors such as the emergence of a small-mission culture, advances in lightweight technology and the improved ability of European manufacturers in general to provide cheaper hardware, offer the possibility of cheaper missions if the management approach that was used until recently is modified.

The new challenge for the Science Programme, therefore, in seeking a new and more innovative approach, is to launch missions at least as often as in the past, whilst remaining within the decreasing budget envelope and whilst maintaining the record of excellence that ESA has established as a World leader in space science.

Considerations

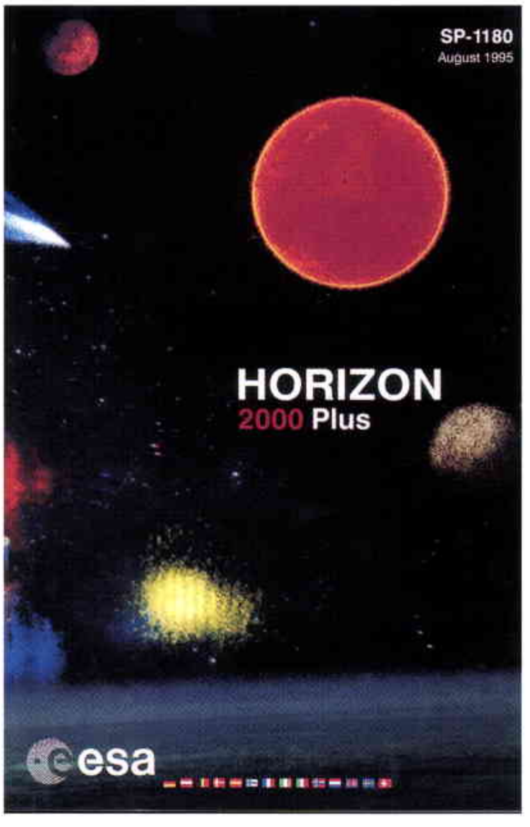
The first question is: "How can missions be made cheaper?"
"Cheapness", being a comparative term, implies that there is an accepted cost reference. However, the scientific satellite business tends to be of a "one-off" nature, with the same type of satellite rarely being flown twice, making direct comparisons difficult. Comparison with NASA or other space agency missions is another option, but this approach is not without its pitfalls, due to the quite different accounting procedures used by other organisations. Such comparisons tend therefore to be subjective and at best imprecise.

Experience has shown that, rather than trying to define an absolute reference, the best means of achieving value for money is first to identify the cost-driving elements of a particular mission. Appropriate management procedures can then be applied to minimise both the baseline cost and the risk of cost increases due to changes in these elements. This is the approach that has historically been taken within the ESA Science Programme. The question now is whether, in order to satisfy today's demands, this approach can be improved to give cheaper missions than hitherto? The answer may be yes, if the spacecraft can be developed over a shorter time scale and at a lower management cost by accepting a higher degree of risk.

Achieving shorter time scales

A shorter overall development time is possible if, before the main development is started, the design architecture for the project is already well established, the hardware elements and software are readily available, and no changes to payload or mission requirements are allowed after contract signature. The down side is that the Agency becomes less flexible in response to requests for change brought about by changing requirements, scientific or otherwise.

Technology preparedness is a key item. Pre-development of the correct technology simplifies the design process, and it ensures that the hardware/software elements that will be needed are indeed available and well understood, thereby reducing the risk of time-consuming changes being required at a late stage. However, technology preparation involves more than just showing that a given technology is feasible. To be useful, it has to be available exactly when needed. The current dilemma is that technology development requires time and funding. Funding is not normally released until project approval, which means that new technology, until now, has been developed from the feasibility to the flight-readiness stage during the actual project development. This process inevitably introduces the risk of an increase in the overall project cost, as large teams are employed on the project, so any delay due to late technology availability translates directly into an increase in overall cost.



To break this cycle of events, the new approach foresees key technologies being developed to flight standard in advance of mission approval. This implies that the requisite technology is identified in advance and the necessary funds allocated to the development effort. It also means that a mission would not be approved unless the technology is available. The down side here is that funds could be spent on technology for a mission which may eventually not be selected, but the amount involved would be small compared to the potential costs associated with project over-runs. The technology needs will be identified via system studies of projects that have been identified by the scientific community as good candidates for future missions.

Achieving lower management costs

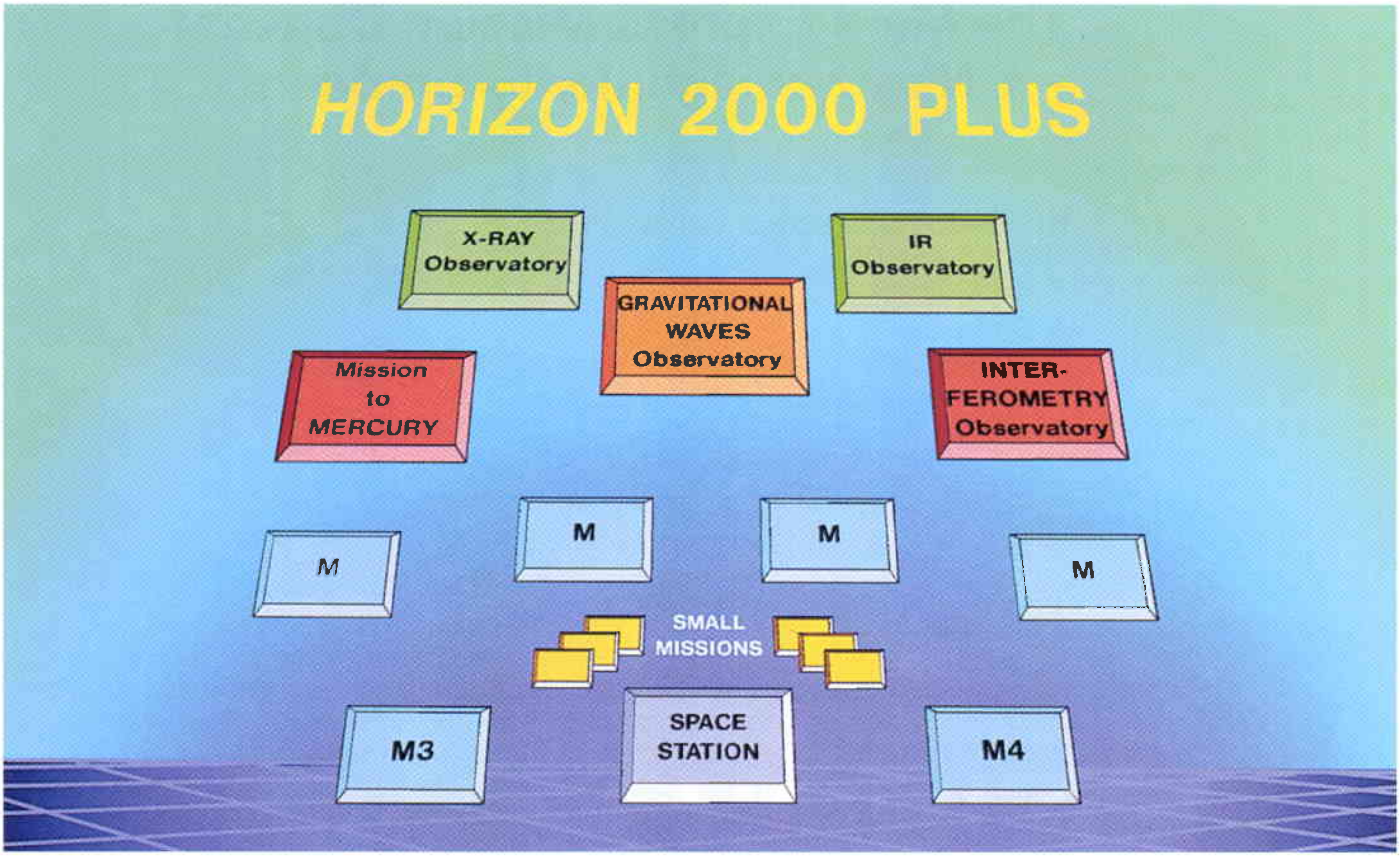
This aspect is perhaps the most controversial. The aim is firstly to compress the project-selection process from its current five-year cycle (average) to less than two years; and secondly to constrain the design and development phases to less than five years, giving a mission concept-to-launch time of some seven years. This is to be compared with the 11 years that has sometimes been the case for past missions. Also, more responsibility will be delegated to industry, thereby reducing the cost associated with management interactions between the Agency and the Contractors.

A number of key considerations must be addressed if this approach is to be successful.

Firstly, one must be more critical when selecting projects, particularly as far as proposed time scales are concerned, i.e.- Can the proposed instruments actually be developed and delivered in time?
- Are the scientific specifications well defined and properly framed?
- Are all of the technologies needed actually available?
- Can the project be well enough defined for ceiling-price contracts with industry to be applied?

Such considerations imply a subtle change in mission assessment criteria. In the past, the value of the science was usually the overriding determinant in the choice of a mission, and so mission ideas from all disciplines of space science could be proposed for assessment and eventual selection. Now the feasibility of implementing a project within strict time and cost constraints will have more weighting in the selection. This means that although a good scientific return remains essential, the choice of project is essentially limited to those missions that can be implemented within a short time period. The traditional calls for mission proposals will be more focussed than hitherto, with preference being given to proposals that can be clearly shown to meet the imposed time and cost constraints. This implies that the essential hardware elements already exist, either via another project development or from a pre-development activity such as the SMART missions (see accompanying article).

Secondly, more responsibility must be given to Industry, so that ceiling-price contracts can be agreed, with the Contractor taking responsibility for the interface management of the science payload elements of the mission. Giving more responsibility to Industry means taking more risk on the Agency side, as there will be less visibility of the Contractor's work.



Consequently, the cumulative experience in ESA across many projects and missions cannot be used to the same extent to identify potential problems at an early stage. The fact that today space industry also has accumulated wide experience should help to keep this risk acceptable.

It also means that the scientist will interface directly with Industry and must therefore accept all of the limitations that the strict budget ceiling involves. Industry will have the right to agree or veto changes to the interfaces within the cost ceiling. To help avoid conflict situations arising between the scientist and Industry, the potential Prime Contractors will strongly support the instrument-selection process. This should ensure that both Industry and the instrument provider have a good mutual understanding of each other's requirements and constraints.

Last but not least, the new approach will mean freezing the design interfaces early, so that Contractors can proceed with the hardware implementation without expensive and time-consuming negotiations associated with changes in requirements or in interfaces. This means that mission requirements and payload interfaces will have to be agreed prior to the main contract signature, and that no changes will be accepted thereafter if they result in increased cost.

The benefits

The SMART-1 and Mars Express projects, described in the two articles that follow, are expected to demonstrate the benefits of the new approach. In the case of SMART-1, the technology for future deep-space missions will be developed and flight-tested, thus enabling later, more sophisticated missions to be implemented at lower cost and without the risk associated with new technology development during the main industrial contract. SMART-1 will demonstrate the feasibility of deep-space electric propulsion and prepare the ground for future missions to Mercury and the asteroids, and for astronomy missions that need to be conducted at large distances from Earth.

The Mars Express mission is pioneering a new management approach, which if successful will be applied to future scientific missions. The benefits are to some extent already being demonstrated in that the decision cycle has been successfully compressed to some 18 months from concept approval to the start of the main industrial contract (about one-third of the time needed for previous missions).

It is also evident that, for both Mars Express and SMART-1, the ESA and industrial teams are already highly motivated by the challenge, and a motivated team is crucial to project success!

The Mars Express Mission Concept – A New Management Approach

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Mars Express, planned to be the first 'flexible mission' in the revised ESA Long-Term Scientific Programme, is based on a fast implementation scenario and will be launched towards Mars in June 2003 by a Soyuz/Fregat launcher. The mission is cost-capped at 150 MECU and will be submitted for approval by ESA's Science Programme Committee in November 1998. Its payload has already been selected and European industry will submit bids for the design and development phases (Phases-B/C and D) at the beginning of September 1998.

The spacecraft will carry a payload of seven instruments for remote observation of the red planet, four of which are based on developments in ESA Member States for the ill-fated Russian Mars-96 mission. There is also a possibility to carry a 60 kg lander, provided the financing needed for its development can be borne by the sponsoring scientific institutions.

ESA's aim is to implement a top-class mission at a much lower cost than hitherto achieved. Savings will be made by reusing, as far as possible, equipment from other missions, compressing the implementation schedule from mission approval to launch to less than four years, by adopting a new working relationship with industry, and by providing a direct interface between the scientific community and industry.

Introduction

In 1997 ESA's Space Science Advisory Committee (SSAC) confirmed the importance of Europe being involved in the exploration of Mars. The Committee therefore recommended that a Mars mission should be launched during the 2003 opportunity, as this is the most efficient launch window in 19 years due to the favourable celestial positions of Earth and Mars. Another good launch opportunity will not occur until 2009, which would be much too late to satisfy the community's needs. An original scientific contribution from a mission with such a limited budget would be unlikely after the probable return of Martian rock and soil samples in 2007.

In mid-1997 a Science Definition Team (SDT), composed of European experts in Mars science, was set up with the task of defining a baseline mission scenario together with a model payload. An enhanced mission scenario was also defined in case surface stations would be made available in response to an Announcement of Opportunity. In order to alleviate the cost burden to the Member States, the SDT recommended a model payload whose science objectives could be partially fulfilled by instruments that had been developed for the unsuccessful Russian Mars-96 mission. However, new instruments would also be considered if funding and technical readiness were guaranteed.

ESA's advisory bodies, having completed an analysis of the international opportunities for the exploration of Mars, recommended involvement in the exploration of the red planet, up to a ceiling of 150 MECU. This budget would allow the Agency to procure, launch, and operate a Mars Orbiter over two calendar years. Recently, ESA was asked to consider an extension of the mission to four calendar years (i.e. about two Martian years) in order to offer data-relay services during the 2005 - 2007 period, when other European and American missions could place landers on the Martian surface. This extension is currently considered to be part of the baseline mission design.

The main goal of the Mars Express mission is to study the planet's atmosphere, surface and subsurface via co-ordinated measurements. Specific objectives of the mission are:

- global high-resolution photo-geology at 10 m resolution
- global spatial high-resolution mineralogical mapping of the Martian surface at 100 m resolution

- global atmospheric circulation and high-resolution mapping of atmospheric composition
- subsurface structures at km-scale down to permafrost
- surface/atmosphere interaction, and
- the interaction of the atmosphere with the interplanetary medium.

Mission scenario

The loss of the Russian Mars-96 mission and the potential discovery of much earlier biochemical activity on the red planet, meant that ESA could not wait too long before pursuing a Mars mission. Mars Express was conceived to provide European scientists with the chance to participate in the current international Mars exploration effort with a high-profile mission at a very modest cost (150 MECU for the entire programme). The spacecraft parameters, launcher capability and the celestial constellation of Mars and Earth lead to a launch window opening on 1 June 2003 and closing 11 days later. The launch will be performed by a Soyuz/Fregat launcher from Baikonur in Kazakhstan. ESOC will conduct the operations using the ESA ground station in Perth (Aus.).

The mission was conceived as an orbiter observing the Martian surface from a polar orbit, with a pericentre of 300 km and an apocentre of 6800 km. Originally, up to four landers complemented the orbiter mission with in-situ exploration of Mars, specifically addressing the planet's internal structure, surface chemical/mineralogical composition, and to identify possible signatures of life. Due to financial constraints within some Member States, it was concluded that landers should be deferred to the next launch opportunity in 2005. ESA has, however, instructed the industrial contractors to retain the possibility of carrying one lander weighing a maximum of 60 kg. At the time of the writing, new developments suggest that it may be conceivable to finance and build such a lightweight lander in Europe. The Italian Space Agency (ASI) has offered to provide the data-relay system for lander/orbiter communications. The efforts by the International Mars Exploration Working Group will allow the same data-relay system to be used for other landers on Mars.

The Mars Express spacecraft will carry the following complement of instruments:

- High Resolution Stereo Colour Camera - HRSC (G. Neukum, Principal Investigator)
- Atmospheric Planetary Fourier Spectrometer - PFS (V. Formisano, PI)
- Visible and Near-Infrared Mapping Spectrometer - OMEGA (J.P. Bibring, PI)
- Atmospheric UV Spectrometer - SPICAM UV (J.L. Bertaux, PI)
- Subsurface Sounding Altimeter - SSRA (G. Picardi, PI)
- Analyser of Space Plasmas and Energetic Neutral Atoms - ASPERA (R. Lundin, PI)
- Radio-Science Investigation - RSI (M. Paetzold, PI)

Payload financing is a national task and shortage of resources led to a payload complement being driven by the desire of national funding authorities to give priority to the re-flight of instruments originally developed for Mars-96. Despite this limitation, there will also be new instruments onboard.

Management aspects

The decreasing frequency of scientific satellite launches and the balance of missions among the scientific communities led the ESA Directorate of Scientific Programmes to revise its long-term programme. Mars Express is therefore the first of a new breed of missions in which the concepts of "cheaper" and "faster" are rigorously applied. A new management style will also be introduced for the Mars Express project. The internal ESA team will be much smaller than hitherto, with key tasks such as the management of the interfaces with the scientific instrument teams, the technical interface to the launch authorities, and the test-facility procurement being delegated to the prime contractor.

The industrial contract awarded will cover design through to launch under fixed-price or cost-ceiling conditions.

Interface between industry and Principal Investigators (PIs)

One of the new features of the Mars Express mission will be the management by industry of the interfaces between spacecraft and scientific instruments. Traditionally, ESA has always provided a group of payload engineers to act as the interlocutor for the instrument teams in all aspects of a technical nature and for passing relevant information to industry. As part of the drive for increased efficiency, the Agency will hand over this task to industry and thus restrict itself to monitoring the progress of instrument development. ESA will, however, retain control over all scientific issues arising during the development and test programme, and will define the flight-operations plan for the payload. Industry will take responsibility for the timely delivery of all payload elements and will also ensure that the allocated payload resources are respected. This new approach will require a fast learning process. Interface changes that have a cost impact either on industry or on the instrument teams will have to be negotiated between the two parties.

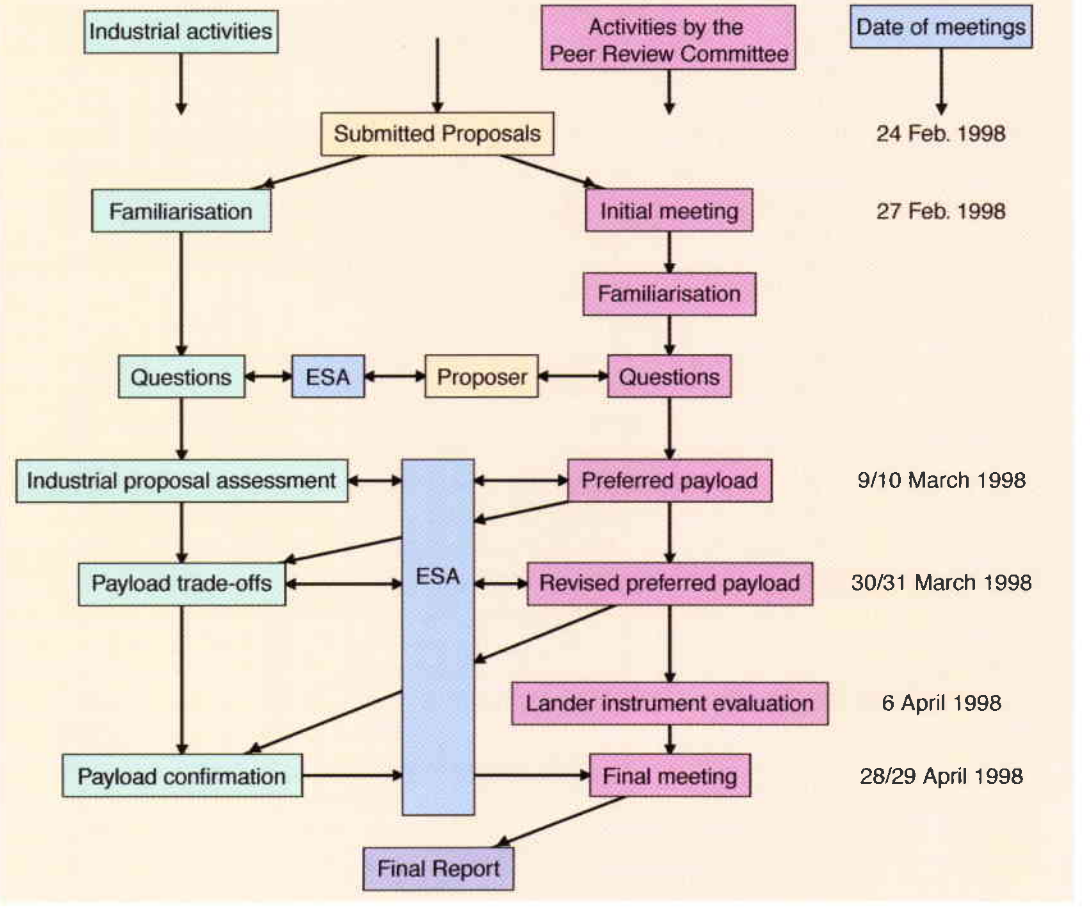
Study phase and payload selection
Following the mission's initial approval by the Science Programme Committee, an intensive phase of preparatory work for the Announcement of Opportunity (AO) for the scientific investigations and for the industrial study activities was undertaken, during which the feasibility of the project was also established. The industrial study phase effectively started in October 1997 with the release of the Invitation of Tender (ITT) for a six-month study contract. The ITT only contained top-level requirements and it was intentionally left to industry to elaborate the detailed mission design. Four bids were received by the Agency and the technical kick-off meetings with Dornier, Matra-Marconi and Alenia, together with Aerospatiale, took place in late January and early February 1998.

The AO for the scientific instruments was issued in December 1997, with replies due on 24 February 1998. ESA received a total of twenty-nine proposals for orbiter, lander and combined lander-orbiter investigations. Seventeen proposals concerned Mars Express orbiter investigations proper, while three submissions dealt with complete lander proposals including a preferred set of scientific investigations. Eight proposals were made for instrumentation to be accommodated on a lander, and one for wave propagation between one or more landers and the orbiter.

The industrial study phase was split into two intervals. During the first six weeks, the contractors had to develop a conceptual design for the spacecraft based on the model payload as recommended by the Science Definition Team. Their designs were then further refined during the second period, lasting about 3.5 months until the second half of May. At the start of that second phase, the responses to the AO from the scientific community were received. A formal review cycle was initiated, with industry fully involved in the analysis of the scientific proposals.

To maintain confidentiality among the three industrial contractors, a procedure for the exchange of information and data was conceived whereby interactions between payload selection committee, industrial contractors and scientific community were enabled without breaching the confidentiality requirement (Fig. 1). The rational for setting up dialogues as shown was driven by the need to select the payload within about eight weeks. To minimise the time and resources needed to

Figure 1. The information flow between instrument proposers, industry and ESA



freeze the instrument configuration, the PI teams needed greater knowledge of the capabilities and limitations of the spacecraft platform selected. Close liaison between project personnel and the PI institutes was essential to achieve this in the early phases of the project.

Industry and ESA insisted on confidentiality and did not permit design details to be passed from one contractor to another. The flow of information between contractors and the Peer Review Group was always channelled via ESA. Three iteration loops were executed during which the Peer Review Committee identified either specific questions to industry or preferred sets of payload elements; industry assessed the feasibility of these preferred sets against their spacecraft concept. For better understanding of the instruments, industry could also raise questions, which were passed via ESA to the respective proposers. The responses by the instrument teams were also handled via the Agency. In both cases, the questions and answers (more than 800) were screened and recommendations for harmonising the process were made by ESA wherever necessary. Only after confirmation by the Solar System Working Group of the recommended payload composition did ESA allow industry to contact directly the PIs of the seven instruments, which at that time had still to be recommended to the Science Programme Committee for final endorsement.

Schedule

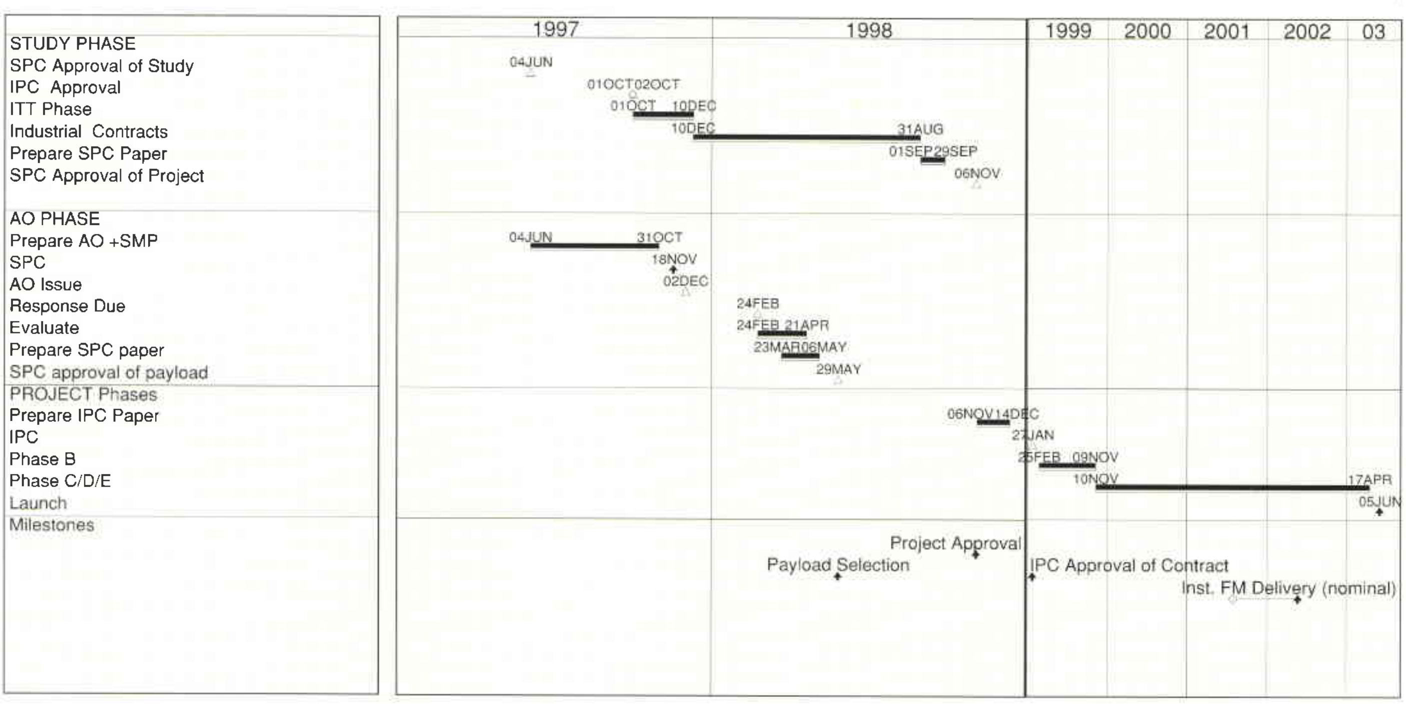
The schedule is constrained by the fixed launch date, demanding both an early proof of concept and an early start to flight-model production in order to allow ample time for testing and verifying the spacecraft's performance. This approach imposes relatively early delivery dates for the payload elements.

Figure 2 shows the outline plan for spacecraft procurement, from now until its launch in June 2003. Despite the very compressed schedule, all milestones to date have been met. The industrial study activities were concluded with final presentations in the second half of May, while the Science Programme Committee endorsed the selection of the instruments on 28 May 1998. The project schedule dictated this date in order to allow industry to include the final payload in preparing their bids for Phases-B/C/D, due for submission to ESA in early September 1998. The preparatory work for the release of the ITT for the spacecraft development phase at the end of June is proceeding according to schedule. Following submission of the bids, it is expected that the Prime Contractor's selection will be confirmed in January 1999 at the latest.

Early lessons learnt

There is a certain risk associated with selecting the scientific payload whilst mission definition by industry is still in progress. The confidentiality of the scientific and industrial activities makes it difficult to negotiate with or pass information to the scientific community. The refinement of the mission design can, however, lead to the modification of major mission parameters and it must be ensured that the scientific proposals submitted remain valid. An example of the sort of problem that can occur, and its resolution, are described below.

Figure 2. Master schedule for the Mars Express project



The industrial studies concluded that the initial estimates for the overall payload mass, number of landers and selected orbits, had to be revised whilst the scientific community was still working on their competitive instrument proposals. The ITT that was released in October 1997 had specified the following payload and orbital requirements:
- 120 kg of orbiter payload
- up to four landers with a total mass not exceeding 120 kg
- provision of attachment hardware and orbiter/lander data-relay services
- orbit: 300 km by 8300 km, inclination 122.6°, period 5.7 h.

In December 1997, it was decided for scientific reasons to increase the total lander mass allocation to 180 kg, with 30 kg of lander support hardware on the spacecraft. The extra mass was supposed to be recovered by changing the apocentre height of the final mission orbit. The revised mass allocation and orbital parameters were then as follows:

- 120 kg of orbiter payload
- up to four landers with a total mass not exceeding 180 kg
- 30 kg of attachment/release hardware and orbiter/lander data-relay services
- orbit: 300 km by 13 100 km, inclination 90°, period 8.5 h.

The AO for the scientific investigations was based on these new assumptions. Soon after its release, however, three major problems were identified:

- The three industrial contractors demonstrated that carrying a total of 330 kg of payload and lander-related hardware at launch was unrealistic unless a more powerful launcher than the baselined Soyuz/Fregat could be used.
- Radio-communications studies performed independently by ESTEC and NASA, revealed that the orbit with a 13 100 km apogee was extremely unsatisfactory as far as the number of contacts with the landers on Mars, their duration and the amount of transmitted data were concerned.
- During the Mars Express proposers briefing meeting, held on 16 January 1998 at ESTEC, it became clear that a ground-penetrating radar must use wavelengths that would not penetrate the Martian dayside ionosphere, and would therefore have to be operated on the anti-sunward side of the planet (where there is no ionosphere) in order to detect subsurface water. Neither of the orbits specified above provide acceptable coverage of the night side of Mars.

There was thus a significant problem with the lift-off mass and, at the same time, a strong desire to lower the apocentre of the baseline orbit to resolve the previous two problems, which would require even more onboard fuel. Immediate advice was sought from the Science Definition Team. In line with the scientific recommendations of the Peer Review Committee and the financial resources available in the Member States, the following payload constraints were then established:

- 113 kg of orbiter payload
- possibility to carry one lander weighing a maximum of 60 kg
- 15 kg of hardware to include data-relay services and dedicated antennas, inter-experiment harness, instrument purging equipment and other hardware specifically required by some instruments
- orbit: 300 km by 6800 km, inclination 90°, period 4.6 h.

This new orbit meets the needs of the high-resolution spectroscopic camera and ground-penetrating radar, and the radio-communication requirements for the European and NASA-provided landers on Mars in 2005.

Outlook

Industry is currently preparing its fixed-price bids for Phases-B/C/D, which have to be submitted to the Agency at the beginning of September 1998. Re-confirmation of the Mars Express mission by ESA's Science Programme Committee will be sought in November 1998. Following this, the contract proposal for the selected Prime Contractor will be submitted to the Agency's Industrial Policy Committee (IPC) for approval. Phase-B will start in February 1999 and will nominally last until November 1999. Phase-C/D will commence in January 2000 and last until the end of 2002. Spacecraft delivery at that point will complete the industrial activities. It is left to industry to confirm these dates in their proposal. A shorter Phase-B and an earlier start to Phase-C/D is conceivable if this was found to be advantageous from a technical or cost point of view.

The launch campaign is planned to last from April to end-May 2003, with the nominal 11-day launch window opening on 1 June 2003.

Conclusion

The complete industrial mission design for Mars Express, up to the level of a pre-Phase-B study, as well as the entire payload-selection process from release of the AO to confirmation of the selection by the SPC, has been completed in less than seven months. At the time of the instrument selection and

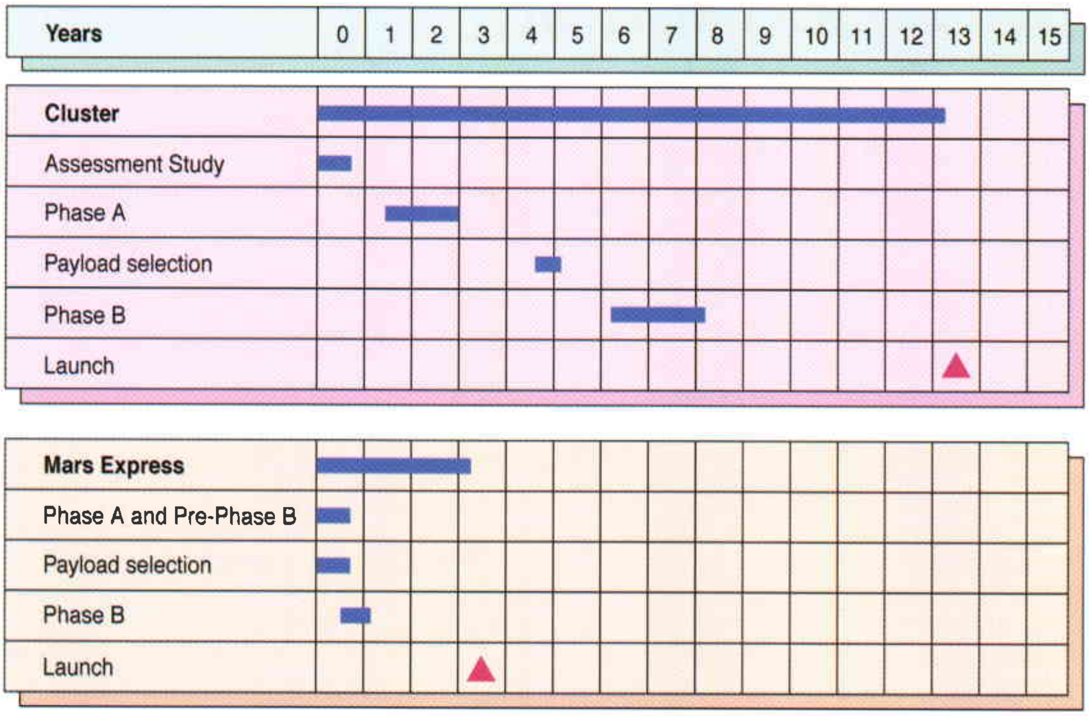


Figure 3. Comparison of the implementations of Cluster, as part of the first Cornerstone mission, and Mars Express in running years

endorsement by the SPC, the industrial study was already consolidated and industry started to prepare their firm fixed-price offers for Phases-B/C/D.

For the first time, industry has analysed all the proposals submitted in response to the AO and assisted ESA and the Peer Review Committee with their evaluation. The scientific payload has been chosen prior to finalisation of the spacecraft and, more specifically, before the spacecraft/instrument interfaces had been defined. At first glance this appears risky, but in reality this approach has been shown to lead to a significantly reduced time interval between the start of mission definition and the start of Phase-B.
The stringent cost limitations for all elements of the mission can only be met by implementing a rigorous design-to-cost approach, with extensive re-use of existing items. The Prime Contractor is therefore likely to choose subsystems and units from ongoing spacecraft programmes, such as Rosetta, XMM and national programmes. A similar philosophy also applies for the mission operations at ESOC. Rigorous cost control is being applied in developing the ground segment for Rosetta, which will be launched only about five months before Mars Express. Compatibility, and if possible even commonality, between the two systems could therefore be a fertile source of economic savings.

The PI teams' strength in the management and engineering of the instruments is determining the speed at which development problems can be solved. Such ability is directly linked with the level of up-front funding available during the early definition of the instruments. This aspect has been taken into account during the selection of the payload.

The time interval from the issue of the Mars Express AO in December 1998 to launch is comparable to that for the Giotto project, which took five years from AO issue to the launch. A comparison with the schedule for Cluster is given in Figure 3, where it can be seen that the impact of both the compression and tight scheduling of activities on the overall project duration for Mars Express is dramatic. esa

The SMART-1 Mission

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The SMART-1 mission, to be launched at the end of 2001, is intended to demonstrate innovative and key technologies for deep-space scientific missions. Its use, for example, of solar electric propulsion as its primary drive mechanism will be a first for Europe and is essential in paving the way for future ESA projects with large velocity requirements, such as the Mercury Cornerstone mission. SMART-1 will also be a test case for a new approach in terms of implementation strategy and spacecraft procurement for the ESA Science Programme.

The total life-cost budget allocated to SMART-1 is 50 MECU. This budget constraint imposes use of a cheap launch option, such as an Ariane-5 auxiliary payload launch into a standard GTO or a Rockot escape-trajectory launch. This in turn limits the planetary bodies that can be reached within a given short (1.5 - 2 year) overall mission lifetime, which do, however, include the Moon and Earth-crossing asteroids or comets.

The mission is presently under Phase-B definition by the Swedish Space Corporation. The funding of the mission is being used to compensate Sweden and Switzerland for the deficits in their industrial returns. The mission is expected to be funded partly by France and the United Kingdom, which presently have an industrial-return surplus. The Directorate of Industrial Matters and Technology Programmes, via the Technology Research Programme, and the Directorate of Scientific Programmes would provide the remainder of the funding, within agreed limits. The mission would thus effectively be a partnership between ESA and the participating Member States.

Introduction

SMART-1 is the first of the Small Missions for Advanced Research in Technology within ESA's Mandatory Scientific Programme (Fig. 1). These missions have been introduced by the Agency as one of the strategic elements for reintroducing balance and flexibility into the Horizons 2000 Science Plan. They constitute a preparatory technology-development programme focusing on items identified as critical to the success of the Cornerstone missions, including flight demonstrations where deemed appropriate. The scientific importance of the SMART-1 mission therefore resides mainly in its preparatory nature for upcoming scientific missions, and in particular for those missions that will benefit from primary electric propulsion and deep-space communications.

The importance of Solar Electric Primary Propulsion (SEPP), i.e. electric propulsion fed by Sun-generated electrical power and used as the spacecraft's main propulsion system, has been well-recognised in several past studies, including the Mercury Cornerstone study (to enable a low-circular-orbit mission). Earlier studies of the Solar Corona Probe and Solar Stereo missions had also identified SEPP as being of primary importance. Astronomy interferometric missions like the IR Interferometer Cornerstone and LISA might also benefit from the timely development of such a technology.

SMART-1 will therefore demonstrate the use of SEPP on a small mission representative of future deep-space scientific mission, with the emphasis on the common system aspects, rather than the choice of a particular engine, which is more mission-specific. Several other

Table 1. Typical specific impulse (Isp) and thrust levels for satellite on-board propulsion systems

	Typical Chemical Propulsion			Electric Propulsion		
Engine	Solid Boost Motor	Hydraxine mono-prop.	Hydraxine bi-prop.	PPS-1350	RIT-10	UK-10
Isp [s]	290	220	300	1600	3000	3200
Thrust [N]	50 000	0.5 to 400	4 to 6 000	0.070	0.020	0.020

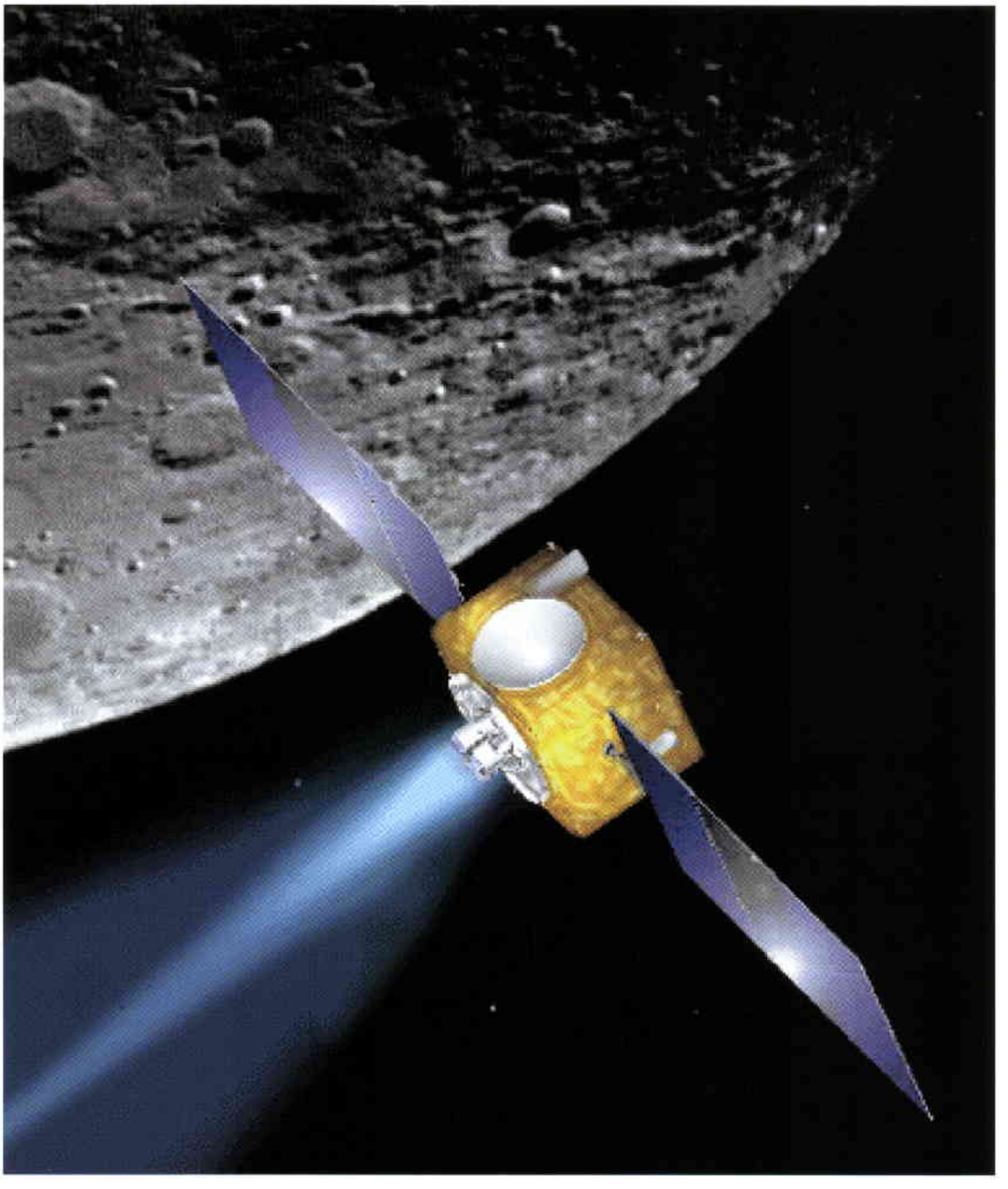


Figure 1. Artist's impression of the SMART-1 spacecraft

technologies are planned to be tested, including some of the candidate technologies that pave the way for approved Horizon 2000 scientific missions and others that are more general in nature (e.g. Li-C batteries, Ka-band, cascade solar cells, etc.) and would be useful for a wider range of future missions.

Being part of the Science Programme, it is also important that SMART-1 should achieve a valuable scientific return. An Announcement of Opportunity has therefore been issued for scientific instruments to be flown on this mission with a view to: (i) directly demonstrating the adequacy of the technology for science, and (ii) providing the scientific community with an early possibility for scientific investigation.

Mission overview

The low overall mission budget for SMART-1 means that a low-cost launch is required. An obvious European choice is therefore accommodation on an Ariane-5 as an auxiliary passenger. This, however, limits the spacecraft mass to 80 kg in the case of the ASAP-V platform for micro-piggybacking, or about 350 kg for a Cyclade configuration. In both cases the spacecraft would be delivered into a standard Geostationary Transfer Orbit (GTO) (perigee altitude 620 km, apogee altitude 35 946 km, inclination 7°, argument of perigee 178°, longitude of descending node 10° W).

Another alternative would be direct injection into an escape orbit by a small launcher such as the DASA/Khrunichev Rockot, which can deliver a 1900 kg payload into a 200 km x 200 km Low Earth Orbit (LEO). From there a suitable solid-rocket-motor upper stage can accelerate a 350-400 kg spacecraft onto a parabolic escape trajectory from the Earth's gravitational influence (Fig. 2).

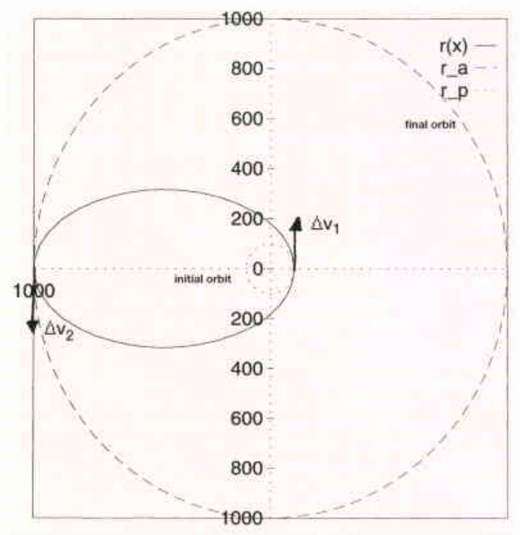
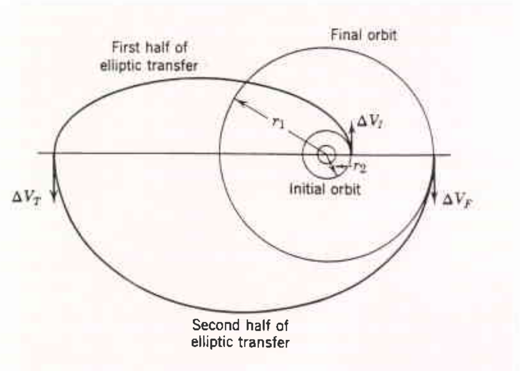
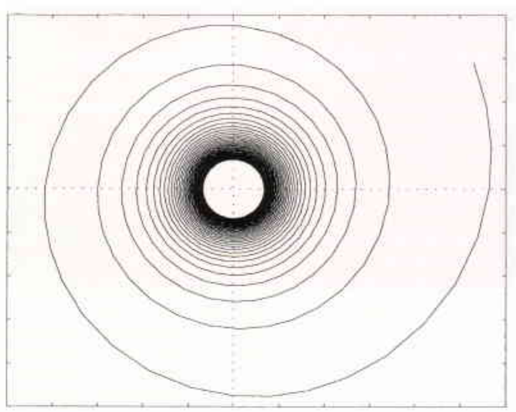


Figure 2. Comparison of impulsive (a and b) and low-thrust (c) orbit-transfer trajectories

a. Hohmann transfer



b. Bi-elliptical transfer



c. Low-thrust trajectory

With these two launch options, two types of planetary bodies generally classified as Near-Earth Objects (NEO) can be reached: the Moon and Earth-crossing asteroids or comets. Three mission options have therefore been considered for the preliminary assessment of the SMART-1 mission:

- A mission whose trajectory is bound to the Earth-Moon system. This includes missions to the Moon, with weak capture in an elliptical lunar orbit. Alternatively Earth-Moon system tours can be conceived involving flybys or rendezvous with the Moon or the equilateral L4/L5 Lagrangian points. The allowable payload mass varies from 10 to 20 kg and the minimum mission lifetime from 250 to 450 days.
- A flyby to an NEO, either an asteroid or a comet. This mission can be performed with an Ariane-5 launch to GTO as an auxiliary passenger. The payload mass is limited to maximum of 10 kg and the minimum mission lifetime exceeds 2.5 years.
- An NEO rendezvous mission using a dedicated launcher like Eurockot. The expected payload mass, depending on the chosen asteroids and launch date, is approximately 20 kg, with some limited growth possibility. The minimum mission lifetime is about 1.5 years and varies greatly according to the target.

A cruise phase during which the electric-propulsion engine is not operated is a feature of all of the above mission categories. The length of these cruise phases, lasting from 100 days to 1 year, depends strongly on the mission option and target selected.

Lunar mission from GTO

An important difference between the Rockot and Ariane-5 GTO launch strategies is the escape strategy. For the Rockot option, there is

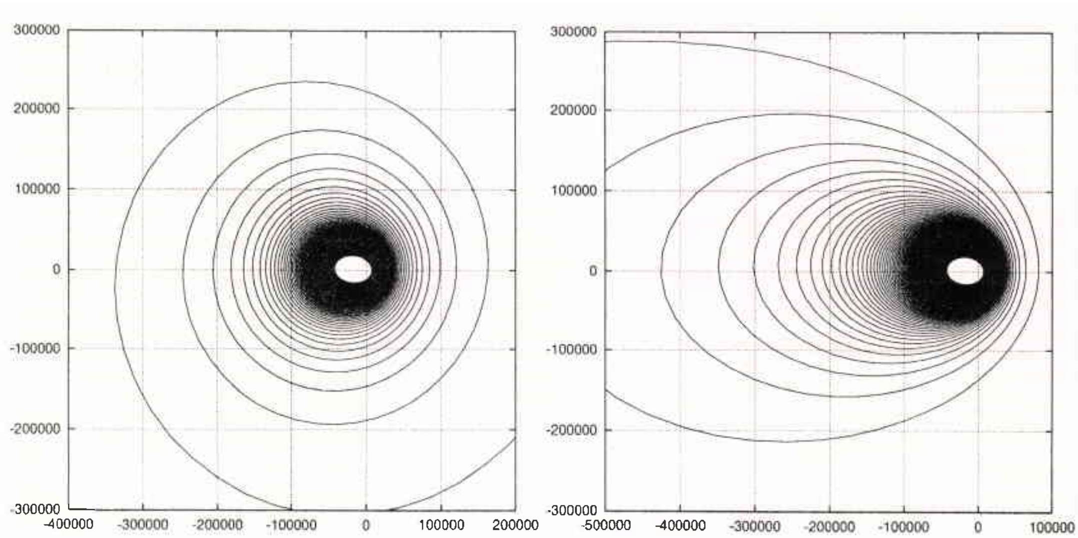


Figure 3. GTO escape spirals with (left) and without (right) coast arcs

sufficient mass available to allow an injection into lunar transfer using an additional boost stage. For the Ariane case, the spacecraft must spiral out, propelled by its SEPP thrust, spending a considerable time in the Earth's radiation belts. Solar arrays are very sensitive to damage from such radiation, which would result in a progressive degradation in SEPP performance. This solar-array degradation has therefore been modelled and coupled to the mission-analysis trajectory-optimisation software to provide direct information on the SEPP power available for a given trajectory. Typical GTO escape trajectories are shown in Figure 3.

The desired final lunar orbit is a polar 1000 km x 10 000 km elliptical orbit with its pericentre located at one of the poles. The optimisation of a low-thrust transfer trajectory connecting the GTO to such a lunar orbit is a difficult problem. Although several authors have tackled it and partially solved it for particular cases, no general optimisation procedure is yet available.

In the framework of the SMART-1 mission analysis, the problem has been tackled in several ways and the work is still in progress. The preliminary results indicate that the spiral out from GTO can be performed with either tangential or circumferential thrusting. The plane change for a year-long launch window can be accommodated by means of out-of-plane thrust. The introduction of coast arcs improves the trajectory for the engine with higher thrust. The capture in the lunar orbit is performed by passing in the vicinity of the cislunar L1 Lagrangian point. The low acceleration (in the order of 1×10^{-4} ms^{-2}) causes some problems with the capture and stability of the initial lunar orbit. Some results of the trajectory calculations are shown in Table 2, and a sample trajectory in Figure 4.

Table 2. Lunar mission trajectory performance

	SPT-100	UK-10 or RIT-10
ΔV	3.6 km/s	4.5 km/s
Fuel	64 kg (estimated)	33 kg
Payload mass	10 kg	24 kg
Time of flight	250 days	450 days

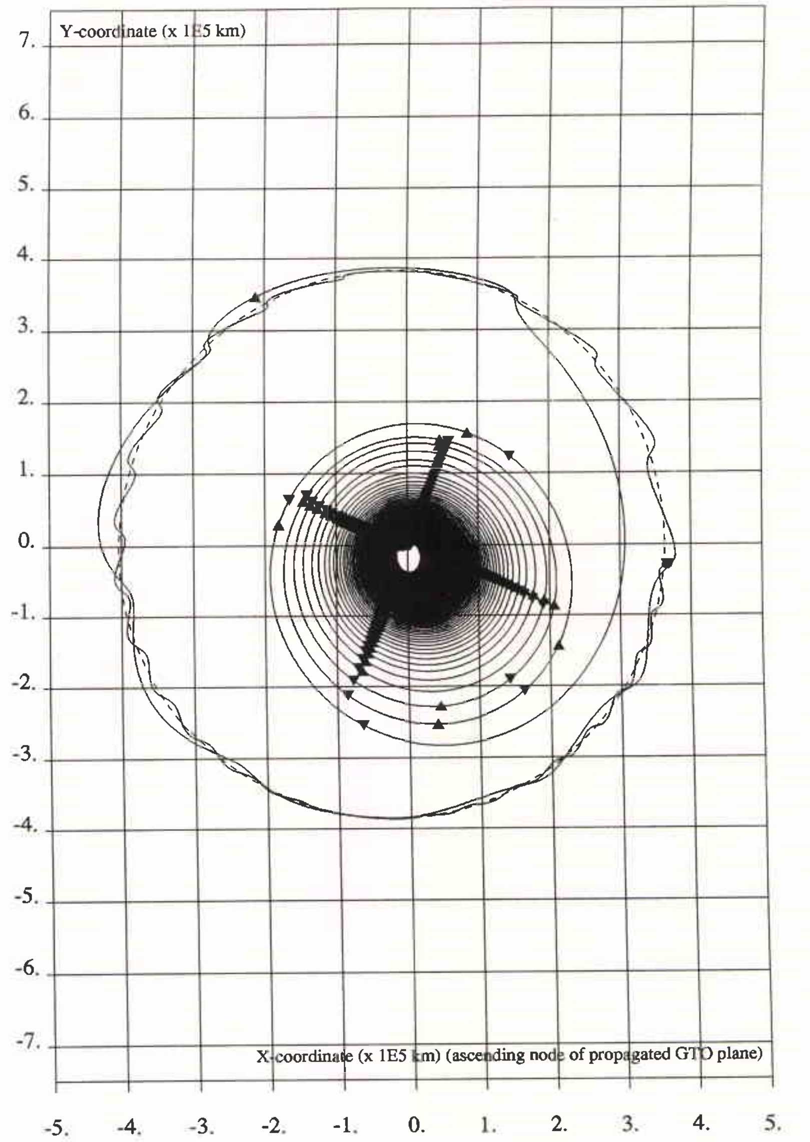


Figure 4. Lunar transfer trajectory in inertial coordinate system

Asteroid missions from GTO

NEO flyby and rendezvous have been studied starting from a GTO. First the escape spiral has to be performed, similar to that of the previous lunar transfer trajectory. In this case, however, the optimisation aims at minimising the fuel whilst maximising the orbital energy and no conditions for the lunar capture need to be set. The time required to achieve a parabolic escape varies between 230 and 450 days, depending on the type of engine and the thrust strategy used.

The target NEO has been selected from a Catalogue (ftp.lowell.edu) providing osculating elements of 35 065 asteroids at epoch September 1997, with launch assumed to take place in November 2001. Several trajectories have been computed with classical Pontryagin-type optimisation techniques, including a partial optimisation of the switching strategy. The results have shown that: (i) no asteroid rendezvous is feasible; (ii) just a few asteroids (1996 XB27, 1993 BX3, 1989 ML, etc.) and comets (Tempel-2, Haneda-Campos) can be reached, but only with high specific impulses (>3000 s); (iii) the flyby velocity is of the order of 10 km/s for the comets and 2-4 km/s for the asteroids; (iv) the minimum time of flight is of the order of 3 years. These results seem to discourage the choice of such a mission option.

Asteroid missions from direct injection
Clearly, an asteroid rendezvous mission offers the most promising scientific results. It also involves all of the typical features of a fully-fledged deep-space mission. The direct-injection launch option has been considered primarily for these reasons.

A mass at escape of 350 kg, with an optimised escape velocity and 20% gravity loss, is assumed for a launch date starting from November 2001. With these assumptions and using the high-specific-impulse engine (>2000s), many rendezvous opportunities with asteroids can be identified (Table 3). The "killer asteroid" 1997 XF11, for example, can be reached almost every year. This, however, is not the most favourable mission scenario.

The main problem with the asteroid missions investigated so far is the large distance from Earth at which the rendezvous takes place – up to 2 AU – placing high demands on the deep-space link. The mission-analysis effort is therefore continuing, seeking closer targets.

Table 3. NEO rendezvous trajectory performance

Target	Launch date	Launch mass [kg]	Time of flight [days]	Payload mass [kg]
Orpheus	29-01-2002	321	442	42
1989 UQ	18-05-2002	320	416	14
1989 ML	25-07-2002	302	409	43
1993 HA	02-10-2002	317	518	25
1997 XF11	09-08-2001	310	1063	6
1997 XF11	29-07-2003	327	994	9

Science and technology objectives

Science objectives and model payload
We have seen that the bodies that could be explored in the course of this mission are Near-Earth Object(s) (NEO) and/or the Moon. The Moon is one of the oldest bodies of the Solar System and so, besides its own evolution, it has also recorded the first "footprints" of the Solar System's history. Its scientific study can therefore improve our understanding of the evolution of the Solar System, terrestrial planets, and the Earth-Moon system as well as of the Moon itself.

The NEOs form the present population of potential Earth impactors. Their exploration can provide insight into the physical nature of the bodies that have dominated our planet's cratering record since 4 Gyr and have apparently had an important impact on its biological evolution. It is generally agreed that there are two sources for these ephemeral bodies: (a) collisional fragments of main-belt asteroids delivered by efficient eccentricity pumping, due to resonances with Jupiter and Saturn, into Earth-approaching orbits; and (b) cometary nuclei surviving long past their active lifetime as inert objects, either devolatilized or covered by a surface crust of refractory material.

Some typical planetary-science goals, and the types of instruments on SMART-1 which could address them, are summarised in Table 4. Depending on the particular mission scenario chosen, the payload mass is between 10 and 25 kg. Important science – for instance involving astrophysical observations – can also be carried out during the mission's cruise phase, as indicated in Table 5.

Table 4. Planetary science and instrumentation

Planetary Science	Instruments
Mass and gravimetry	Flyby tracking
Coarse volume and density	Micro-cameras
Rotational properties	Cameras
Coarse imaging/albedo	Narrow FOV imager
Geology and morphology	High-resolution camera
Stereo mapping / topography	High-resolution camera
Mineralogy	IR mapper
Geochemistry	X-ray spectro-imager
Planetary environment	Wide FOV and UV imager

Table 5. Cruise science and instrumentation

Cruise Science	Instruments
Earth magnetospheric auroral imaging and geo-coronal emissions	UV camera
Sky large field imaging	Visible and UV cameras
Monitor of variability of selected cosmic X-ray sources (AGN's, cataclysmic variables, active binaries)	X-ray spectro-imager
Molecular line observation in selected bands (e.g. O_2 at 60 GHz)	Sub-mm receiver

Science payload selection

Following issue of the Announcement of Opportunity (AO) for SMART-1's scientific payload on 6 March 1998, ESA received fourteen proposals for instrument-based scientific investigations from European Principal Investigator (PI) teams, providing excellent coverage of the science and technology objectives described in the AO. In addition, three proposals and ideas for support science investigations involving no hardware were also received. The Agency established an independent Science Payload Peer Review Committee to assess the proposals and its recommendations have subsequently been endorsed by the ESA Advisory Groups – Solar System Working Group, Astronomy Working Group and Space Science Advisory Committee – and by the Science Programme Committee (SPC).

Evaluation criteria

The Science Payload Peer Review Committee rated the proposals according to the following criteria, as indicated in the AO:

- Science, technical, programmatic compatibility with SMART-1.
- Value for future Cornerstone missions (for example, mission to Mercury, deep-space astronomy missions).
- Support to technology demonstration and environment characterisation for the SEPP mission.
- Originality of science/technology with regard to current and planned missions.
- Relevance for mission scenario and proposed target.
- Demonstrated technological feasibility, reliability, readiness and development status of the proposed instrumentation.
- Competence and experience of the team in all relevant areas (science, management, space technology, proposed techniques, software development and technology, etc.).
- Adequacy of funding, manpower, management, schedule.
- Communication, public outreach and education aspects.

The Committee also set the following priorities for the mission:

• Rendezvous with Near-Earth Objects after Lunar Gravity Assist Flyby

The NEOs recommended, in order of interest, are Comet Asteroid Transition Objects and C-type asteroids, which are believed to represent the final phase in the evolution of dying comets and may constitute up to 40% of NEOs. Besides their interest for cometary and early Solar System understanding, they represent a class of objects that pose specific hazards to the Earth. They are indeed of low density and loosely bound, so that they could be split during close encounters with our planet, increasing the likelihood of later Earth impacts. It is important to characterise the internal and surface chemical and physical inhomogeneity of these objects. Other rocky or more rigid asteroids are, however, also of interest as they could represent the seeds from which the inner planets have accreted.

Target objects for rendezvous have been identified for a launch in 2001-2002 and a decision will be taken after an exhaustive search and optimisation effort. The lunar gravity assist might allow an enhanced payload and a shorter cruise phase, as well as an opportunity for a lunar polar science flyby. This would, for instance, allow one to pursue the remote exploration of permanently dark polar areas as possible ice reservoirs, and to validate some scientific results from the Lunar Prospector mission. High-resolution mapping of the crater-rim areas that are almost permanently sunlit is also of interest in the context of future lunar landings and outposts.

• Lunar Near-Polar Orbit

This option would allow an orbit with 1000 km perilune and 10 000 km apolune, thereby providing an additional lunar-science contribution to the flyby. The lowering of the orbit would cost significant fuel, but the high-resolution instruments would provide better data even from 1000 km perilune. The mission could then address several topical problems, such as: the accretional processes that led to the formation of the planets; the origin of the Earth-Moon system; the dichotomy between the far- and near-sides; the relatively long-term activity and the thermal and/or dynamic processes responsible for this volcanic and tectonic activity; and the external processes on the surface (impact craters, erosion and regolith formation, deposition of ice and volatiles).

The recommended science payload is compatible with both the asteroid and the lunar mission scenarios, the final choice depending on the choice of launcher and the resources available from the spacecraft. Both scenarios would provide extended periods for cruise-science astronomy observations.

The science model payload

A core science payload has been identified and is summarised in Table 6. It includes a multi-camera system with integrated electronics. The high-resolution GEMINI optics can provide 14 m definition at 1000 km or 0.4 m at 25 km (typical NEO rendezvous distance), fulfilling the

*Table 6. Science model payload**

Instrument	Mass [kg]	Comment	Cornerstone	Solar System	Astronomy
GEMINI : high res. optics	2.3	Wide FOV replaced by AMIE	X	XXX	X
SI : light optics	4.0	No scan unit, no electronics		XX	
Common SAGA electronics	2.4	SAGA control electronics and DPU	XX	XXX	X
AMIE WAC	0.8	Only 20° FOV, shared DPU	XX	XX	X
RSIS	0	Uses S/C X-Ka transponder	XXX	XX	FP**
SPEDE	0.5	Reduced boom to 0.5 m	XX	XX	
IXS light	3.4	20 cm focal length, 1-2 CCD	X	XX	XX
SMOG	3.3	Combined with S/C antenna	XX		XX

* The number of X's is an indication of each instrument's potential contribution to the future Cornerstones of Horizons 2000 and to the Solar System and Astronomical sciences.

**FP= Fundamental Physics

mission goals for both lunar and NEO science. It reuses a detector already being developed for Rosetta. The AMIE wide-field instrument uses a micro-camera system and includes a miniature data-processing unit that is of major interest for future missions. The SI visible near-infrared spectral imager will help in mapping mineral distributions on the targets. The electronics for these three channels will be integrated into a single package known as SAGA (SI-AMIE-GEMINI Assembly) sharing common subsystems. This not only has the advantage of reducing mass, but also paves the way for the integration and miniaturisation of the electronics required for future missions.

An Imaging X-ray Spectrometer (IXS) will provide X-ray images with energy discrimination, allowing mapping of the major elements on the target surfaces. It will also provide an opportunity for X-ray astronomy during the cruise phase, particularly temporal monitoring of X-ray sources in stellar clusters and Active Galactic Nuclei. It builds on the development effort for XMM's X-ray CCDs, and also serves to prepare for future Cornerstone missions.

A Radio Science Investigation (RSIS) using a planned technology X-Ka radio link permits the mass, moment of inertia and internal density distribution of the asteroid to be measured. It should also provide improved measurements of relativistic space-time curvature.

The lightweight Spacecraft Potential, Electron and Dust Experiment (SPEDE) will both characterise the plasma environment around the spacecraft and also provide useful scientific data.

The SMOG instrument is designed to detect and map galactic molecular oxygen with unprecedented sensitivity. It will also serve as a technological demonstration ahead of the FIRST and Planck scientific missions.

This model scientific payload is currently being verified in terms of spacecraft-resource and financial viability. Depending on the outcome, as well as on the technology payload allocation (see below), other potential scientific payload items have been earmarked, such as a Lyman-Alpha and UV mapper for measuring lunar or asteroid outgassing as well as astronomical observations, or additional micro-cameras on pointing micro-turrets.

The technology model payload

The SMART-1 payload will also include bus and instrument technology payloads, again selected during the design phase via an AO that was issued in April 1998. The technology proposals received by the 5 June deadline are described below. The electric propulsion system, however, was not part of the AO, and will be procured via a competitive Invitation to Tender (ITT).

Electric propulsion

The most important technology to be flown on SMART-1 is the Solar Electric Primary Propulsion (SEPP) system demonstration. Today, Europe already has a large inventory of electric thrusters either under development or already at the qualification stage, primarily for telecommunications spacecraft applications. Several of them are candidates for use as primary propulsion thrusters for deep-space missions the size of SMART-1, including the so-called stationary-plasma, radio-frequency-ionisation and electron-bombardment-ionisation types.

Stationary Plasma Thrusters are a family of electric propulsion engines belonging to the category of "Hall-effect Thrusters" (Fig. 5).

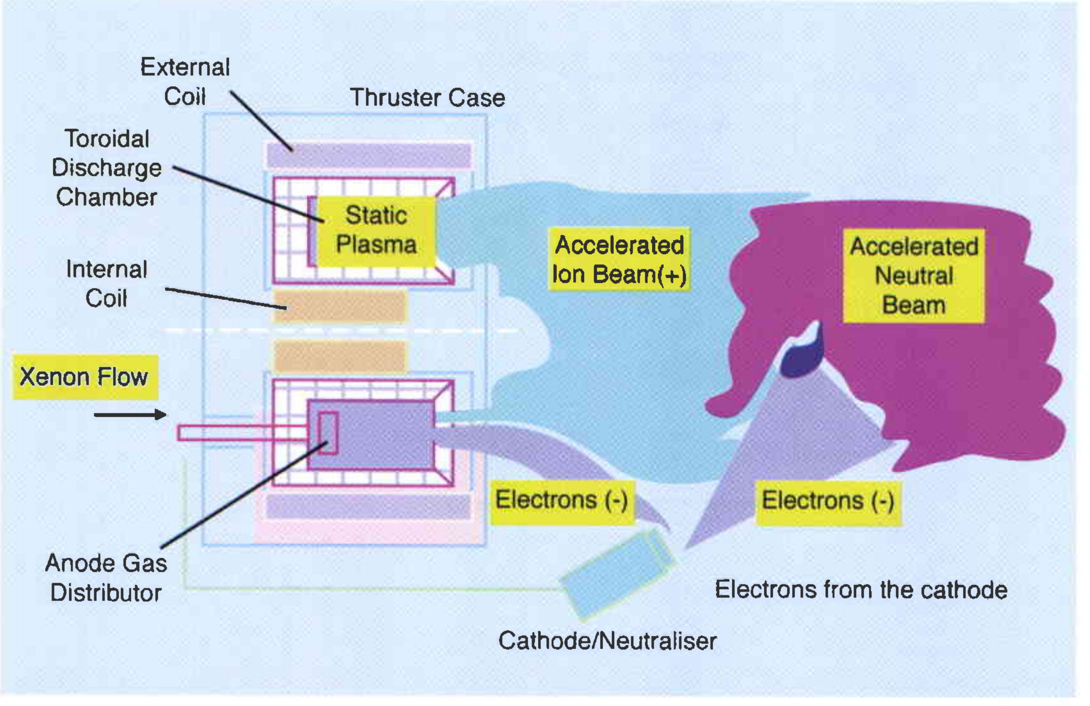


Figure 5. Schematic of a Stationary Plasma Thruster

Electrons from an external cathode enter a ceramic discharge chamber, attracted by an anode. On their way to the anode, the electrons encounter a radial magnetic field created between inner and outer coils, causing cyclotron motion around the magnetic field lines. Collisions between drifting electrons and xenon propellant create the plasma. The ions created are then accelerated by the negative potential existing near the exit of the chamber due to the Hall effect. The external cathode acts also as a neutraliser, injecting electrons into the thrust beam to maintain zero-charge equilibrium both in the beam and on the spacecraft. The PPS1350 has an exit diameter of 100 mm and provides a nominal thrust of 70 mN at 1640 s specific impulse (Isp) and 1350 W of nominal input power. This type of thruster, which can also work at reduced power, has already completed 7000 h of cyclic-operation qualification (corresponding to a total impulse of $2x10^6$ Ns).

Radio-frequency Ionisation Thrusters (Fig. 6) fall into the category of ion engines. The xenon propellant flows inside a ceramic discharge chamber through the extraction anode, which also serves as a gas distributor. The discharge chamber itself is surrounded by an induction coil connected to a radio-frequency (RF) generator. Free electrons within the xenon gas collect energy from the RF-induced electric field and ionise the neutral propellant atoms via inelastic collisions. The discharge is ignited by the injection of electrons from the neutraliser. Thrust is generated by the acceleration of ions

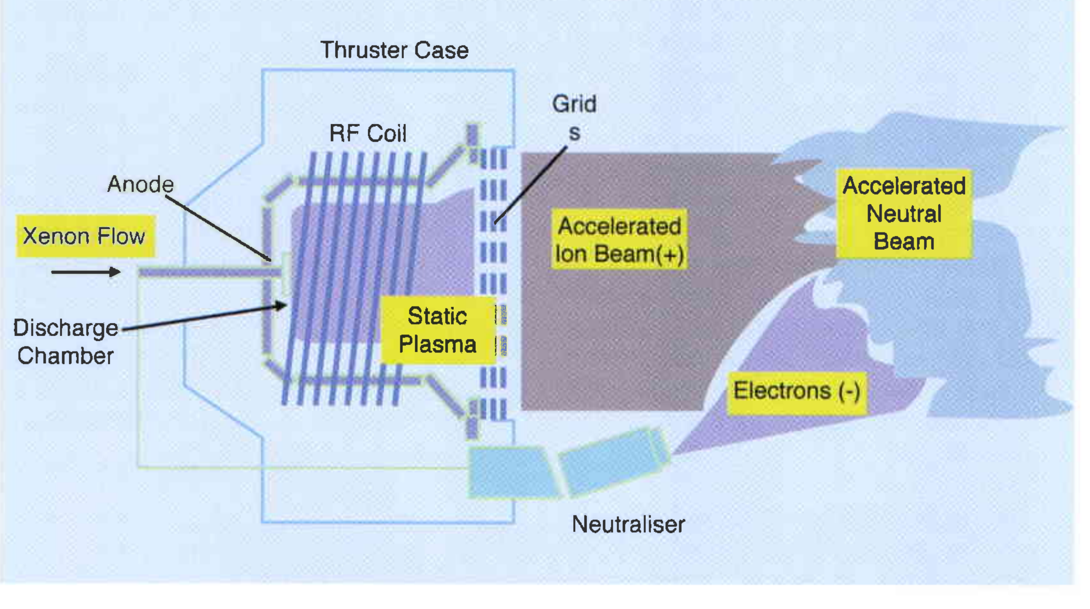


Figure 6. Schematic of a Radio-frequency Ionisation Thruster (RIT)

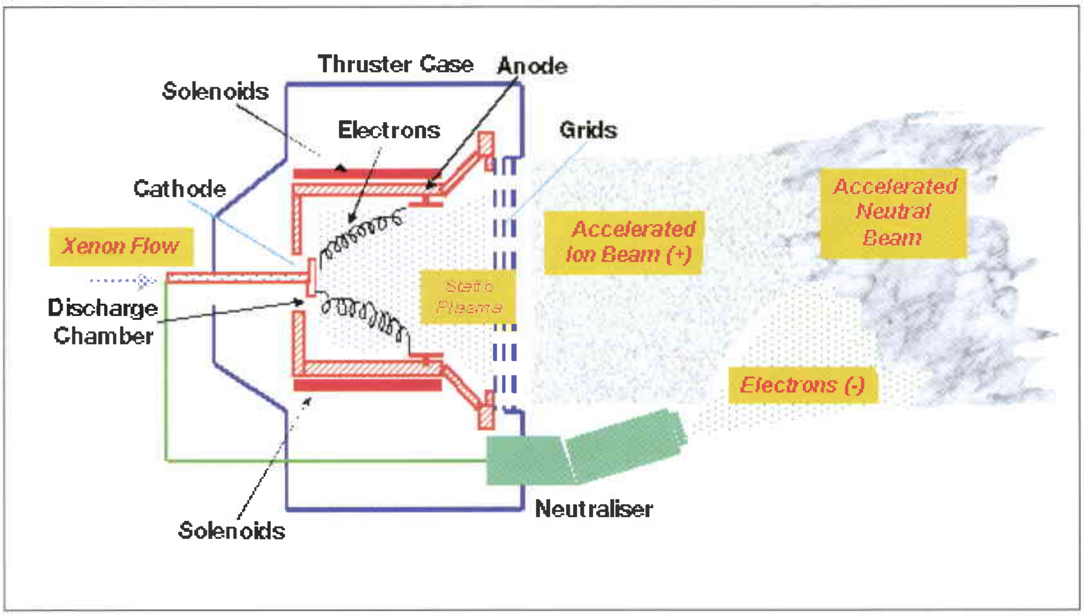


Figure 7. Schematic of an Electron Bombardment Ionisation Thruster

in the electrostatic field applied to an extraction system consisting of the extraction anode and three grids. The negative potential of these grids accelerates the positive ions out of the static plasma. A neutraliser injects electrons into the beam to maintain its zero-charge equilibrium and that of the spacecraft. The RIT-10 has an exit diameter of 100 mm and provides a maximum (modulatable) thrust of 23 mN at 3060 s Isp for an input power of 700 W. The thruster is presently being qualified for 15 000 h of cyclic operation (corresponding to a total impulse of 1×10^6 N) at 15 mN.

Electron Bombardment Ionisation Thrusters (Fig. 7) also belong to the ion-engine category. In this case the xenon propellant flows inside a ceramic discharge chamber through a gas distributor. Free electrons produced by a cathode inside the chamber are attracted by an anode pole at the end of the chamber and flow along magnetic field lines created by a number of electromagnetic coils surrounding the chamber. Along this path, the electrons hit the propellant atoms and ionise them. Thrust is generated by the acceleration of the ions in the electrostatic field applied to an extraction system consisting of the extraction anode and three grids. The negative potential of the grids accelerates the positive ions out of the static plasma. A neutraliser injects electrons into the beam to maintain zero-charge equilibrium in the beam and on the spacecraft. The UK-10 has an exit diameter of 100 mm and the current version provides a maximum (modulatable) thrust of 23 mN at 3400 s Isp for an input power of 700 W.

<u>Technology Announcement of Opportunity</u>

Within the scope of the present AO for technology items, the following categories of Technology Experiments were considered:

- Key spacecraft technologies, which shall be prime constituents of the spacecraft or of one of its sub-systems. An example of such a technology item could be the Lithium-Carbon battery used as sole power source during eclipse and not backed-up by any conventional type of battery. An example of a complete spacecraft unit realised as a technology experiment could be a deep-space TT&C package, including an X/Ka-band transponder and antennas, if fully supporting all telemetry of the scientific data.

- Technology for science and technology experiments/instruments ancillary to or in support of the mission and of its prime objective (demonstration of SEPP). Examples of items falling into this category could be the InP MMIC front-end of the millimetre-wave radiometer, or a plasma-diagnostic package for characterising the solar electric propulsion environment.

- Technology experiments for spacecraft units, which are complements of on-board technology items to be operated as experiments, i.e. in parallel with a spacecraft unit/part realised with a conventional technology. One such example could be a novel type of gyro, operated in parallel with the nominal ACS device, to characterise and compare its in-flight performance, or a small technology experiment such as a miniature laser altimeter supporting autonomous planetary navigation.

Spacecraft procurement and management

Spacecraft design

The three-axis-stabilised spacecraft has been preliminarily designed for accommodation on Ariane-5 (Cyclade configuration) or within the Eurockot fairing. This requirement strongly constrains the geometric envelope to a cylinder 2.4 m in diameter and 1.0 m high, making the size of the solar panels a critical spacecraft design parameter. The maximum power available therefore ranges from 1300 W with GaAs/Ge cells, to 1500 W with GaInP/GaAs/Ge cells. The solar panels rotate to provide continuous tracking of the Sun during the mission, whilst also allowing rotation perpendicular to the solar vector to cover all thrust directions. Lithium-Carbon batteries will be used. A data-handling and attitude-control system based on that of the Odin spacecraft is foreseen. Star sensors will provide attitude information. Fibre-optic gyros or accelerometer packages are also foreseen for safe modes and rate damping. The actuators will be reaction wheels and mono-propellant hydrazine thrusters, in addition to the two-axis gimbals of the SEPP. The communication system is based on an S-band transponder supporting packetised command and telemetry. A X/X-Ka band transponder is also foreseen as a technology experiment, together with a TWT high-power amplifier. In the case of the NEO mission, the communication subsystem would be based on an S/S-X or X/X-band deep-space transponder and high-gain antennas. The platform's dry mass ranges between 250 and 290 kg, depending on the type of engine chosen and the degree of redundancy implemented. The amount of xenon fuel needed, and consequently the payload mass available, strongly depends on which mission is chosen. However, the maximum expected fuel load is 70 kg, and an upper limit of 20 kg for payload has been set.

Management approach

To achieve the mission objectives set, within the strict budgetary constraints and given the obligations of the ESA Scientific Programme, a project management plan has been devised based on the following guidelines:

- Full up-front ESA involvement in the design phase in an integrated team with the prime contractor, in order to ensure that the design fulfils the mission requirements and scientific and technology payload-selection criteria.
- Minimum ESA involvement during the development phase in non-critical activities, but with the delegation to the prime contractor allowing ESA full visibility.
- ESA involvement as the supplier of critical technologies.
- Full down-stream ESA involvement in the critical mission operations and in the assessment of the technological results.

This new management approach is aimed at maximising the use of the existing technical expertise, whilst reducing the management overhead, maintaining a high product standard and controlling the associated risks.

Acknowledgement

The authors wish to acknowledge the contributions of all those who have supported SMART-1 project in recent months, in particular: the team led by the Swedish Space Corporation; the staffs of the ESA Directorate of Technical and Operational Support, Directorate of Industrial Matters and Technology Programmes and Contracts Department; the external Science Team; the small ESA project team; and the Delegations for their constructive involvement.

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Improving Rosetta's Return-Link Margins

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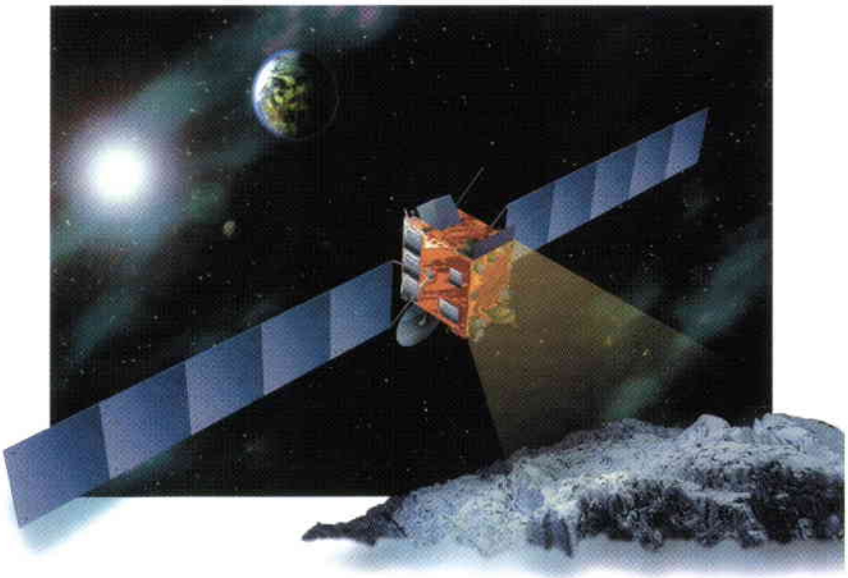
The Rosetta mission is designed to study in-situ a cometary nucleus' environment and its evolution in the inner Solar System. To be launched in January 2003 by an Ariane-5, Rosetta will rendezvous with Comet P/Wirtanen in 2011, after one Mars- and two Earth-gravity assists, and two asteroid fly-bys. The near-comet operations, which are scheduled to last about 1.5 years, will require a minimum return-link telemetry data rate of 5 kbit/s to meet the scientific goals, with about 14 hours of daily coverage.

Rosetta will operate in the frequency bands allocated by the Geneva-based International Telecommunications Union (ITU) to deep-space missions operating 2 million kilometres or more from Earth. These bands enjoy stringent protection requirements, making them virtually free of radio-frequency interference from other services. Moreover, the limited number of such missions makes it acceptable to adopt coding and modulation schemes that are optimum for power-limited as opposed to bandwidth-limited systems. This article describes the efforts currently being made to optimise Rosetta's communications capabilities in this respect.



Artist's impression of the Rosetta mission

Introduction

Rosetta will be ESA's most demanding mission to date in terms of its ground-station requirements (Fig. 1). In order to be able to support the mission using the Agency's own facilities, development of the first ESA deep-space antenna, to be sited at Perth in Western Australia, has been initiated (Fig. 2). Despite the high performance of such a state-of-the-art antenna — with its diameter of 34 m, cryogenically cooled low-noise amplifiers, and receivers with bandwidths as narrow as 0.3 Hz, etc. — the return-link margins needed for Rosetta can only just be satisfied, with little contingency for performance degradation during a mission with a nominal lifetime of about 11 years, operating some 5.8 AU from Earth. In extreme situations in which only Rosetta's Low-Gain Antenna (LGA) can be used, even low-rate telemetry cannot be supported using existing systems.

In 1993, a new signal-coding concept known as 'turbo coding'* was introduced by Berrou et al. It attracted much attention by promising greatly improved communications performance as close as 0.5 dB to the Shannon limit, which represents the theoretical optimum. Following regulatory discussions at the May 1996 Meeting of the Consultative Committee for Space Data Systems (CCSDS), ESA decided to place a study contract with the Communications Group at Politecnico di Torino to investigate the technique further. One aspect of interest stemmed from the fact that the end-product is the received frame instead of the received bit. It was therefore decided to investigate whether the Frame Error Rate (FER) performance would be as good as the Bit Error Rate (BER) performances being cited in the turbo-code-related papers appearing in the literature at the time. The real goal was to develop design criteria aimed at finding turbo codes with gains about 1.5 dB (at an FER = 1×10^{-4}) higher than that of the CCSDS standard concatenated code adopted as the baseline for Rosetta.

Figure 3 illustrates the evolution of coding for space applications. It shows how, from the first missions of 1958 until the end of this century, higher coding gains have brought increasing decoding complexity, and how turbo codes

* Turbo code: licence France Télécom & Télédiffusion de France

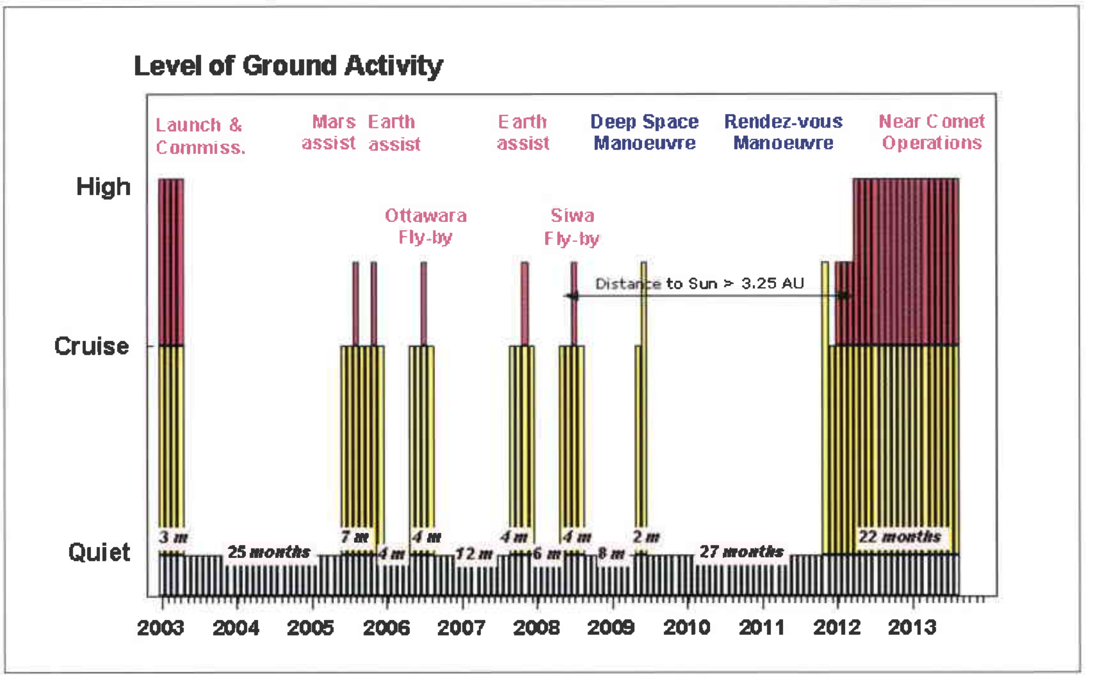


Figure 1. Rosetta mission-activities chart

offer the prospect of high gains with still moderate complexity. The concatenated code currently baselined for all ESA and NASA missions was first used in 1981 on Voyager, while the first ESA mission to use it was Giotto, launched in 1985. It is currently being used for ESA's Cluster-II and is presently also baselined for Rosetta. The convolutional code used on ESA's recent ISO mission was first flown on Voyager in 1977. It can be seen that these codes lay on a straight line in the complexity versus gain domain. Large deviations from this line were necessary due to the problems with the Galileo antenna. The so-called long constraint length (14, 1/4) convolutional code needed for the Galileo missions is shown to produce an extra margin of 2 dB over the concatenated code at the expense of a three orders of magnitude increase in complexity! The turbo codes considered here are potentially on the straight line again, yet achieve better performance than the Galileo codes and closely approach the theoretical limit predicted by Shannon.

The Rosetta telecommunications

As is customary with deep-space missions, Rosetta's down-link modulation scheme will be binary PCM/PSK/PM* on a square-wave subcarrier. The CCSDS-recommended coding scheme is the concatenated Reed-Solomon (255,223) and convolutional (rate 1/2, 64

* PCM / PSK / PM = Pulse-Code Modulation / Phase-Shift Keying / Phase Modulation

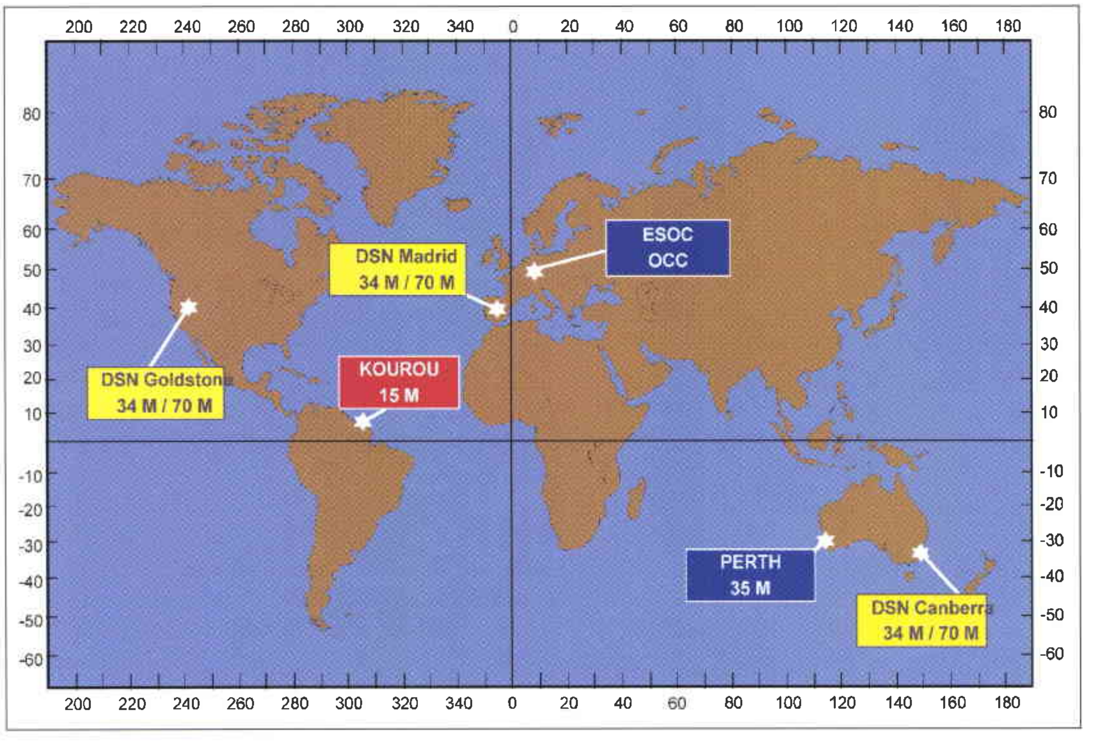


Figure 2. The Rosetta ground-station network

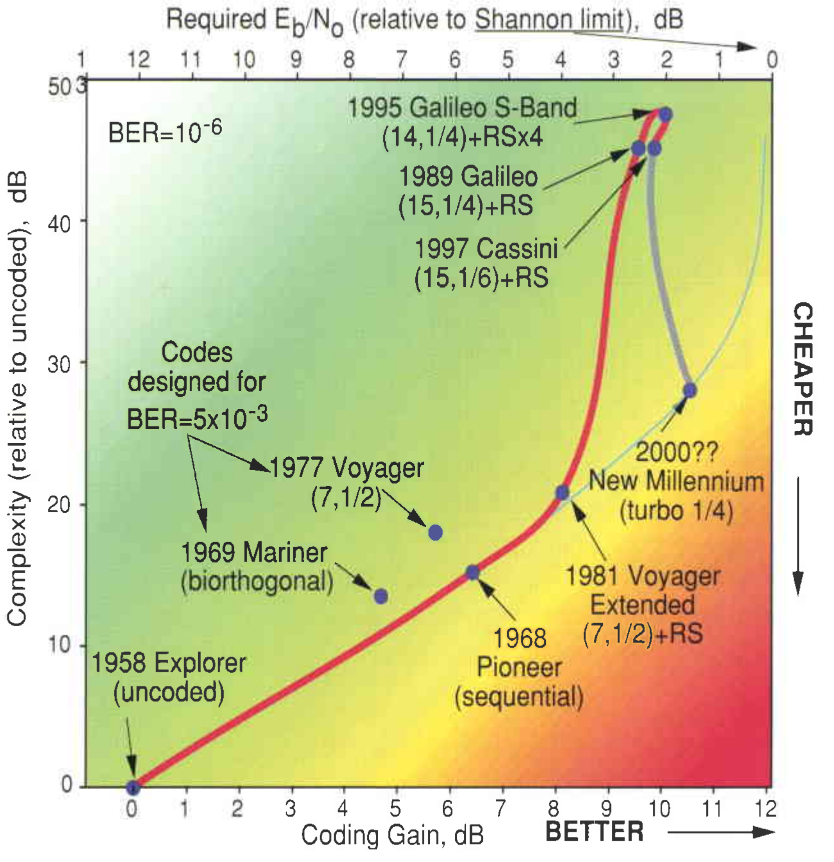


Figure 3. Historical evolution of coding for deep-space missions
(Courtesy of NASA/JPL; Copyright JPL/Caltech)

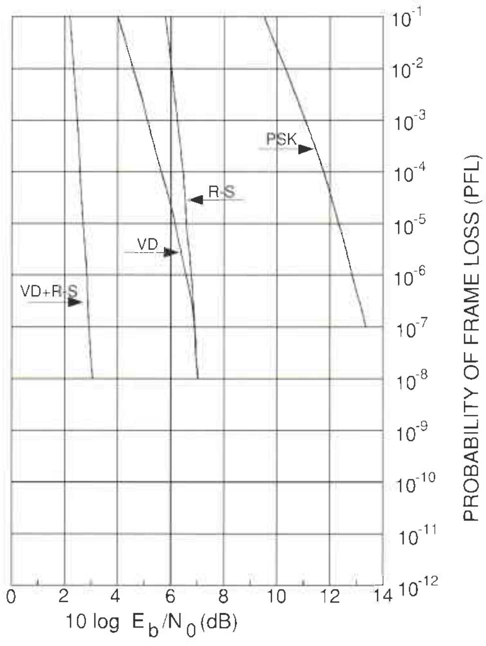


Figure 4. Frame Error Rate (FER) performances of the various CCSDS codes

Turbo Encoding

A turbo code, which functionally is a Parallel Concatenated Convolutional Code (PCCC for short), is formed by two convolutional encoders and one interleaver (Fig. 5). The information sequence u enters the first encoder C1, which generates the coded sequence x1. At the same time, u is permutated by the interleaver into a new sequence uP, which is successively encoded by the second encoder C2, giving rise to the coded sequence x2. The code sequence x of the PCCC code CP is obtained through the concatenation of the two encoded sequences x1 and x2. Designing a PCCC involves optimising the two convolutional encoders and the interleaver.

To be compatible with one of the existing frame lengths allowed by the current standard concatenated coding scheme, the interleaver length N was chosen equal to 8920 bits, corresponding to 5 input words of a (255,223) Reed-Solomon code with 8 bits per symbol (N=8920=5*223*8). The development effort has therefore been decoupled into two separate design stages, the first optimising the two convolutional encoders, and the second seeking a suitable interleaver with length N=8920.

To perform the first step, the presence of an 'average' interleaver, called the 'uniform' interleaver has been assumed, so that the two convolutional encoders can be optimised as those offering the best performance averaged with respect to the whole class of interleavers.

The optimisation has been performed for PCCCs with rates of 1/2, 2/5, 1/3, 1/4, and 1/6, and upper bounds to the Frame Error Rate (FER) have been evaluated in the presence of the uniform interleaver. Figure 6 shows the FER performance for different interleaver lengths and numbers of states (and therefore complexity) of the convolutional encoders. Figure 7 only shows the performance of the selected 16-state turbo code versus E_b/N_0 (signal-to-noise ratio) for three different interleaver lengths (and therefore frame lengths). Looking at these figures, an FER of better than 10^{-4} is obtained by the CCSDS standard at $E_b/N_0=2.62$ dB, and better than 10^{-6} at $E_b/N_0=2.88$ dB. Both the rate 1/2 and 1/6 turbo codes achieve a gain with respect to both FER specifications. However, the gain at $FER=10^{-6}$ appears to be marginal, and this can be attributed to the relatively poor performance of the uniform interleaver.

Having optimised the two convolutional encoders, the interleaver has been designed using the so-called 'spread-interleaver' approach, which leads to an interleaver permutation whose integer values are chosen randomly, although this imposes a constraint on the minimum separation of two consecutive interleaver positions.

Figure 8 shows as an example the simulated results and the extrapolated curve for the rate 1/6 PCCC, obtained by concatenating a 16-state, rate 1/4 optimal systematic, recursive convolutional encoder with a rate 1/2 encoder obtained from the optimal 16-state rate 1/3 encoder by eliminating the systematic bit. The curves show a frame error probability of around $4.4x10^{-4}$ at -0.2 dB.

states) code, for which both ESA and NASA have coders and decoders available off-the-shelf. With a Reed-Solomon code interleaving depth of 5, the Rosetta Frame Error Rate is met when the bit signal-to-noise ratio (SNR = E_b/N_0) is greater than 2.62 dB. The performance of this code is shown in Figure 4, where it (indicated as VD+R-S) is compared with the uncoded Phase-Shift Keying (PSK), the Reed-Solomon (R-S) and the convolutional (VD) performance. The coding rate, currently set to 1/2.28, could be reduced to 1/6 without problems. Thanks to the coherency between symbol clock and subcarrier frequency, the ESA ground-station demodulators achieve symbol synchronisation down to SNR values much lower than required for concatenated decoding and could therefore accommodate coding schemes with lower rates without needing to redesign the demodulation chain.

The coding improvements

Extracting extra dBs of gain from the Perth antenna is not possible without incurring major costs, as its specifications are state-of-the-art for a 34-m antenna. Increasing its diameter beyond 34 m would require a completely new design and double the cost. Enlarging Rosetta's on-board High-Gain Antenna (HGA) or increasing its transmit power is also not viable, and moreover would not help in emergency situations where the HGA cannot be used. The development efforts have therefore been focused on potential improvements in the coding area, and turbo coding in particular for its promise of approaching the theoretical maximum gain obtainable (the Shannon limit). The details are given in the accompanying panel.

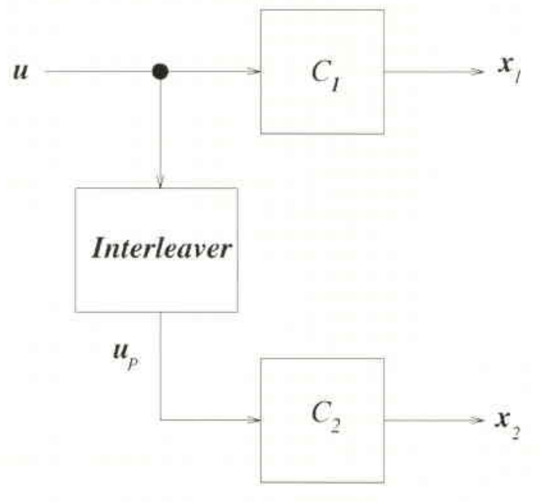


Figure 5. The turbo-encoding concept

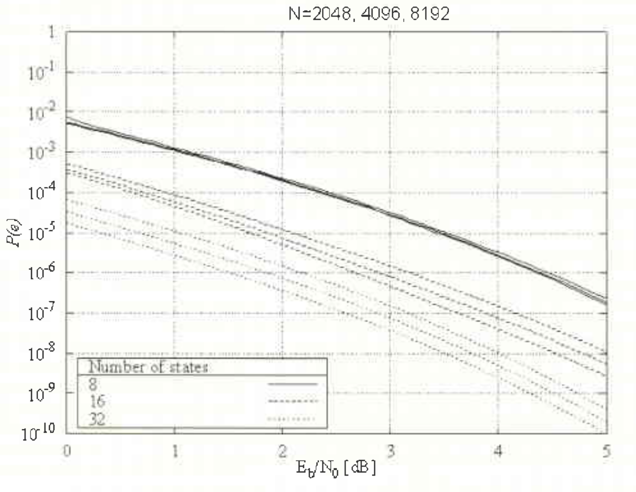


Figure 6. FER versus E_b/N_0 bounds for proposed rate 1/2 turbo codes

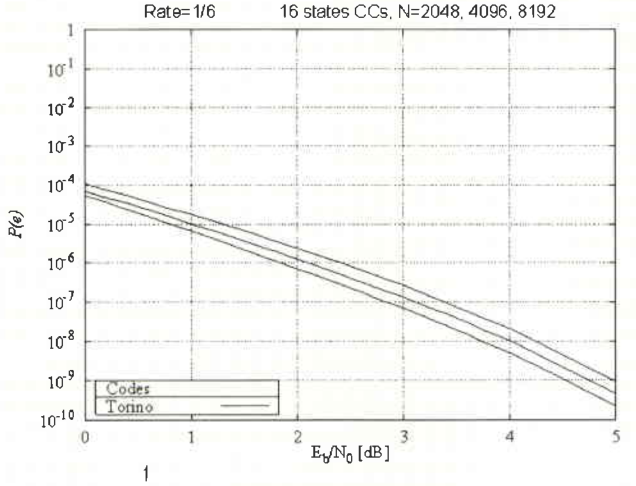


Figure 7. FER versus E_b/N_0 bounds for 16-state rate 1/6 turbo code

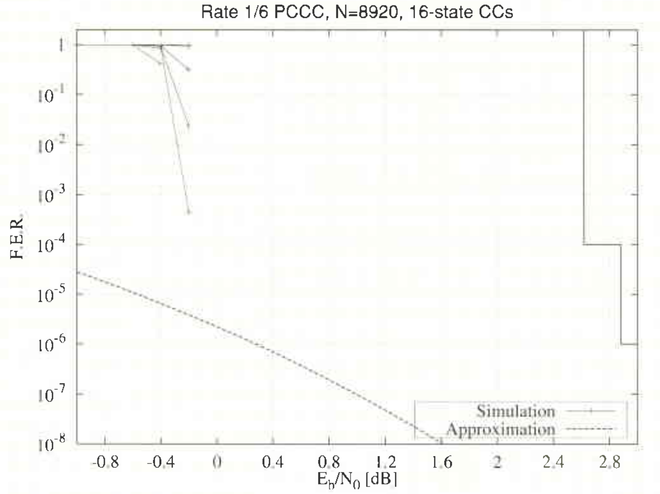


Figure 8. Simulated FER versus E_b/N_0 curves for 16-state rate 1/6 turbo code and spread interleaver (N=8920)

The coding gains of the proposed 16-state Parallel Concatenated Convolutional Codes (PCCCs) over the present 64-state CCSDS standard are summarised in Table 1 for various code rates and for the two representative values of FER, i.e. 10^{-4} and 10^{-6}. These gains are based on the turbo encoders proposed for CCSDS adoption (with the exception of rate 2/5).

Table 1. Estimated improvement compared with current CCSDS concatenated coding scheme (Reed-Solomon and 64-state convolutional encoder)

Code Rate	Improvement [dB]	
	@ FER = 10^{-4}	@ FER = 10^{-6}
1/2	1.7	~ 1.2
2/5	2.0	~ 1.6
1/3	2.3	~ 2.0
1/4	2.5	~ 2.0
1/6	2.7	~ 2.0

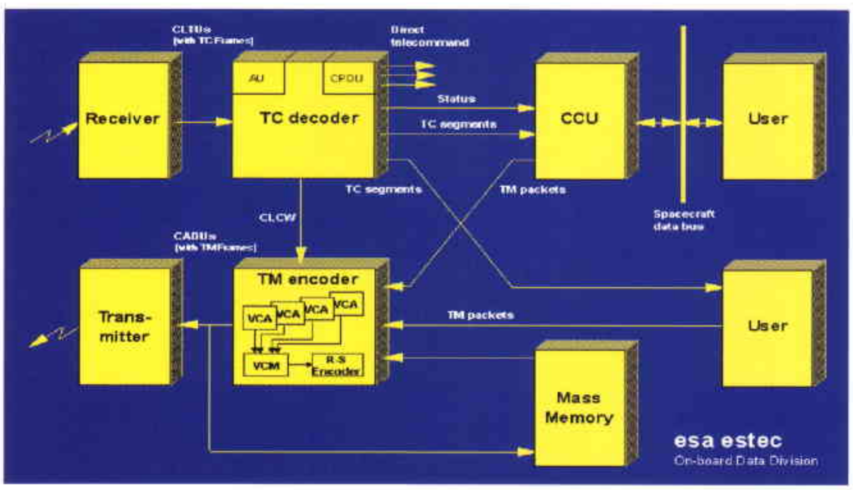


Figure 9. A typical onboard telemetry and telecommand data-processing approach for an ESA spacecraft

The extensive simulation results suggest the following conclusions:

- With respect to the CCSDS performance goal, the use of parallel concatenated codes yields a significant saving in E_b/N_0 for both frame error probabilities considered (10^{-4} and 10^{-6}).
- For the higher frame error probability, i.e. 10^{-4}, the expected gain ranges from 1.7 dB (for the rate 1/2 code) up to 2.7 dB (for the rate 1/6 code). Note that these coding gains have been obtained by simulating the iterative very reliable.
- For the lower value of frame error probability, i.e. 10^{-6}, the expected gain ranges from 1.2 dB (for the rate 1/2 code) up to 2.0 dB (for the rate 1/3 code). Decreasing the code rate does not seem to yield improvements in this case. These coding gains have been obtained through a semi-analytical extension technique, which implies maximum likelihood decoding, and must therefore be considered good approximations of those obtainable with the iterative decoding algorithm.
- The sensitivity of performance to the phase jitter due to the carrier recovery scheme of a practical receiver has been measured in terms of bit error probability degradation. It has been verified that a carrier-to-noise ratio of 17 dB in the carrier recovery loop (the same as required by the present standard) is sufficient to guarantee a degradation below 0.1 dB in E_b/N_0, for both rate 1/2 and rate 1/6 codes.

The outlook for Rosetta

CCSDS standard concatenated encoding is the baseline for Rosetta and will be implemented on board with the usual ESA data-processing approach based on dedicated hardware, as shown in Figure 9. Since the frame-length values proposed in the turbo-code option of the CCSDS Channel Coding Recommendation (undergoing Agency review) correspond to those allowed for Reed-Solomon encoding, it will be possible to retain the current upper-layer implementations unaltered, still using the standard ASICs for on-board frame generation.

As the data rates needed for Rosetta are comparatively low, the turbo encoding can be implemented in software and used only when required to achieve the necessary link margins. The uncoded frames would always be generated by the VCM ASIC, be encoded by software routines, augmented by the addition of the required synchronisation markers, and then sent to the 'transmitter'. The only foreseen impact of turbo coding on Rosetta's on-board telecommunications system is that a different symbol rate has to be accommodated by the transponder's modulator, unless the information bit rate is properly adjusted.

Since the turbo routines are proposed for software implementation, different coding schemes (potentially even closer to the Shannon limit) could be loaded onto the spacecraft by ground commands during the 11-year mission, for use as required. As the existing ground-station demodulation chains are also compatible with the proposed codes, only replacement or augmentation of the existing decoders and frame synchronisers would be required. It is therefore believed that this choice is the most cost-effective solution for increasing Rosetta's return-link margins by as much as 2.7 dB.

Acknowledgement

The authors would like to acknowledge productive discussions with Prof. C. Berrou of Ecole Nationale Supériore des Télécommunications de Bretagne, Dr. F. Pollara of NASA/JPL and Dr. J-L. Gerner of ESA/ESTEC.

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Looking Back at ISO Operations

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The Infrared Space Observatory (ISO), the world's first true orbiting infrared observatory, was switched off in May 1998, long after the expiry date foreseen in the specifications for the mission. Instead of the required 18 months, the highly-successful in-orbit operations of this excellent satellite continued for more than 28 months leading to an extensive database of observations which will be providing astronomical surprises for years to come. This article looks back at the way operations were conducted.

Introduction

ISO consisted essentially of a large cryostat which contained at launch about 2300 litres of superfluid helium to maintain the Ritchey-Chretien telescope, the scientific instruments and the optical baffles at temperatures of 2 – 8K. The telescope had a 60-cm diameter primary mirror. A three-axis stabilisation system provided a pointing accuracy at the arc-second level. ISO's sophisticated instrument complement, built by international consortia of scientific institutes and industries, consisted of an imaging photo-polarimeter (ISOPHOT), a camera (ISOCAM), a Short Wavelength Spectrometer (SWS) and a Long Wavelength Spectrometer (LWS). Together the instruments provided a variety of spectral and spatial resolutions across the wide wavelength range of 2 – 240 microns. ISO was placed into a highly-elliptical orbit on 17 November 1995 by an Ariane-4 launcher. The launch and early operations phase was planned and controlled by ESA's main Operations Centre, ESOC. Once the spacecraft status had been checked out, and the perigee-raising manoeuvre was executed, the operations were transferred to ESA's Satellite Tracking Station in Villafranca, Spain (Vilspa).

In orbit, all satellite systems performed superbly with the pointing accuracies being up to ten times better than specifications and with the liquid helium coolant lasting until 8 April 1998, nearly 30% longer than specified, not only leading to more observations but also permitting access to the Orion region of the sky, which was not visible during the nominal mission. All instruments worked very well and returned vast quantities of high quality data. The many scientific highlights of ISO include: the detection of water on Titan, on the giant planets, around young and old stars and in distant galaxies; peering into the cradles of star formation; elucidation of the nature of the mysterious power sources energising some of the most luminous galaxies; and peeking back in time to gather clues to the formation and early evolution of galaxies.

Following exhaustion of the liquid helium supply, a number of technological tests, aimed at gathering data to benefit future missions, were carried out. The satellite was then switched off on 16 May 1998.

Operational concept

The operational concept of ISO was driven by several constraints: severe sky coverage limitations due to pointing constraints on the spacecraft, the complexity of the scientific instruments, and the necessity to conduct many short observations under ground station coverage (no onboard data or command storage for instrument operations). The overall pace of operations and the individual observations in a single programme being widely separated in time meant that 'observers' were not present during the execution of their observations. Thus, ISO was operated in a service observing mode with each day's operations planned in detail up to three weeks ahead in time.

This concept drove the design of the ground segment, which consisted of the Spacecraft Control Centre (SCC) and the Science Operations Centre (SOC), both co-located at ESA's Villafranca premises near Madrid, Spain and two ground stations. ESA provided one ground station, located in Villafranca. The second ground station, located at Goldstone,

More details about ISO, its instruments and its early scientific results may be found in articles in ESA Bulletin numbers 84 and 86. The project information is also available via the ISO WWW server at: http://www.iso.vilspa.esa.es/

California, was contributed by the National Aeronautics and Space Administration (NASA). Additional resources, enabling ISO to be operated for a longer period per day, were supplied by the Institute of Space and Astronautical Science (ISAS), Japan. Together, both tracking stations provided approximately 22 hours/day of real-time support. Figure 1 gives an overview of the main elements of the ISO Control Centre.

The SCC team, within the Directorate of Technical and Operational Support (D/TOS), was responsible for the conduct and control of the flight operations for ISO, and had full responsibility for spacecraft health and safety, including that of the scientific instruments. The SOC team, within the Directorate of Science (D/SCI), was responsible for the operations of the scientific instruments, including observing programmes, and data reduction and distribution.

Community support

ISO – as an observatory – was open to the astronomical community including expert and non-expert users. The community support task was to facilitate scientifically-effective use of ISO and included handling all requests for observing time as well as providing concise and up-to-date information.

Approximately 45% of ISO's time was reserved for those parties contributing to the development and operation of the scientific instruments and the overall facility, namely: the instrument teams; the Mission Scientists; the scientific staff of the SOC; and ESA's international partners in the mission, NASA and ISAS. Definition and coordination of these guaranteed-time observations started some eight years before launch. In addition to its scientific value, this early start was important both to help define observing modes and also to be able to publish 'worked examples' to the community with the pre-launch call for proposals.

The remaining more than half of ISO's observing time was distributed to the general community via the traditional method of proposals and peer review. One 'Call for Observing Proposals' was issued pre-launch (April 1994) and one post-launch (August 1996). Over 1500 proposals, requesting almost four times more observing time than available, were received in response to these Calls. Some 40% of the proposals arrived in the last 24 hours before the deadlines. All proposals were evaluated scientifically by an 'Observing Time Allocation Committee' consisting of approximately 35 external scientists, supported by members of the Science Operations Centre (SOC) for technical evaluations. The necessary flexibility for follow-up observations during the mission was provided by discretionary time proposals, with over 150 proposals being received, of which 40% were in the last four months of the mission. Despite being very manpower intensive over relatively short periods of time, the proposal process worked very well.

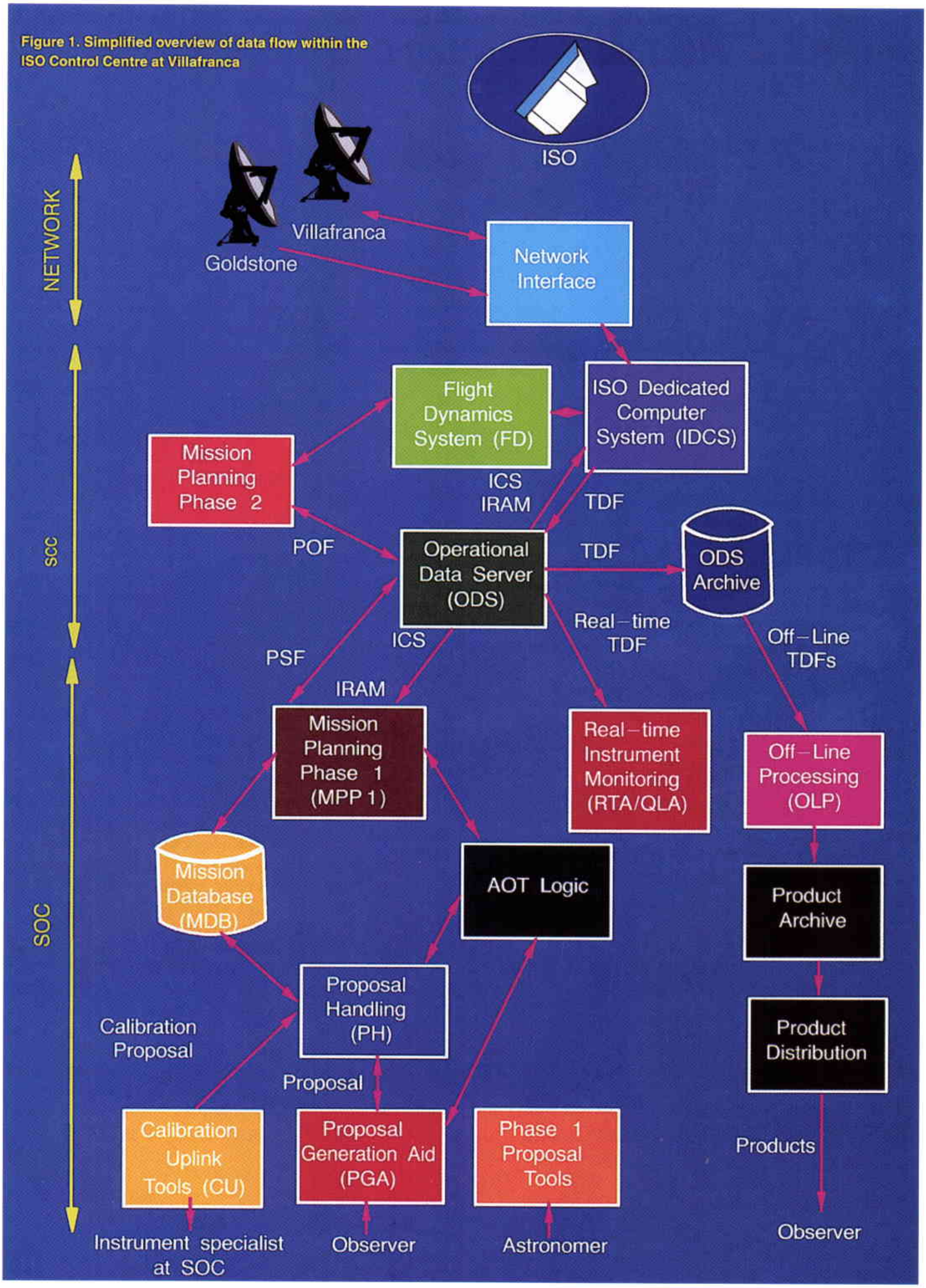
Successful 'proposers' then moved on to the next phase of the process. Here they had to enter full details of their observations into the SOC's databases. Prior to launch, this typically involved a visit of around a week to a specific data-entry centre set up in ESTEC (for US observers, a similar centre was operated at IPAC). The European centre at ESTEC was co-located with the Science Operations Centre during its development phase, prior to moving to Spain. The Infrared Processing and Analysis Center (IPAC) was designated by NASA as the support centre for US ISO observers. Over 500 astronomers visited ESTEC in the first six months of 1995 and were assisted by resident astronomers and technical assistants in finalising and entering their observational programmes. Post-launch as experience and confidence grew, visits were almost completely replaced by remote logins across the Internet.

During the in-orbit operations, observers were permitted to tune up their programmes – via Internet communications with the Science Operations Centre – to take full advantage of results from previous observations and of improving knowledge of how best to use the instruments. The facility was widely used, with – averaged across the entire set of observations – each programme being updated around three times. Because scientific judgement often had to be involved, checking that updated observations did not duplicate existing ones was a very labour-intensive task.

Prior to launch, user documentation (such as observers' manuals, data reduction manuals, information notes, etc.) was mainly paper-based. However, during the operations, this completely switched to being Web-based. The ISO WWW site opened in 1994 and had over 1 million hits (from non-ESA machines) during operations. It rapidly became the essential way of communicating with observers. The site was continually upgraded, e.g. with the addition of galleries of science results and of tools for detailed monitoring of execution of observing programmes.

By its nature, community support is a labour-intensive and open-ended task and will always be limited by available resources. On ISO, it

Figure 1. Simplified overview of data flow within the ISO Control Centre at Villafranca



worked very well; however, looking back, one would have liked to have been more proactive in getting even more information out to the community.

Science operations

ISO science operations were organised almost as a factory 'production line'. The starting point was the databases into which observers had entered all the details required to implement their observations in service mode. Each observation was technically validated and then loaded into the so-called Mission Data Base (MDB), which at the end of the mission included more than 40 000 observations.

The next step was to generate a long-term plan, showing when and how the most scientifically-important observations could be implemented. This was particularly important in the case of a mission like ISO with a short lifetime and with only a limited part of the sky accessible at any given time. A coarse pre-scheduling of the next three months was made. This process was extremely time- and resource-consuming and never worked quite as expected since one was dealing with a 'moving target'. In other words, the flexibility offered to the observers to optimise their observing programmes meant that the input changed faster than the plan. This flexibility was necessary and greatly enhanced the scientific return. However, extensive and complex manual work was required to enable ISO to successfully execute nearly 98% of the highest priority observations. Similar missions in the future should be able to generate a representative long-term plan within a few days with minimal human intervention.

Next in the production line came the detailed planning of each day's observations to the level of instrument commands at a granularity of 1 second of time. The goal here was to minimise slew and dead time, and generate efficient schedules while preserving the scientific content (i.e. carrying out the high priority observations). The system worked very successfully and produced schedules with an average efficiency of 92%, where efficiency is defined as the ratio of the time the satellite was accumulating scientific data to the available science time. In fact, the actual efficiency achieved can be considered to be even higher since nearly two-thirds of the time for slewing between targets was used to gather serendipitous data at previously-unsurveyed infrared wavelengths with the photometer, and since the camera and Long Wavelength Spectrometer collected data in parallel modes when the observer had specified use of another instrument. Part of the trick was to do 'overbooking'. In other words, the mission database was filled up so that it always contained about twice as many observations as could be accommodated during the remaining ISO lifetime. In essence, short lower-grade observations were used to fill in gaps between high-grade ones.

The SOC monitored the instruments in real time as the observations were executed automatically, but had the capability to intervene manually if necessary. There were few instrument anomalies; typical interventions were, for example, the 'closing' of the camera if a bright target entered its field of view. This was required to avoid saturation and its long-lasting effect on the detectors.

The final steps in the production line involved the processing, quality control, archiving and finally the distribution of the data on CD-ROMs. From an operational point of view, the processing and archiving of the data worked flawlessly. Over 10 000 CD-ROMs were distributed to observers. The processing algorithms and calibration were initially far from perfect and, in fact, improvements will continue for the coming years. However, within one year of launch, an ISO-dedicated issue of Astronomy and Astrophysics containing nearly 100 scientific papers, had been published. Given the inherent complexity of the instruments and in particular of the behaviour of the IR detectors, this is a significant achievement.

One of the major factors in the successful operation of ISO's sophisticated instruments was the assignment to each of an 'Instrument Dedicated Team' (IDT) of experts at Villafranca. The teams' responsibilities included: the overall maintenance of the instruments (including the real-time monitoring software and procedures); the calibration; and the design and much of the coding and testing of the data processing algorithms. Other experts, back at the Principal Investigator institutes, worked in close cooperation with the SOC's Instrument Dedicated Teams. These teams were crucial in making instrument operations run smoothly by rapidly diagnosing and fixing anomalies, by optimising the observing modes and by getting the instruments properly calibrated.

Much of the necessary complexity of science operation was embedded in the over one million lines of code of the SOC software. More than 1700 Software Problem Reports (SPR) were responded to and over 250 System Change Requests and Extra Wishes (SCREW) implemented in the course of the mission. This comes on top of the ~1000 SPRs and ~100

SCREWs implemented pre-launch, during and after the period of integration, tests and simulations. All of the SOC's software maintenance team had been involved in the development of the SOC software before launch. Such breadth and depth of experience turned out to be a major factor in the success of ISO science operations.

The SOC benefited greatly from having all functions (e.g. from establishing observing programmes to data distribution; from system design to software maintenance) integrated into the one centre as this streamlined interfaces and improved communications. For the same reasons, the co-location with the Spacecraft Control Centre was also very beneficial.

Another key factor was the extensive period of end-to-end tests and simulations through which the entire ground segment software and procedures were exercised prior to launch. Not only was this essential in uncovering bugs not found by lower level tests, but it also ensured that the whole SOC was fully trained and operational at launch. In particular, the full 58 days of the Performance Verification phase had been scheduled and validated on the software simulator prior to launch. This permitted that, 2.5 months after launch exactly as planned, the routine phase could start with over two-thirds of the observing modes fully commissioned and ready for use by the scientific community.

The Spacecraft Control Centre (SCC)

The Launch and Early Orbit Phase (LEOP) was supported directly from the Operations Control Centre at ESOC, Darmstadt; all subsequent operations were successfully supported from the SCC. The mission phases were as follows:

- Launch and Early Orbit Phase:
  17 to 20 November 1995
- Satellite Commissioning Phase:
  21 November to 8 December 1995
- Performance Verification Phase:
  9 December 1995 to 3 February 1996
- Routine Mission Phase:
  4 February 1996 to 8 April 1998
- Operations Run-Down Phase:
  9 April to 16 May 1998

Given the large number of relatively short observations, operations had to be carried out in an automated way. Starting from manual use of the Flight Operations Plan and associated procedures, operations were gracefully automated during the commissioning phase to use, by the end of this phase, a fully pre-programmed Central Command Schedule (CCS), reflecting the output product of the Mission Planning Phase 1 (SOC) and of the Mission Planning Phase 2 (SCC). This schedule contained all platform and payload commands. On average, some 10 000 commands had to be uplinked to the spacecraft every day. Therefore, only minimum operator intervention was required for spacecraft and instrument operations.

The CCS contained dedicated 'windows' during which either spacecraft or science operations could be scheduled. Additionally, 'event designators' and 'keywords' were defined that triggered certain command operations to be inserted in those windows, when required. A skeleton schedule for a revolution (orbit) is shown in Figure 2. The baseline approach during routine operations was that all four instruments were activated and de-activated automatically by the schedule, irrespective of whether a particular instrument was scheduled for use in that orbit or not.

To optimise the time available for scientific observations, spacecraft operations and instrument activation and de-activation were placed along an orbit in such a way that they did not use science time (defined as the time the satellite spent outside the main parts of the van Allen belts, i.e. above an altitude of approximately 40 000 km). Interleaved manual commanding was, in principle, only required to support ranging, ground station handover, and a few specific operations of the Attitude and Orbit Control Subsystem. The schedule offered 'hold', 'resume' and 'shift' functions in order to recover from, and to minimise the impact of, spacecraft, instrument or ground segment anomalies. When required, recovery from problems was initiated following the relevant Flight Control Procedures (FCPs) and Contingency Recovery Procedures (CRPs) of the Flight Operations Plan. It is worth noting that approximately 1000 FCPs and 500 CRPs had been written and validated with the platform simulator before launch.

During pre-launch testing, it was already realised that the command schedule was highly susceptible to ground-segment problems because of the very high scientific instrument command rate. In the event of problems, e.g. when commands could not be verified due to loss of telemetry, the schedule was suspended. In the worst case, a short drop in telemetry could cause the loss of a scientific observation of several hours' duration.

Throughout the in-orbit operations, a wide variety of efforts were successfully undertaken by the SCC to prevent or minimise the loss of

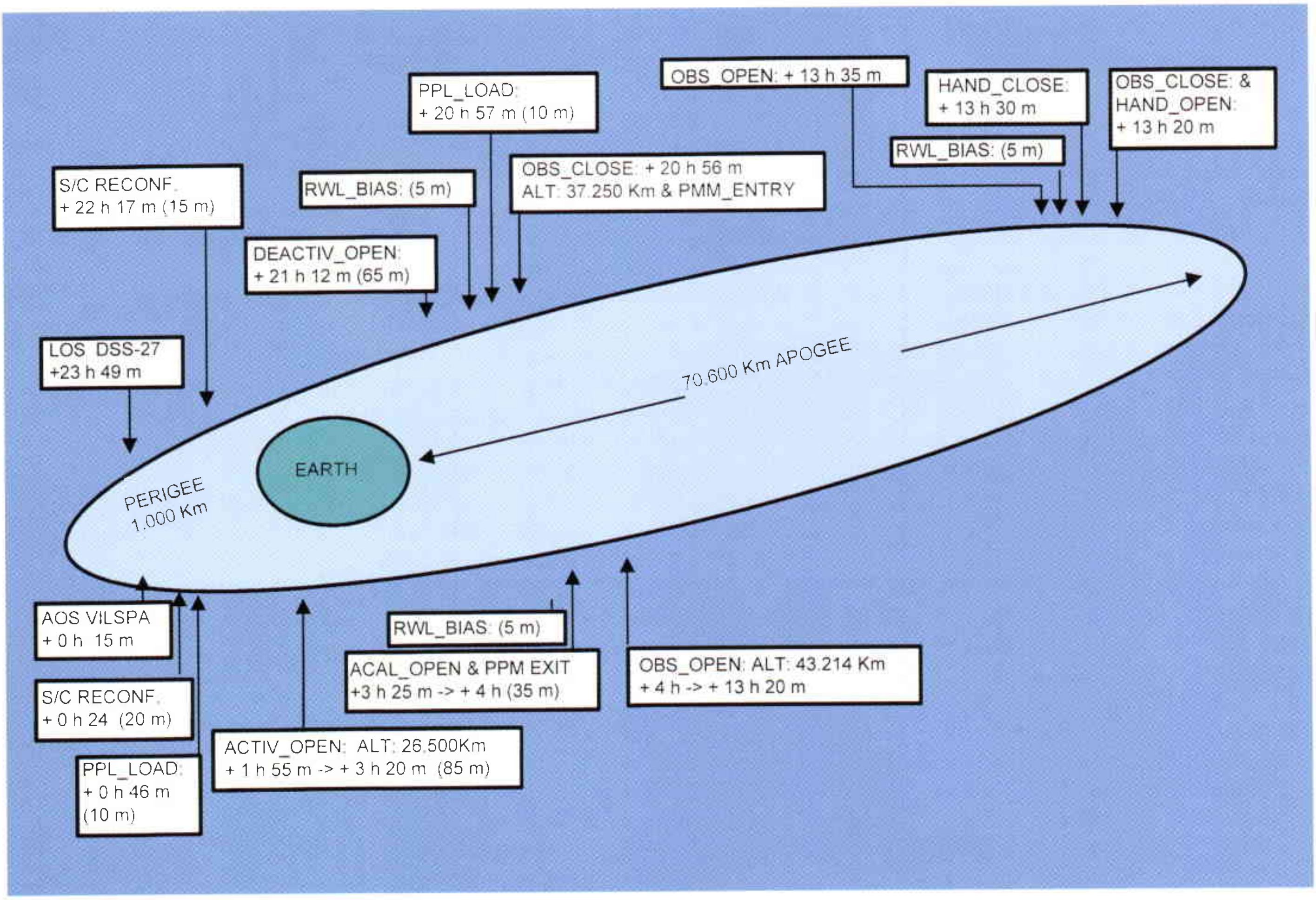


Figure 2. Skeleton schedule for ISO activities along an orbit, showing activities from acquisition of signal (AOS) at Vilspa to loss of signal (LOS) from the Goldstone DSS-27 antenna. Times are given in hours and minutes since perigee passage, and the duration of an activity is shown in brackets. Science observations started with the opening of the observation window (OBS_OPEN) about 4h after perigee passage and continued – with a short break at the time of handover from Vilspa to Goldstone – until OBS_CLOSE nearly 21h after perigee passage. The instruments were activated and de-activated during specific windows (ACTIV and DEACTIV), which also contained instrument calibration and trend analysis activities. PPL and PPM refer to a programmed pointing mode for autonomous pointings to an uplinked list of safe attitudes. During the ACAL window, various spacecraft attitude calibrations were carried out. Depending on the planned observing programme, the reaction wheels (RWL) had to be biased at various times during the day's operations

science. Major improvements included the implementation of an automatic telemetry link re-configuration on the ISO Dedicated Control System, which reduced the impact of telemetry drops considerably. The implementation of the Hipparcos/Tycho Guide Star Catalogue in the Flight Dynamics System (FDS) contributed greatly in solving the guide star acquisition problems encountered early in the mission. In a joint effort between the SOC and the SCC, a new observing mode was implemented for the Long Wavelength Spectrometer, enabling it to gather science data even when not scheduled as the 'prime' instrument.

Another improvement, which made a major contribution to the science output, was the reduction of the satellite's absolute pointing error from 4 arcsec during the commissioning phase to the 1 arcsec level in the routine phase, especially since the system specification was < 11,7 arcsec.

The ISO Mission Control System (see Fig. 3) performed all aspects connected with the operations and safety of the spacecraft, including safety monitoring of the scientific instruments. The hardware of the control system consisted essentially of two VAX 4600 redundant Spacecraft Monitoring and Control computers (ISORT/ISODV), six associated Sun SPARC-20 workstations, associated spacecraft control software, and the mission planning system software as far as Mission Planning Phase 2 was concerned. The system was designated as the ISO Dedicated Control System (IDCS). The FDS consisted of a set of five Sun workstations and dedicated software. These systems were networked on a partially-redundant OPSLAN to prevent single point failures and isolated the SCC from the outside world.

Two redundant micro-VAX 3100-76 computers formed the Operational Data Server system (ODS-1/2). The ODS constituted the interface between the spacecraft control system of the SCC and that of the SOC as far as science real-time data reception in the form of Telemetry Distribution Formats (TDF) was concerned. The latter contained not only telecommand history data, but also specially provided derived telemetry parameters. These parameters were utilised within the SOC for instrument monitoring and control purposes, using the Real-Time Technical Assessment (RTA) and Quick-Look Analysis (QLA) software, which ran on the four instrument workstations (one dedicated per instrument). The ODS was also the interface between the Mission Planning Phase 1 (MPP1) of the SOC and that of the SCC (MPP2) for interchanging mission planning files.

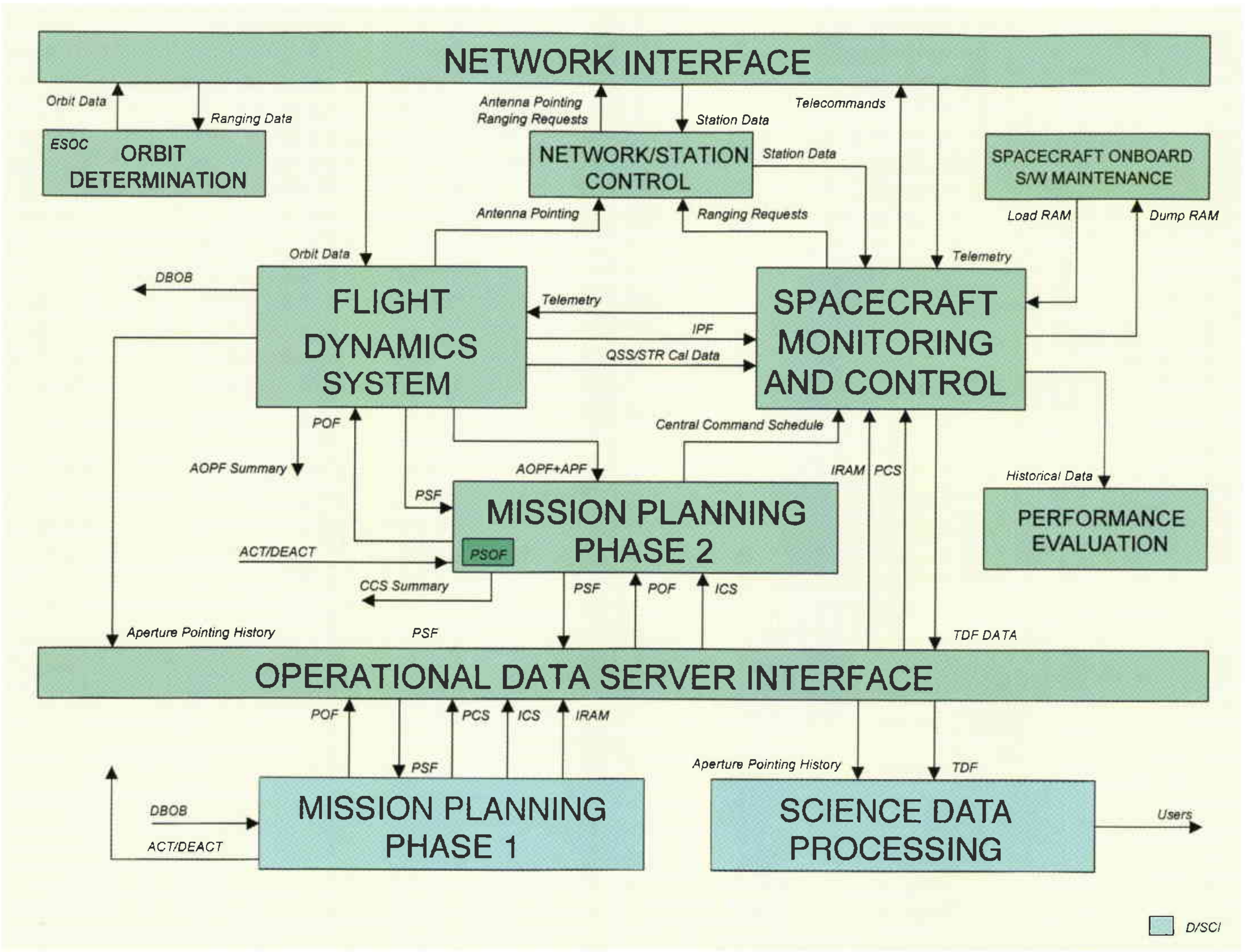
Furthermore, the ODS provided the short history archive of the science telemetry and archived TDFs onto optical disks for access from the SOC Science Data Processing system. The network interface provided the connectivity of the IDCS with the ground stations through the Integrated Switching System (ISS), as part of the OPSNET. Support functions were provided for: Spacecraft Performance Evaluation (SPEVAL), required to determine all aspects of spacecraft performance which could impact the life of the mission and mission efficiency; and spacecraft on-board software maintenance for the AOCS, STR and the OBDH. Communications Services were provided to interface with the ground stations, and with ESOC for ranging and orbit-related activities. Two spacecraft hybrid simulators were provided to support a variety of tasks, such as testing and validating procedures, AOCS on-board software maintenance and validation, and spacecraft anomaly investigation.

Extended mission

One very significant achievement was the mission extension beyond September/October 1997. During this time, ISO's orbital geometry was such that it underwent eclipses of exceptionally long duration. Additionally, during early September, marginal violations of the Earth constraint on the pointing direction could not be avoided for some minutes each day as ISO went through perigee. Since the spacecraft was required to be operated beyond design specifications with respect to power, Sun and Earth constraints, it was necessary to develop and implement a new operations strategy, which deviated considerably from the well-proven routine-phase operations concept. In addition to the above, there was a strong requirement from the scientific community to observe the Orion and the Taurus regions of the sky, which became visible to ISO during this period for the first time in the mission.

During the period 7 September to 7 October 1997, when eclipses reached a maximum of 166.5 minutes, i.e. more than twice as long as the baseline design of 80 minutes, the power of the two batteries had to be preserved by switching off non-essential units, by restricting scientific pointings to one observation during eclipse, and by restricting the use of the

Figure 3. The ISO Mission Control System



instruments to two out of four during the peak eclipse period. To ensure proper pointing stability in eclipse, a second 'roll star' was used by the Star Tracker. This star, some 2° away from the guide star, was used to control the gyro drift with respect to the satellite x-axis and hence the telescope boresight. At the same time, the Earth warning and forbidden regions had to be violated, since no constraint-free corridor was left around perigee. This was crucial for the Attitude and Orbit Control Subsystem (AOCS) and therefore for the telescope pointings around perigee. In order to reduce the impact of the penetration into the Earth-constraint region, the Sun constraint had to be relaxed.

All of the above required disabling most of the autonomous fallback functions of the AOCS and On-Board Data Handling Subsystems, i.e. the satellite was safeguarded by relying on ground control only. Both on-board batteries showed excellent performance with less than expected depth of discharge and reached full charge each revolution. The effect of violating the Earth constraints was less than predicted. The telescope upper baffle temperatures increased by just under 4 K, returning to nominal temperatures within 45 minutes thereafter. The AOCS pointing performance was very stable and hence scientific observations performed during eclipses did not suffer from any degradation in pointing. The period passed uneventfully and routine operations continued until the helium was depleted on 8 April 1998.

After helium depletion

After depletion of the liquid helium supply, an extensive 'technology test programme' was carried out with the spacecraft. Interleaved with these technical tests were observations using the shortest wavelength detectors of the Short Wavelength Spectrometer instrument to extend a stellar spectral classification scheme to the infrared. Various software and hardware systems that, due to the superb performance of the spacecraft, did not have to be used during the operational phase were subjected to detailed tests. Results from these tests will benefit future ESA missions, e.g. XMM and Integral, which use some of the same components, such as the Star Trackers guiding the spacecraft.

Operations summary

Operations ran very smoothly from the start. They were well served by a superb spacecraft, working much better than specified, and by robust instruments which, in general, suffered only a few anomalies of a relatively minor nature. All elements of the ground segment also performed excellently, leading to an overall system availability during routine-phase operation of 98.3% of the time scheduled for science. Taking into account all possible reasons for failure, only 4% of observations were lost.

Very few anomalies occurred with the spacecraft and the instruments. The largest single spacecraft anomaly occurred in May 1996, when a sequence of on-board events led to the Earth entering ISO's field of view for about 2 minutes. No damage was done to the satellite and full science operations were resumed within 36 hours. On the instrument side, the main anomalies were periodic increases in noise for some of the detectors of the photometer and some positioning difficulties with an exchange wheel of the Long Wavelength Spectrometer. Scientific usage of the instruments was temporarily interrupted while solutions were determined, tested and implemented.

During the routine operations phase, some 50 000 pointing requests (slews) were executed in order to carry out over 31 000 observations (including astronomical calibration observations). In total, over 26 450 science observations were carried out successfully for nearly 600 observers in over 1000 separate research programmes. About 400 hours of science observations were carried out per month, with an average of 41 observations per day but ranging from 6 to 238. The average observation duration was 24 minutes, with the shortest single observation having had a duration of 36 secs (a camera calibration) and the longest single observation having been nearly 8 hours on Titan. Figures 4 and 5 give information covering the relative usages of the different instruments and observing modes.

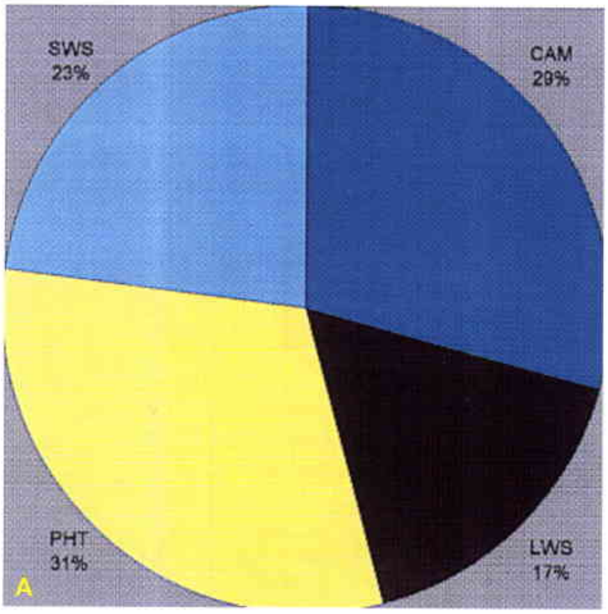
Organisation

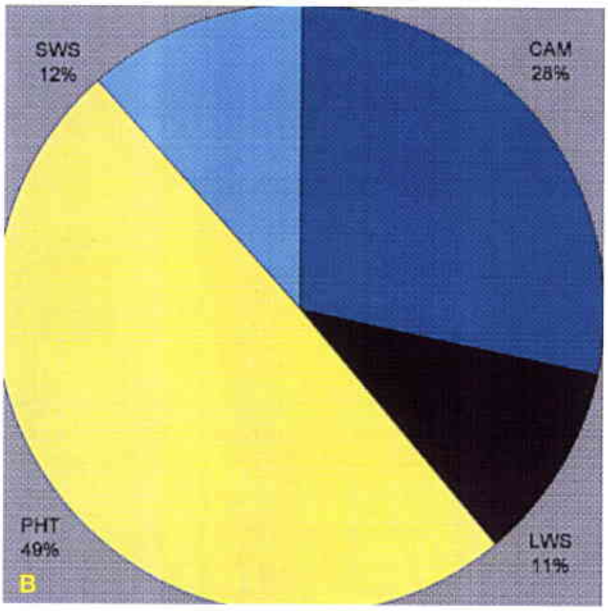
The SCC was led by the Spacecraft Operations Manager and, throughout the routine operations phase, there were 28.3 staff in post (Fig. 6).

The SOC was organised into two teams: the science team, led by the Project Scientist, which was responsible for community support and for setting the overall policy for the SOC; and the operations team, led by the Science Operations Manager, which was responsible for instrument operations and the SOC infrastructure. On average during the routine phase, the SOC had 92 members (Fig. 7).

Future scientific activities

A collaborative effort, coordinated by the ESA



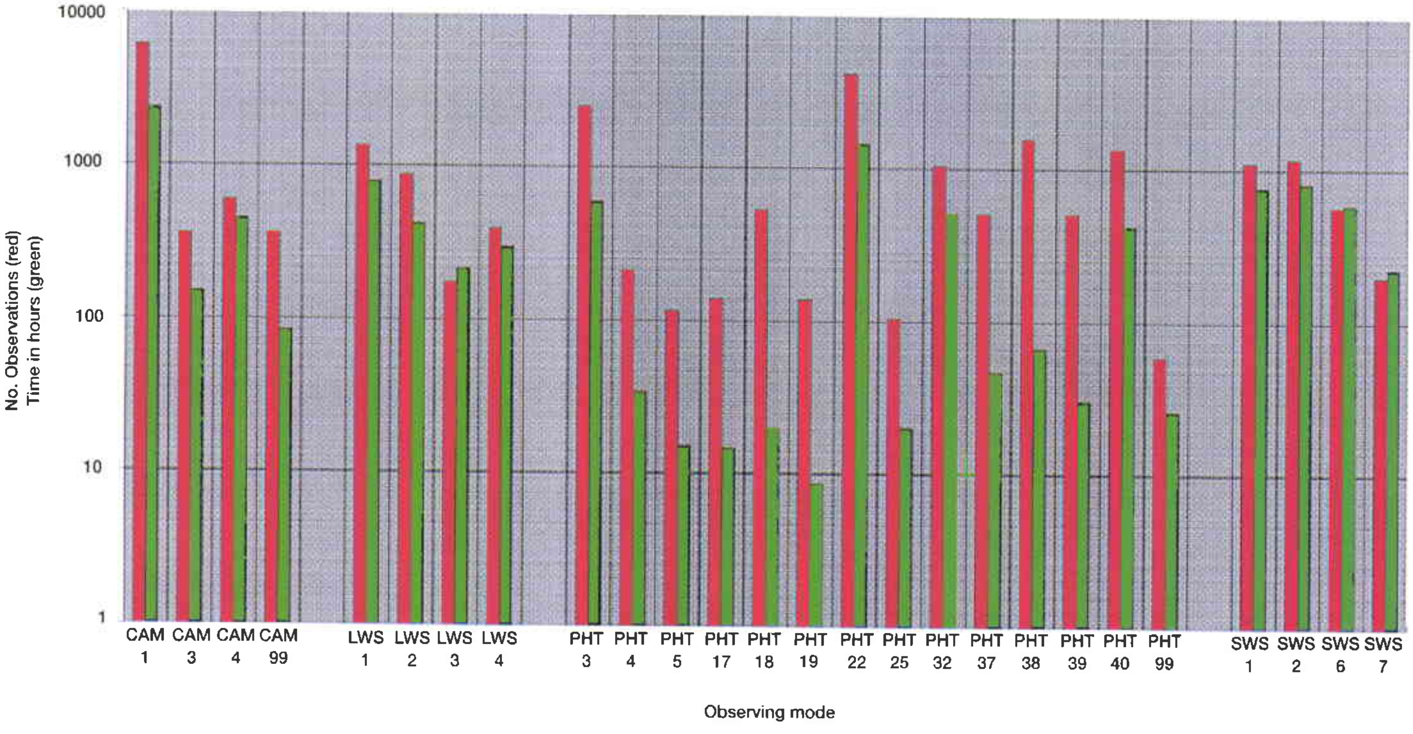


ISO Data Centre at Villafranca in Spain, is already underway to maximise the scientific return of the mission by facilitating effective and widespread exploitation of the data and by preparing the best possible final archive to leave as ISO's legacy. This effort is expected to last until the end of 2001 and includes deepening the understanding of the performance of the instruments and the satellite, improving the data processing and supporting the general community in the usage of ISO data products. The first homogeneously-processed archive of ISO data will open via the WWW in autumn 1998.

The centres involved in this effort are:
- ISO Data Centre at Vilspa in Spain
- Five Specialist National Data Centres (NDC):
  - French ISO Centres, SAp/Saclay and IAS/Orsay, France
  - ISOPHOT Data Centre at MPIA in Germany
  - Dutch ISO Data Analysis Centre at SRON in the Netherlands
  - ISO Spectrometer Data Centre at MPE in Germany
  - UK ISO Data Centre at RAL in the United Kingdom
- ISO Support Centre at IPAC in the United States.

Figure 4. Relative usage of the four ISO instruments by (a) time and (b) number of observations. (CAM = Camera; PHT = Photometer; SWS = Short Wavelength Spectrometer; LWS = Long Wavelength Spectrometer)

Figure 5. Usage of the different observing modes of the four ISO instruments by time (green) and number of observations (red)



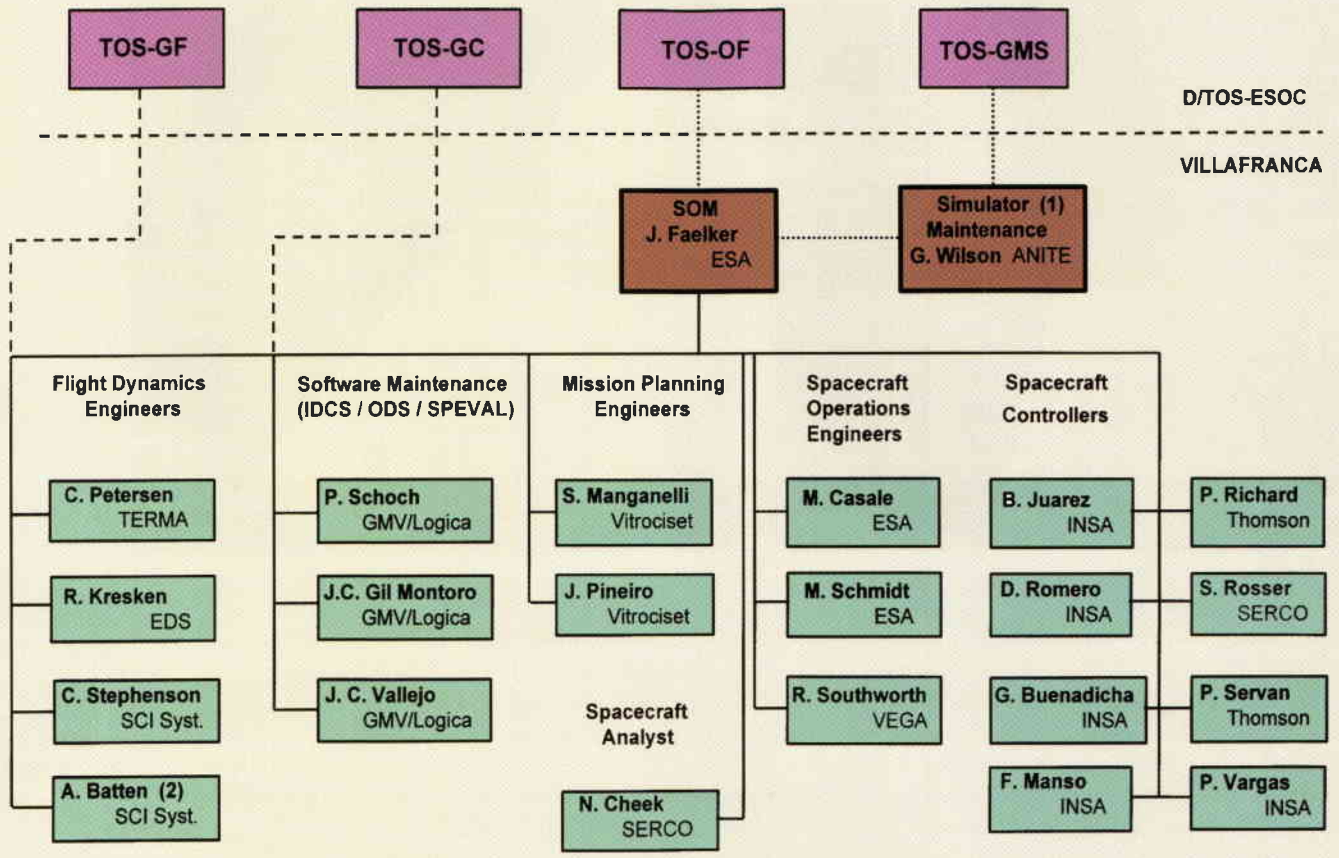


Figure 6. Organisation of the ISO Spacecraft Control Centre (SCC), showing routine phase staffing levels

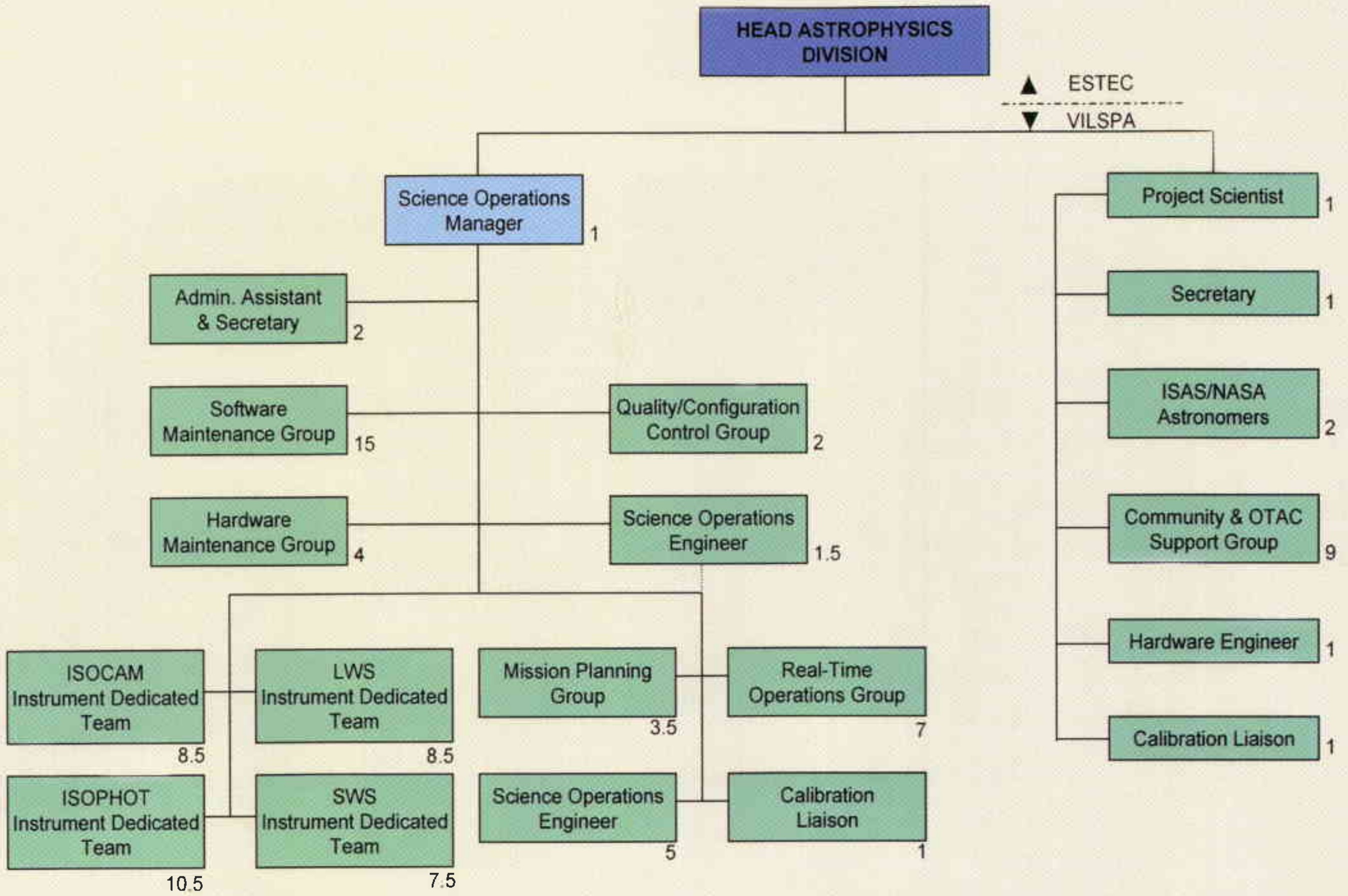


Figure 7. Organisation of ISO Science Operations Centre (SOC), showing average staffing levels during the routine operations phase

Figure 9. The ISO Spacecraft Control Room

The ESA ISO Data Centre is responsible for the archive, the general off-line processing ('pipeline') software and supporting the general European user community. The National Data Centres (NDCs) are responsible for detailed instrument-specific software and expertise, including the provision of software modules for the pipeline, and for supporting their local and national user communities. IPAC is responsible for supporting the US user community.

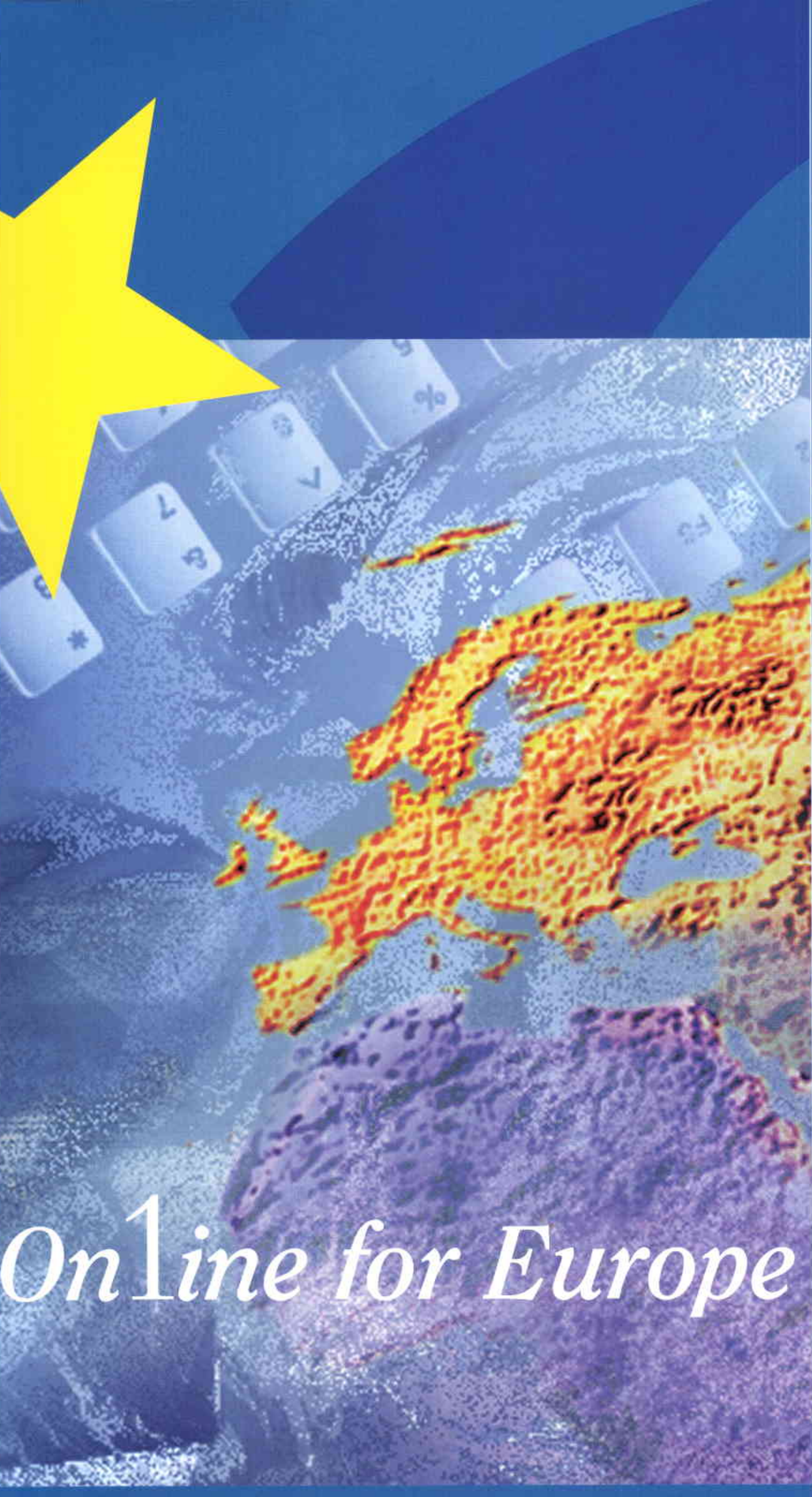
Conclusions

ISO was an outstanding technical, scientific and operational success. Operations were conducted effectively and efficiently by the teams of the Spacecraft Control Centre and the Science Operations Centre, co-located in Villafranca, Spain. The satellite commissioning and performance verification phases were carried out as planned, enabling the scientific data gathering phase to start on time with a well-understood satellite. There was very little down time, with overall system availability in the routine phase being above 98%. Taking into account all possible reasons for failure, only 4% of observations were lost and at least some of these will be recovered during the post operational phase. The timelining system for the observations yielded an average scheduling efficiency of 92%.

All of this was made possible by the professionalism, competence, dedication and sheer hard work of all personnel involved in the preparation, testing and execution of this challenging but highly rewarding mission.

ISO's lasting legacy to the scientific community is a huge treasure trove of tunique and top-quality data, exploitation of which has barely started. Doubtless, over the coming years, many more ISO provided astronomical surprises await us!

Figure 10. The ISO Instrument Control Room


On1ine for Europe

Future Satellite Services, Concepts and Technologies

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In a competitive global environment, the space sector has to target part of its R&D towards service-oriented missions where the specific characteristics of space-based systems can be of advantage. Several markets have been analysed, and a preliminary design study performed for two of the most promising missions for the future in terms of returns and appeal to users. The studies have shown that the predominant space-segment architectures will be satellites as large as the launchers allow, relatively small activity-oriented spacecraft, and satellite constellations. An important finding is that, to capture a significant share of the corresponding markets, the space-segment costs have to be reduced to less than 1/5 of current costs, which is not possible with existing technological solutions and production methods. Technology development thus lies at the foundation of successful future space systems, as it is perceived as the way to reduce life-cycle cost and time-to-market and to provide increased performances per unit of cost/mass/volume/power. Applied research must be encouraged in Europe, and ESA needs to foster those developments directly applicable to space and to provide opportunities for their demonstration in orbit.

Introduction

Thirty years ago, the objective of the space sector was to be in space. Now, the main drive is to use space, to sell it, and to profit from it. The space sector is currently in the transition phase from being funded mostly by the public sector to raising funds from private shareholders; from being a purely research-oriented activity to a commercial venture with such successful applications as satellite television, satellite navigation and satellite-based mobile communications. This state of transition creates unrest, since structures are transformed, alliances modified, users become customers and their requirements change and have to be satisfied quickly.

The space sector begins to fall under the strong influence of market forces. That market is formed by investors and customers for whom space is just another means of providing a certain type of service. What interests them are the services, their costs and quality, rather than the means used to provide those services. The space sector therefore has to fight for its place in competition with other industrial sectors capable of supplying alternative solutions for the provision of the same, or at least very similar services. Space-based systems are also increasingly forming just a part of much larger systems, where space's role varies in significance depending on the particular application. The main advantage of spacecraft is their location in orbit and, as history shows, the highest location has strategic importance due to its wider areal coverage, be it for communications, observation or navigation.

In what follows, the discussion revolves around market-oriented services that have a space infrastructure as a major component. Life-cycle costs, compared to those of alternative solutions, are the main reason for commercial companies to include or exclude space-based systems in their production processes. Current technologies and manufacturing methods common to the space industry result in very high life-cycle, end-to-end costs, which results in a limited number of competitive niches for the space sector.

Under ESA's General Studies Programme, a study on 'Future Satellite Concepts, Architectures, Technologies and Service Capabilities' was performed by Alenia Spazio, in cooperation with ESYS and MDA, to analyse the main future markets in which space could intervene, the roles that space could play, and the conditions for playing those roles.

Services

The market study part of the above analysis covered satellite communications, Earth observation and navigation, and also considered several other minor markets. Its main findings can be summarised as follows:

Satellite communications

The demand for satellite services is estimated to grow from 10 billion ECU in 1990, to over 30 billion ECU per year by the year 2000, with demand almost doubling every five years. Many of the satellite services driving growth are the result of commercial pressures to complement fibre-optic cable. The current demand for satellite communications is about 2% of the world-wide demand for communications. Although a niche sector, satellite communications represent a substantial market. The service with highest demand is currently direct-to-home television. Its growth will continue but, world-wide, by 2005 it is expected to share leadership with mobile satellite and bandwidth-on-demand services.

For future satellite-based services, the price to the end user should be reduced by a factor of 5 to 10, while maintaining or improving the quality of service. All current types of service would benefit significantly from those price reductions. In a number of cases, they would enable satellite services to begin to compete directly with terrestrial-based services. Conceptually, all current services could be achieved through the deployment of broadband systems which 'leapfrog' present capabilities. The three distinct types of broadband services identified as targets are: mobile asymmetric (10 kbps up, 10 Mbps down), mobile two-way (over 100 kbps both ways), fixed/semi-fixed two-way (about 100 Mbps both ways). The addressable market for such services is estimated to be at least in the range of up to 5 billion ECU/year, based on terminal prices of 500 to 1000 ECU and tariffs commensurate with current telephony.

Satellites are ideally suited to linking organisations in rural or remote regions to the information highway. Satellite technology provides the capability for fully mobile, personal broadband services.

Earth Observation

The world-wide revenue from space-based Earth-observation (value-added) products in 1995 was about 600 MECU, with about 200 MECU going to European suppliers. Of those, only 60 MECU were satellite raw-data sales (the European share being 17 MECU). Demand in the year 2000 is expected to increase by about 15% compared with 1995. The Earth-observation market is therefore still very small compared to the communications market and most of its revenues go to value-adding providers. From the number of planned missions, there seems to be a latent mass market, but it has to be noted that a majority of applications are not commercially viable in a strict sense: they would provide data of public interest and thus would be based on public funding (environmental research, climate change, disaster monitoring, support to peace-keeping operations).

The transition to full operation and mass-market applications will call for radical changes in the supply of data compared to today's situation. The value of the data is inversely proportional to its age and its spatial/spectral resolution. Prerequisites are a high revisit frequency and affordable, near-real-time and easy-to-access data-distribution services. These could be satisfied by a constellation of specialised Earth-observation satellites linked to the high-speed communications infrastructure (ground- and space-based) which is becoming available. Most Earth-observation services can be addressed with such an architecture, whereby the number of satellites and their sensor types increase as a function of the market's development. Assuming a price structure and characteristics appropriate to the user's needs, the addressable market could be of the order of 1 to 2.5 billion ECU/year, as a rough order of magnitude. Prime markets would be digital mapping (for GIS, mobile services, cars), followed by resources monitoring, all-weather mapping, and disaster detection.

The 'Report of the ESA Ad-hoc Industrial Working Group on Earth Observation', prepared by Eurospace, provides a comparable analysis, namely:

The European Earth-observation market is fragmented and unstructured, dominated by public-sector users, with a strategic value that should be duly considered, and is being captured by non-European providers. Data distribution has to be improved, since it has not achieved the levels expected; this demands a restructuring of the sector.

Navigation

The Global Positioning System (GPS) has

generated a market of around US$ 20 billion, with an investment in satellites, their launch, ground segments and operations of about US$ 3 billion. The current market is about 1.6 billion ECU/year, with GPS finding application in an increasing number of areas, including satellite orbit and attitude reconstitution. The core of the market consists of user terminals and value-added services such as differential corrections or position data. The existence of GPS and Glonass limits the possibilities for a new dedicated commercial service. Nevertheless, a European alternative of regional scope, with enhanced capabilities, would be facilitated by future satellite technologies and architectures. The greatest opportunities seem to lie in the user segment.

Other markets
Materials processing, waste disposal in space, Earth-crossing asteroid monitoring and deflection, and space tourism are among other possible commercial services. They may represent lucrative opportunities at some point in the future. Exploiting these opportunities requires a radically more reliable and cheaper means of accessing space, with cost reductions of several orders of magnitude.

Concepts
For most of the services discussed above, the space-related infrastructure amounts to less than 15% of the total investment, with the major expenditure corresponding to value-adding activities (extraction of specific information from the data, TV programmes, etc.) and the user segment (hand-held terminals, navigation devices for the car, etc.). It may be said that leverage has been high in those areas where space has created new markets, their value being over 6 times larger than the related space investments.

Further reduction in the costs of, and increased performance of the space segment and its related (ground-) infrastructure is essential to generate revenues in the future, whether by expanding existing markets or by opening up new ones. The final products have to be competitively priced and turnaround times must be short.

To participate in space ventures, commercial investors require a high rate of return, to compensate them for the high risks and long waiting times associated with many space projects (the net present value of a series of cash-flows is dependent not only on the cost of capital, but also on its distribution over time). Users also demand increases in performance before accepting space-based services and products (e.g. most users still prefer a small cellular telephone to a larger Inmarsat terminal, even though the former has poorer coverage).

Absolute cost is the factor that must be most improved to make a service economically attractive. Space-based service providers need high ratios between performance and cost, resulting in cost/benefit ratios comparable to or better than those for similar ground-based services. Today, the spacecraft is the most expensive component in most space-based systems (user segment excluded), followed by the launcher and launch services (20 to 50% of the total cost), ground segment and operations (up to 15%) and management and technical support. The spacecraft is an industrial cost and in new projects around 30% of it corresponds to engineering, followed by development hardware, management, AIV, support equipment, and product assurance. The cost of the actual flight model in a new project could be as low as 15%. This means that costs are reduced dramatically when a design is reused, and the recurrent unit cost may be as low as 20% of that of the prototype. Looking within the platform itself, the attitude and orbit control system (AOCS) is the most expensive subsystem in all modern spacecraft. Next come the power system and solar arrays (with strong differences between projects), the structure, on-board data handling and harness, reaction control, thermal, and command and control (TT&C) systems. Payload costs vary widely, depending on the application, degree of maturity, etc., and may exceed those of the platform if new developments are required (such as for Earth-observation instruments).

One of the basic requirements that a competitive product must satisfy is to be on the market at the right time. For space to compete with the ground, reductions in development and deployment times are a must. All parameters specifying the merit of a commercial initiative (e.g. net present value, internal rate of return, actualised payback) include a time element in their definition, as cash-flow distributions over time (payments and income profiles). On the one hand, revenues from space come very late with respect to those in other sectors. On the other hand, innovation cycles for new products and key technologies are becoming ever shorter.

Since a satellite does not provide services (and thus generate income) until after it has been commissioned in orbit, timing is a critical factor to be addressed. From idea to commissioning, the satellite and its associated infrastructure are solely incurring costs. Therefore, the shorter this time span, the lower the overall costs (including the financial charges for the capital raised). Time is not only important financially, but also strategically: changes happen fast, as has already been seen with microprocessors (a new generation every three years) and mobile telephony (very fast growth, and the transition from analogue to digital), and is currently happening for satellite TV with the rapid introduction of digital direct-to-home broadcasting. The space sector therefore has to develop fast-reaction capabilities and has to be adaptable to the non-space world, if it is not to be left behind.

European industry has well-recognised experience in the space segment, and has also had extraordinary successes in the user segment (e.g. home terminals for satellite TV, GSM telephony). Space industry, alone or through partnerships, should strive to increase its involvement in this segment, given its strategic and commercial importance. The space agencies and regulators should be more concerned about the end users, their demands and evolution.

As far as the launch segment is concerned, Europe has Ariane and its Kourou launch base, which are optimal for launches into geostationary orbit, but less so for polar orbits or orbits with high inclinations. As a result, no satellite-constellation launches have yet been contracted to Arianespace.

Europe is one of the largest and more developed world markets, with both a population and a Gross Domestic Product (GDP) greater than those of the USA. It therefore has an important role to play in regulatory matters in that, for example, authorisation to use allocated frequencies over European territory is a European prerogative. This explains the interest of some American initiatives in adding European industries as partners, in the hope of thereby obtaining licences to operate their services over Europe.

Architectures

The main trends in space-based architectures, for services where the space sector is more active, are currently the following:

- constellations of satellites, mostly in low Earth orbit but also in medium-altitude orbits, for services where the distance to the user cannot be large and coverage must be frequent or permanent (mobile communications, operational Earth observation); the global performance of the system is spread amongst the constellation's satellites, which may become smaller
- big satellites, as large as the launcher allows, mostly in geostationary orbit, where it is economically interesting to concentrate as much as possible of the system performance into just a few satellites (communications, low-resolution but permanent Earth observation)
- small satellites for activity-specific missions, built around a primary instrument or task (science, demonstrators).

There are several considerations that can help us to understand better the possible evolutions of these system architectures:

- The communications demand is in a permanent state of growth. In order to satisfy this ever-increasing market, terrestrial-based systems are constantly improving their capabilities and performances by means of equipment and architecture upgrades. Satellites could easily find a role in this global scenario, but space alone cannot become 'a global service': even under the most optimistic hypothesis, it would be difficult to achieve a penetration of more than 5% into the global communications market by the year 2010, basically for technical reasons.
- The Earth-observation market, to achieve significant growth, requires a very short turnaround between the user request and image delivery, which implies not only that the EO constellation must be able to access any point on Earth very quickly (maximum of 6 h revisit period), but also the ability to transmit the data to ground, process it, and deliver the final product to the user within that period.

From the above, we can conclude that space-based infrastructures will rather form a part of the global architecture in which the user, ground and space segments play their own specific but integrated roles.

Successful constellations will define future space-equipment standards, with their manufacturers influencing, and probably dominating, the subsystem and equipment markets. Although not large enough to be considered mass markets in the sense of the automotive or consumer electronics sectors, constellations are expected to become the paradigm for space utilisation and exploitation, and to be part of the key to reducing the cost of space hardware. Constellations represent a quantum leap in the way space-based systems are conceived, and require adaptation of processes, technologies and sectorial structures for their successful manufacture, deployment in space and exploitation.

Constellations, and their future functional expansion into networks, are certainly becoming the new model for commercial space systems for navigation (GPS, Glonass), mobile telephony (Globalstar and Iridium), and many other planned telecommunications-type applications. Since a large number of satellites have to be deployed before the particular service can start, it is essential to reduce the production and deployment times, during which huge amounts of capital are tied up and interest payments are accruing. The Island Integration approach — already being used for Globalstar — allows the simultaneous assembly, integration and verification (AIV) of several satellites, each of which is in a different AIV phase (corresponding to a particular 'Island') at a given moment. This approach requires a higher initial investment than traditional approaches, to build the larger integration facilities needed and to duplicate the necessary test equipment.

In the framework of the Alenia Spazio, ESYS and MDA study, mentioned above, two services, one related to telecommunications and one to Earth observation (see the accompanying panel for details), were analysed. Alenia performed a preliminary design of the missions required to provide the respective services operationally with the quality levels demanded. State of the art technologies (as per 1997) and current manufacturing (design, assembly, integration, verification) methods were used in both cases, resulting in high space-segment costs and long manufacturing times, incompatible with commercial success.

After an evaluation of demands and trends in applied research for space-related technologies, a second design study was performed assuming that a number of new technologies (Table 1) would be available in the required time frame. Shorter production times, together with increased performances per unit mass/volume/power, resulted in reasonable spacecraft and financially feasible missions.

The main conclusion is that several new technologies have to be developed, together with new AIV methods, and must reach maturity for space-based services to become commercially viable. Even so, the market share that can be captured by space in the most dynamic sectors would be minor (although important in terms of volume of funds).

Methods: reducing the time to market

Spacecraft manufacture is a highly specialised and labour-intensive task. It is expected that in the future extensive use will be made of recurrent equipment. The methods adopted in its design and production will influence the time-to-market of any space-based system:

Project management

Cost and schedule reductions can be achieved by adapting the way in which the space-system development effort is managed, in terms for instance of the organisation of the project team, the documentation management and information technologies used in support of that team, and the manner of interaction with the subcontractors and suppliers. Potential reductions in Life-Cycle Costs (LCC) and schedule may be found among methods that:

- reduce the number of team members
- simplify the activities to be performed during the programme life cycle
- reduce and simplify the interfaces between the various activities and/or groups
- simplify the procurement and integration of parts and equipment.

Two factors that need to be considered carefully in sizing the team are: (a) the ability to solve problems in minimum time, and (b) the ability to do so at minimum cost.

System engineering

This area involves several disciplines that are needed during the lifetime of a space system development. Their impact on LCC and schedule may be very strong. System-engineering activities cover all aspects of a project, from the definition of mission requirements to in-orbit operations, passing through requirements definition at subsystem/equipment level, methods for verifying that the requirements are met, assembly, integration and verification (AIV) and testing, and the launch campaign. The AIV approach selected for series production is very important for commercial systems based on constellations of satellites, which represent a new challenge for the space industry.

Technologies: increasing performances

Advances in technology are important for the payload, the platform and the user/ground segment. In addition to improvements in the fields directly related to the technology, they may have lateral impacts by affecting other disciplines, equipment and subsystems. This is the case for structural ultralights, which are very strong and stiff materials that allow one to reduce the structure's mass, but which simultaneously affect the requirements definition (due to the higher margins allowed), the design (simpler analysis due to the high margins), and the verification process (simplification and reduction in the number of tests due to higher design margins). Today's technology allows one to achieve with small

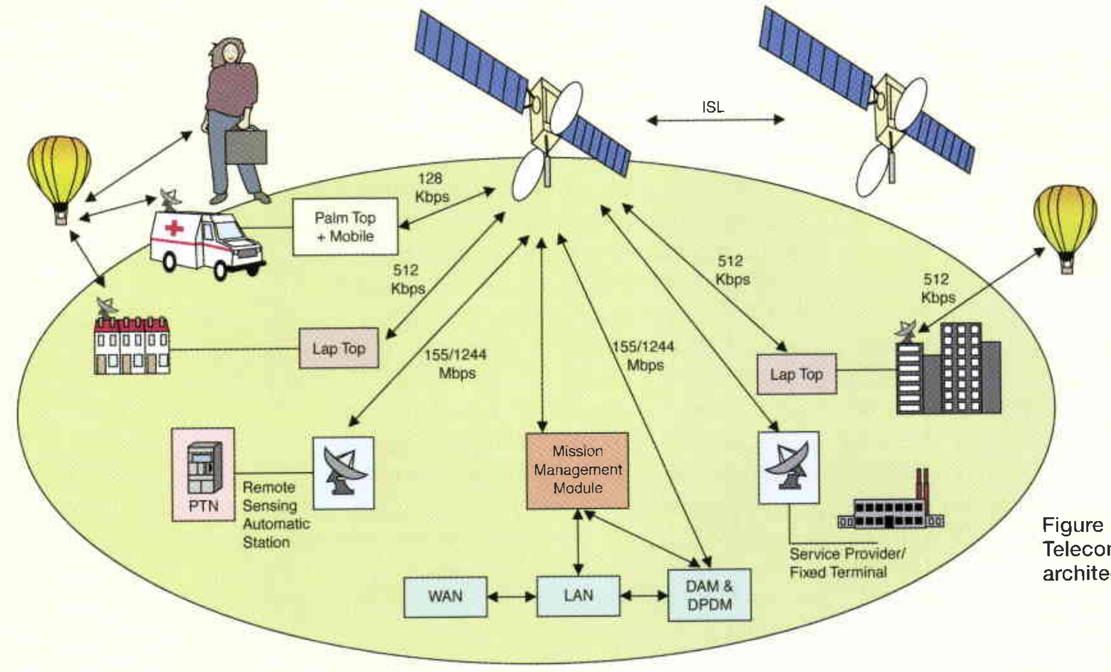
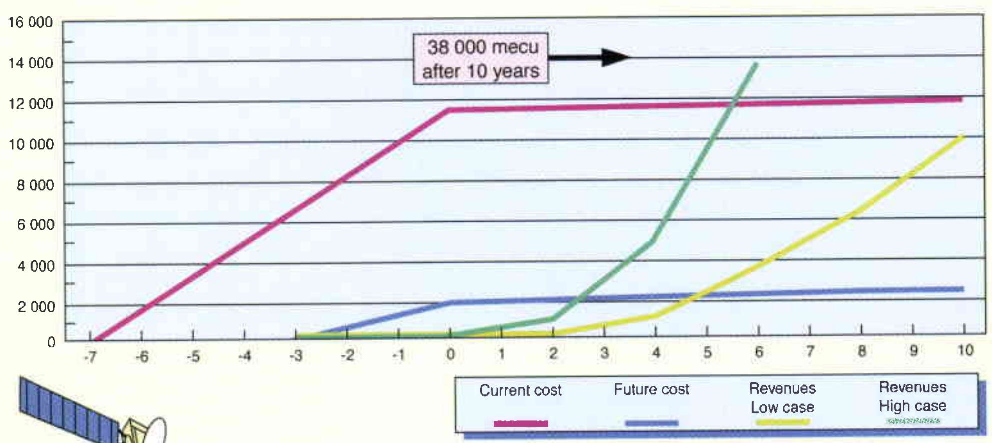


Figure 1. Overall Telecommunications System architecture

Figure 2. Projected cumulative costs/revenues (MECU vs Year) for the Telecommunications Service



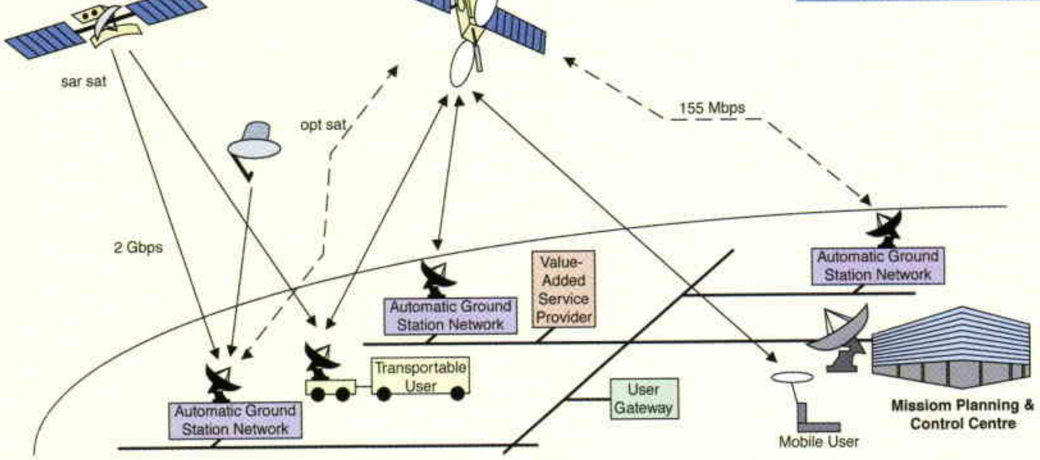
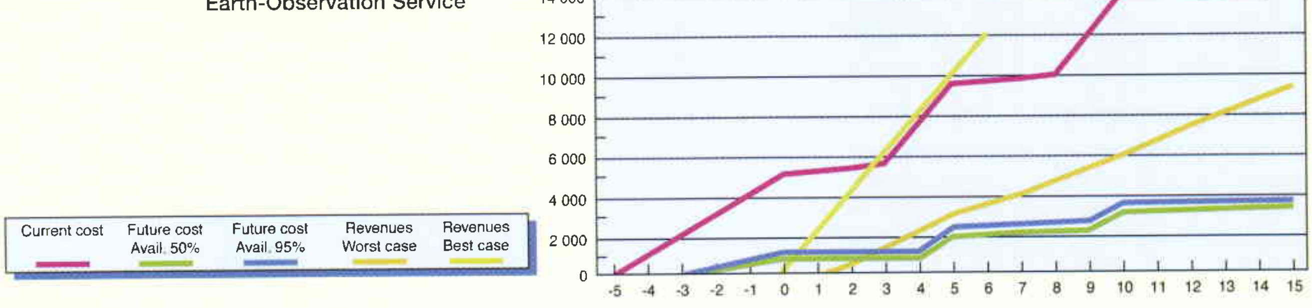


Figure 3. Overall Earth-Observation System architecture

Figure 4. Projected cumulative costs/revenues (MECU vs Year) for the Earth-Observation Service



Examples of Future Service Capabilities

Most of the concepts and approaches described in the accompanying article were considered in modelling two space-based services to be deployed in the 2010 - 2015 time frame, when all of the necessary technologies (Table 1) are expected to be available and consolidated. The two 'model services' analysed were:

A MULTIPURPOSE TELECOMMUNICATIONS SERVICE (Figure 1)

Based on large satellites in geostationary orbit and supporting mobile, fixed/semi-fixed terminals with several media products, the mission would consist of full-duplex services to low-cost user terminals providing:

- low data rates up to 384 kbps accessible by 'palmtop' terminals
- medium data rates, in the 2 Mbps range, accessible by 'laptop' terminals
- high data rates up to 1.2 Gbps accessible by 'fixed' terminals.

Six satellites would be necessary to provide a global service with the availability required, each with a mass of 7000 kg. Each of these satellites would be comparable in performance to three of today's satellites in the 3500 kg and 14 kW class.

The revenues have been estimated on the assumption that the maximum number of users per day per satellite matches the maximum capability of the satellites (in terms of number of channels) at the end of the last year. For each service type, a utilisation price and rate (hours/day) is assumed (optimistic scenario) and then the price and rate of use are reduced by a factor of 2 (revenue per user reduced by 4) (pessimistic scenario). The resulting market penetration would not exceed 2% (6 million palmtop, 2600 desktop users).

Figure 2 summarises the most important results in terms of cumulative costs and revenues (optimistic and pessimistic cases). They show that the proposed communications service, sized and costed on the basis of current parameters and methods is not commercially viable (except by raising the fees charged to the users, which results in the service not being competitive with ground-based services). A service designed around emerging technologies, however, appears very profitable, so that even with a very low market penetration, it is possible to generate profits with rates comparable to those of currently planned ground-based services.

Satellite applications for global purposes will not be possible unless several hundred 7 ton/70 kW satellites are deployed in geostationary orbit and integrated into global information systems.

Optimised use of future large geostationary satellites could be achieved in the framework of 'fixed desktop services', for second-level customers such as Internet-like service providers, or for private Intranets with geographically sparsely distributed users. With satellites resources fully dedicated to these kinds of customers (palmtop and laptop users could be served by other space-based services like LEO or MEO constellations, thereby reducing delay problems), a market penetration of more than 5% could be achieved. Satellites could then compete directly with terrestrial services, especially for small organisations who need limited or only occasional access to high-speed networks, and for developing nations on the verge of significant economic expansion. In both cases, there is a window of opportunity for satellite services to secure a significant market share before the competing terrestrial services become available. Once affordable terrestrial services are in place, it is difficult to displace them, except by providing radically better services. The fixed Gbps service could displace terrestrial services for certain users.

For palmtop and laptop services, the main competitor is likely to be terrestrial Local Multi-point Distribution Systems (LMDS). A different type of competitor could be stratospheric-airship systems, such as the proposed Sky Station. However, neither the LMDS nor airship systems seem to be able to provide a complete solution, thereby still leaving room for satellite services.

AN EARTH-OBSERVATION SERVICE (Figure 3)

With near-real-time and global access and an all-weather capability, this service would be based on a small constellation of satellites in low Earth orbit, with six in a near-noon 280 km-high orbit having an optical payload, and twelve with a microwave (SAR) payload, six of them in a near-noon and six in a dawn-dusk orbit of 410 km altitude.

The high-level mission requirements are:

- all-weather and day-and-night observing capability (microwave)
- high spatial resolution, ~0.5 m for optical and ~1 m for microwave
- multispectral capability
- global access time shorter than 8 hours for end users.

Employing current technologies, each satellite would have a mass of around 1650 kg and a power demand of up to 1000 W. Technologies under development would allow similar performances to be achieved with satellites weighing around 230 kg and with power demands of approx. 800 W (microwave payload).

The analysis has shown that the addressable market is between 4000 and 13 000 MECU by the year 2010; assuming that 50% (conservative assumption) of it is captured by non-space approaches such as air-based systems, and the other 50% is shared by 3 competitors, by 2010 the revenues would be in the range of 600 to 2000 million ECU/year. Figure 4 shows the cumulative costs assuming infrastructures based on current and on future technologies and methods, together with the cumulative revenues for the worst- and best-case scenarios.

It can be seen that:

- in economic terms, the difference between an availability of 50% (no spare satellite in orbit) or 95 % (with in-orbit spares) is not significant, so that the latter should be taken as the baseline
- the Earth-observation infrastructure sized and costed on the basis of current technologies and methods is not commercially viable, except under the most optimistic assumptions, and even then with low rates of return
- the expected future technologies and methods would result in space systems generating an internal rate of return ranging between 25 and 70%, depending on the market assumptions.

satellites performances that were considered exceptional for any satellite just a few years ago.

Commercial comparisons are usually based on cost/benefit ratios, whilst in the public sector cost/utility or cost/performance criteria are often preferred. To reduce total life-cycle costs, technologies need to be developed which can increase the performance-to-cost ratio in as many areas as possible.

At satellite level, improving the benefits derivable from a space-based service means increasing both the payload capabilities and the corresponding platform performances, which are directly related to lifetime, simplicity of operation, electrical power available, processing power, etc. To reduce costs, the volume, mass and power requirements of the overall satellite, and hence those of its individual equipment items, have to be reduced. High priority should therefore be given

Table 1. Technologies for commercial space services

Space Segment (platform and payloads)

• *Propulsion and Power*

Electric propulsion

Solar Generators:
- Thin GaAs/Ge Solar Cells (mass saving)
- Multi-Junction GaAs Solar Cells, Indium Phosphide Solar Cells
- Concentrators for GaAs/GaSb Solar Cells and Solar Arrays
- Lightweight Solar Arrays (cells on flexible Kapton substrate and inflatable Torus solar array)
- Micromachined Blue-Red Reflective Cover Glasses (increased solar cell efficiency)

Power Storage:
- Nickel-Metal-Hydride Battery Cells
- NaS Battery Cells

Power Control:
- Peak-Power Tracking Power Control
- Direct Energy Transfer (use of processor and software)

• *Thermal Control*

- Two-phase Mechanically Pumped Loops, Capillary Pumped Loops
- Advanced Radiators (variable radiating area)
- Heat Pumps
- Integrated Spacecraft Thermal Bus

• *Microwave and Telecommunication Equipment*

- High Power Amplifiers (SSPA, MPM, TWTA)
- 3D-VLSI, 3D-MCM, MMIC, MHCM
- Rain Fading Compensation Techniques
- High-Temperature Superconductors
- Ku/Ka Band Technologies for Receivers, Down-converters (low noise amplifiers,...)
- Multi-Beam Antenna
- Optical Technologies for Beam Forming Networks, Switching

• *On-Board Processing and Data Compression*

- Data-Compression Techniques
- Processors: general purpose and telecommunications payload management

• *Mechanical Systems (antennae, solar panels)*

- Micro/nano-Technologies and Micro-electro/mechanical Systems
- Smart Structures (antenna reflectors)
- Large Aperture Antennas
- Ultra-light Antenna Reflectors
- Electron Beam Curing

• *Optical Equipment*

- Cryo-Coolers
- Focal-Plane Equipment

Ground and User Segment

• *Telecommunications*

User terminals:
- Miniaturisation
- Handwriting/Speech/Vision Recognition, Pen-Based Interfaces, Integrated Voice and e-mail
- Nomadic Computing
- Integration in Networks and Communications with Other Computers

Terrestrial Networks:
- Modulation and Access Schemes
- Security
- ISDN, ATM, Network Integration and Protocols to Incorporate the Space Segment
- High-Speed Infrastructures

• *Earth Observation*

Cataloguing/Archiving:
- Multi-database Management Systems
- Metadata Standards and Catalogues

Automated Information Extraction:
- Distributed Object Based Computing
- Object Based Geographic Information Standards
- Qualitative Reasoning Systems

Automated Order Handling:
- Order Entry
- Processing and Product Distribution
- Data Acquisition Planning

to technologies that reduce such requirements whilst still maintaining or even improving upon the performances delivered (e.g. micro/nano-technologies, deployable/ inflatable structures for large apertures) and that improve the electrical power generation and storage capabilities, on-board computational power, payload performances, autonomy, etc.

At the user and ground-segment level, technologies for data compression, communication standards for integration of terrestrial and space networks, nomadic computing and automated information extraction will be needed to maximise user access and minimise operating costs. User and ground segments must be developed to support the role of the target market, and to provide seamless access to both space-based and terrestrial service providers.

Table 1 lists technologies that need to be developed to make the telecommunications and Earth-observation services discussed above commercially viable. Other lists have also been drawn up based on different criteria. Eurospace, for example, has proposed 10 major technology areas which Europe should develop to increase its worldwide competitiveness. ESA's Basic Technology Research and Development Programme (1997 – 1999) is structured along 13 major technology axes, plus 16 specific and complementary axes, and it is oriented to generate innovative ideas in supporting industry and ESA programmes. Other ESA programmes include application-specific research (e.g. ASTE for telecommunications, FLTP for launchers, SSU for the Space Station).

Recommendations

Europe has to look for specific sectors in space – in line with its goals and commensurate with its capabilities – in which it could excel. The space sector has to concentrate on those activities where it has the potential to prevail over solutions provided by other means. The European space sector needs to establish long-term strategic alliances of world proportions. The maturity already reached by European markets in most growth sectors means that the further growth potential is small compared to that in other geographical areas still under development. Europe therefore has to look not only to its own internal markets, but must also seek to expand in other directions and geographical areas, focussing on activities with high potential for attracting paying users.

New technologies are the key to long-term competitiveness. Technology development is essential to achieve the cost and time-to-market reductions and performance increases characteristic of other competitive sectors. Common-interest technologies are being developed by non-space groups and space industry can profit from these developments (micro/nano-technologies, electronics, processors). The space sector must establish alliances with complementary sectors, with the objective of sharing technologies, and also foster the development of space-specific technologies and technologies oriented towards the solution of space-specific problems, so that total integrated solutions are available on time and at viable cost.

Europe's level of achievement in basic research is high. Unfortunately, transfer to industrial applications is slow, to the advantage of other geopolitical regions that are more aware of the market implications of that transfer. Applied research has to be encouraged in Europe and a technology harmonisation process urgently needs to be initiated, with ESA promoting developments directly applicable to space. More effective coordination is needed between ESA, the national agencies, European institutions and industry to minimise redundancies and overlaps and achieve efficient utilisation of the scarce resources devoted to space. Priority should be given to lines of research where significant increases in performance per unit cost/mass/volume/power can be foreseen. Lines where only minor improvements are to be expected should be abandoned, unless they require only minor levels of resources to accomplish the goals and the inherent development risk is minimal.

The presence of European space industry in the world has to be fostered, and measures contributing to the development of a competitive Europe supported. A global end-to-end approach to technology research and development, open and attentive to the changing world situation and demands, should be adopted. The short- and medium-term importance of marketing has to be exploited. Industry has to be encouraged to be more innovative, to invest more heavily in research and development, to accept risk, and to enter the free market competition. esa

Ultra-lightweight C/SiC Mirrors and Structures

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Silicon-carbide (SiC) ceramic mirrors and structures are becoming increasingly important for lightweight opto-mechanical systems that must work in adverse environments. At DSS and IABG, a special form of SiC ceramic (C/SiC) has been developed under ESA contract which offers exceptional design freedom, due to its reduced brittleness and negligible volume shrinkage during processing. This new material has already been used to produce ultra-lightweight mirrors and monolithic reference structures for eventual space application.

Introduction

Several different SiC-type ceramic manufacturing processes have been developed around world in recent years, usually in seeking to develop structures and components that provide: high stiffness at low mass, high thermo-mechanical stability, and high isotropy. Due, however, to the inherent brittleness of SiC ceramics and their tendency to shrink during processing, hardware made of SiC is limited to a low structural complexity, relatively large wall thicknesses and open-back structures. In seeking to overcome these deficiencies, ESA initiated the development of a new material called C/SiC. Its unique manufacturing process enables one to realise:
- extremely complex three-dimensional structures
- wall thicknesses of less than 1 mm
- open- and closed-back structures for lightweight mirrors.

The manufacturing process is simple and straightforward and makes use of standard milling, turning and drilling. The size of the structures and mirrors that can be manufactured is limited (to 3 m x 3 m x 4 m) only by the scale of currently available production facilities.

Material properties

The new C/SiC material actually resulted from an extensive study of available materials undertaken within the Phase-A study of the Meteosat Second Generation SEVIRI instrument, and a dedicated development effort within the Ultra-Lightweight Scanning Mirror (ULSM) project. Its main features and advantages are as follows:
- Very broad operating temperature range (4 to 1570 K)
- Low specific density (2.70 g/cm^3)
- High stiffness (238 GPa) and strength (210 MPa)
- Low coefficient of thermal expansion (CTE: 2.0×10^{-6}K^{-1} at room temperature, and near zero below 150 K)
- High thermal conductivity (~ 125 W/mK)
- Electrically conductive (2 x 10^{-4} Ohm.m)
- Isotropic characteristics of CTE, thermal conductivity, mechanical properties, etc.
- Very high chemical and corrosion resistance
- No ageing or creep deformation under stress
- No porosity
- Fast and low-cost machining
- Short manufacturing times
- Considerable flexibility in structural design
- Ultra-lightweight capability (small wall thickness and complex stiffeners).

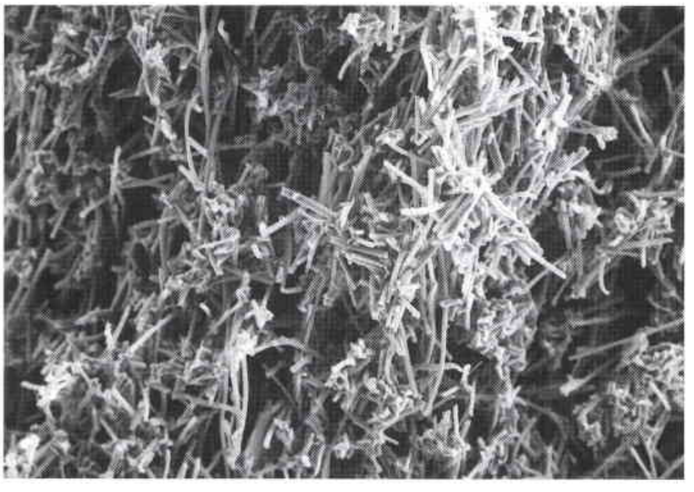
One of the material's most advantageous features for space-borne opto-mechanical instruments is the combination of high stiffness, low CTE and good thermal and electrical conductivity, in contrast to classical optical materials (Table 1). This advantage is even stronger at cryogenic temperatures, where the CTE of C/SiC is low, but its thermal conductivity is still high.

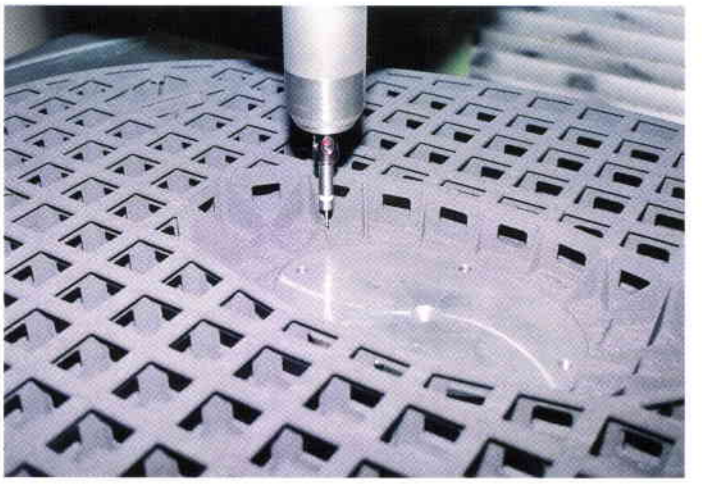
The manufacturing process

The raw material used is a standard porous C/C rigid felt, which is made from short, randomly oriented (isotropic) carbon fibres

Table 1. C/SIC's thermal properties compared with those of other materials

		Units	C/SiC	Zerodur	Be I-70A
CTE @ RT	α	$10^{-6}\ K^{-1}$	2.0	0.05	11
Thermal conductivity	k	W/m K	125	1.64	194
Specific heat	c	J/kg K	700	821	1820
Young's Modulus	E	GPa	270	90.6	289
Steady-state thermal distortion	E k/α		16875	1248	1693
Dynamical thermal distortion	E k/(c)		24.1	1.52	2.8





(Fig.1). The latter are molded with phenolic resins at high pressures to form a type of carbon-fibre-reinforced plastic (CFRP) blank, which can be produced in various sizes. During a pyrolisation/carbonisation heat treatment at up to 1000°C, the phenolic matrix reacts with the carbon matrix (C/C-felt). The resulting so-called "green body" is then sufficiently rigid for milling to virtually any shape.

Milling

As demonstrated in the ULSM mirror programme, very complex structures can be cut from a single green body by standard computer-controlled milling (Fig. 2). Ribs of 1 mm or even less can be milled with a standard tolerance of ±0.1 mm. This is one of the most significant advantages of this new material, as it drastically reduces the forming costs and enables the manufacture of truly ultra-lightweight mirrors, reflectors and structures. It can also be machined to form struts or tubes without the need to machine support structures in another material.

Infiltration

The milled green-body structure is then mounted in a high-temperature furnace and heated under vacuum to temperatures at which the metallic silicon changes into the liquid phase (about 1400°C). The liquid silicon reacts with the carbon matrix and the surface of the carbon fibres to form a silicon-carbide matrix in a conversion process. The amounts of carbon and silicon have to be carefully apportioned to prevent a chemical reaction between the silicon and the reinforcing carbon fibres, and so IABG has developed an optimised infiltration process with precise computer control for different-sized chambers. The largest facility can process mirrors of up to 3 m diameter, or large structures up to 3 m in diameter and 4 m long (Fig. 3).

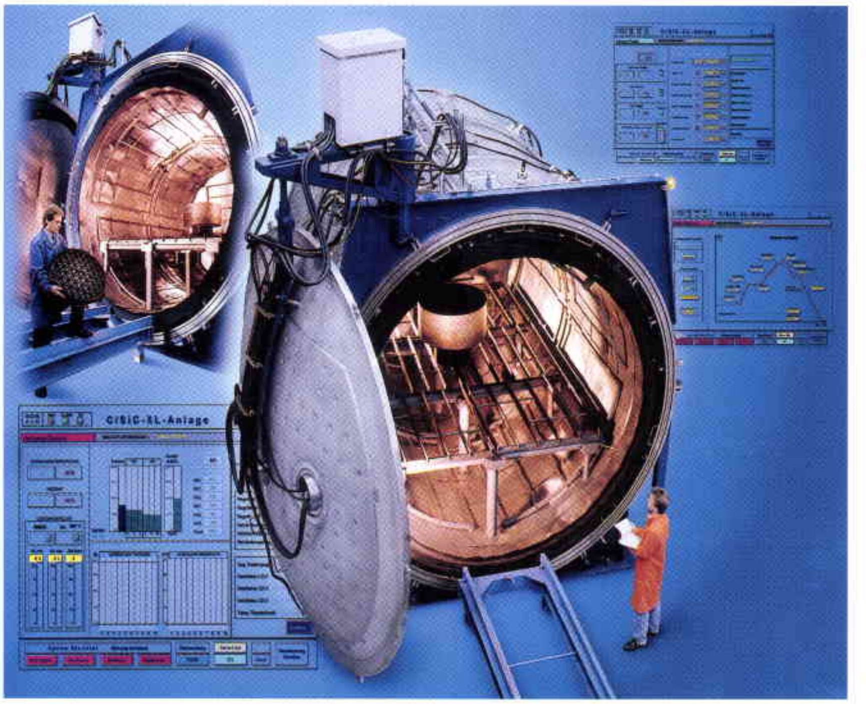
Grinding and polishing

The infiltrated mirror blank is ground to the required surface figure. As the carbon-fibre

Figure 1. REM microphotograph of the green-body chopped fibre material

Figure 2. Milling operations on the 80 cm x 50 cm ULSM blank

Figure 3. The infiltration facility at IABG in Ottobrunn (D)



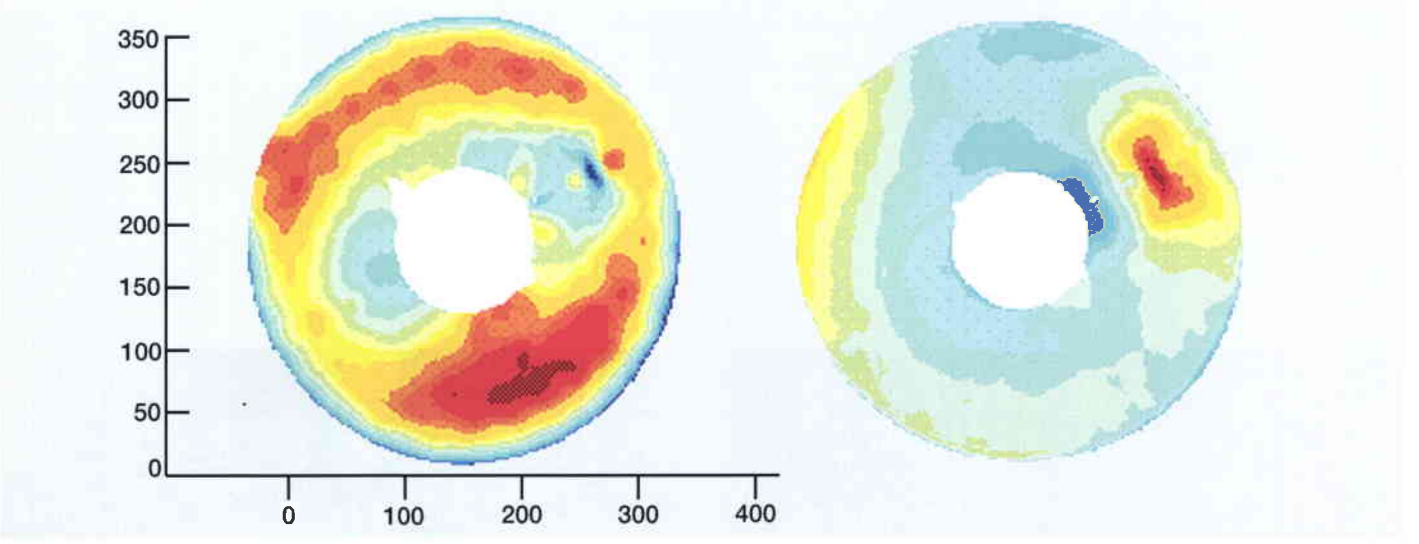


Figure 4. ULSM optical test mirror before and after ion-beam polishing

content contributes to the micro-roughness of the surface, applications at near-infrared, visible and X-ray wavelengths require a polished cladding layer which acts as the optical surface.

Several coating materials and deposition techniques have been tested. The most promising candidates are monolayer chemical-vapour-deposition (CVD) SiC and directly bonded glass. Plasma-vapour-deposition (PVD) Si surfaces are also currently being evaluated. In selecting the most suitable cladding material, the thermal expansion coefficient matching, allowable thermally induced surface error and machinability have all to be taken into account. The differential thermal expansion, the Young's modulus of the surface coating and the coating thickness have to be optimised to keep bi-metallic bending effects in the mirror to a minimum.

Although the CVD-SiC coating on the mirror blank is a good candidate in terms of material property matching, it is difficult to achieve a high optical quality due to the material's exceptional hardness. Too high a pressure on the polishing tool causes a "print through" effect, whilst insufficient pressure increases polishing times and the optical performance remains limited. It can, however, be improved by introducing an additional ion-beam polishing step.

Figure 5. Lightweight closed-back structure with a diameter of 45 cm, made from six pieces joined in the green-body state and infiltrated to a single unit

Ion-beam polishing

After polishing the mirror by classical means, the optical surface is locally treated by plasma etching to reduce the local errors in surface figure and achieve high optical performance. This process was developed by the Institut für Oberflächen-Modifikation in Leipzig for the 440 mm-diameter optical test mirror for the ULSM programme. Figure 4 shows the interferograms before and after the ion-beam treatment. The mirror's rms surface figure error was improved from 123 to 39 nm.

Joining technology

The C/SiC material has another big advantage which is not required in the normal manufacturing process, but which is of considerable benefit for larger mirrors and complex monolithic structures, namely the possibility to join sub-components in the green-body stage to form the final structure. This joining technology allows one to manufacture monolithic mirrors and structures larger than the available green-body C/C felts. It also makes it possible to assemble lightweight mirrors with closed back structures (Fig. 5), and complete instrument structures.

The joining process starts with the gluing of the green-body parts using a special chemical adhesive, developed at IABG, before Si-infiltration. During the subsequent Si-infiltration, the resin reacts to carbon so that a C/C-material is generated which has the same percentage of carbon fibres and carbon matrix, as well as the same porosity, as the rigid carbon felt used. The infiltration process and the reaction with the liquid silicon leads to a monolithic structure which has the same percentage of the three material constituents (carbon fibres, SiC- and Si-matrix), and thereby the same mechanical and thermal properties as the bulk C/SiC ceramic composite itself. This is ideal for, for example, athermal telescopes with mirrors and structures with the same thermo-mechanical properties.

C/SiC applications

ULSM

The C/SiC material was selected as candidate material for the Ultra-Lightweight Scanning Mirror (ULSM) of the SEVIRI instrument on the Meteosat Second Generation (MSG) spacecraft. This mirror has to fulfil very stringent thermo-mechanical-stiffness and optical-quality requirements yet still have an ultra-low mass. Operating in a geostationary orbit on a spacecraft rotating at 100 rpm, it is exposed to both to the heat of the Sun and the intense cold of space and, due to its 45° inclination to the spin axis, to a maximum mechanical loading of 3.2 g at the mirror tips, acting in opposite directions.

The mechanical design of the elliptical ULSM and one of the polished mirror blanks are shown in Figure 6. The mirror's backing structure contains square "pockets" 40 mm across. The individual ribs are only 1.2 mm thick, with each containing a large cutout for structural efficiency and to improve the mirror's thermal properties, especially under vacuum conditions.

The CVD-SiC surface coating has been successfully applied and the optical surface polished to a specification of 60 nm rms surface form error and less than 2 nm rms surface micro-roughness. There was no measurable performance degradation after assembly with the isostatic mounts and the CFRP frame (Fig. 7). The ULSM mirror has since undergone mechanical and long-term thermal-cycling load tests, as well as extreme temperature tests, without showing any deformation of the optical surface. Radiation-hardness tests on the bulk material and the reflective coating were also performed successfully using a small test mirror.

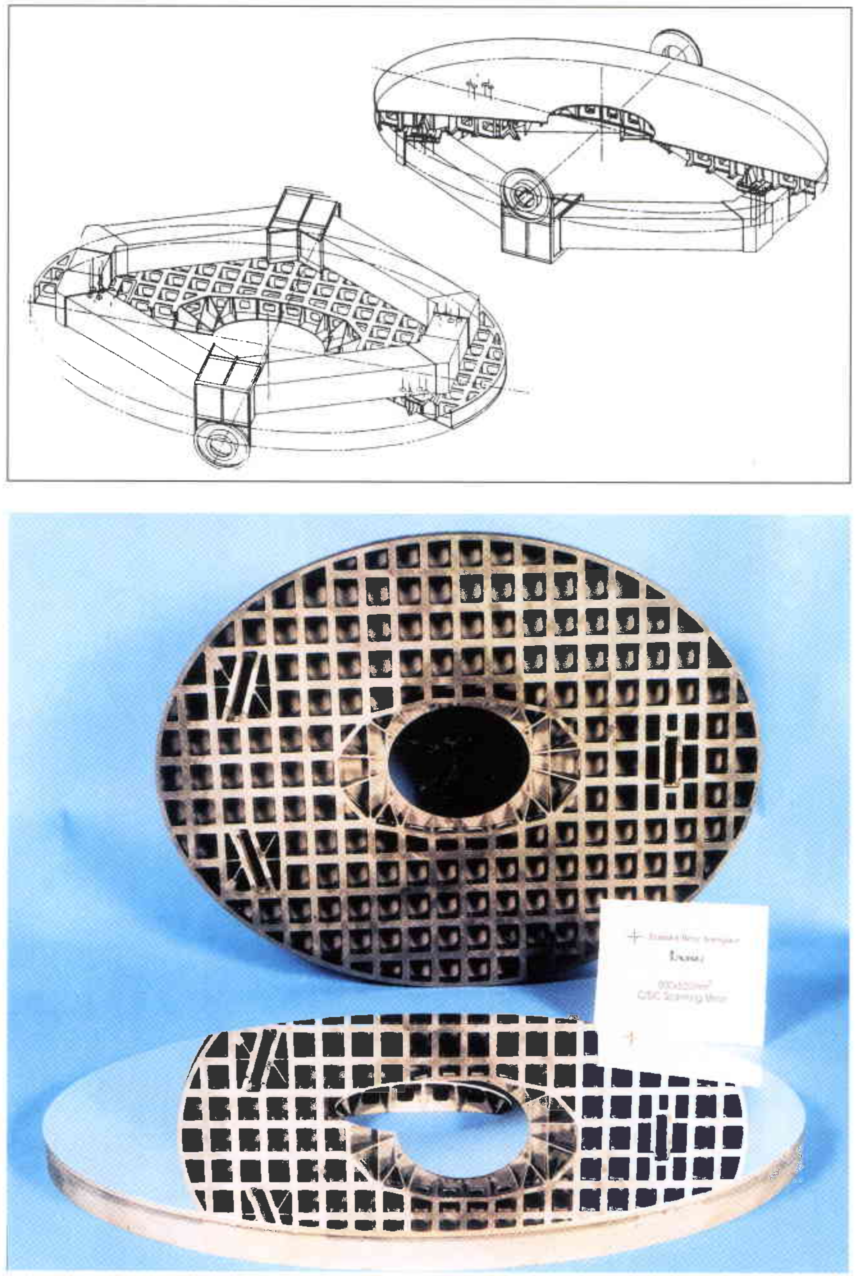


Figure 6. Design and hardware of the 80 cm x 50 cm Ultra Lightweight Scanning Mirror (ULSM), which weighs just 7 kg

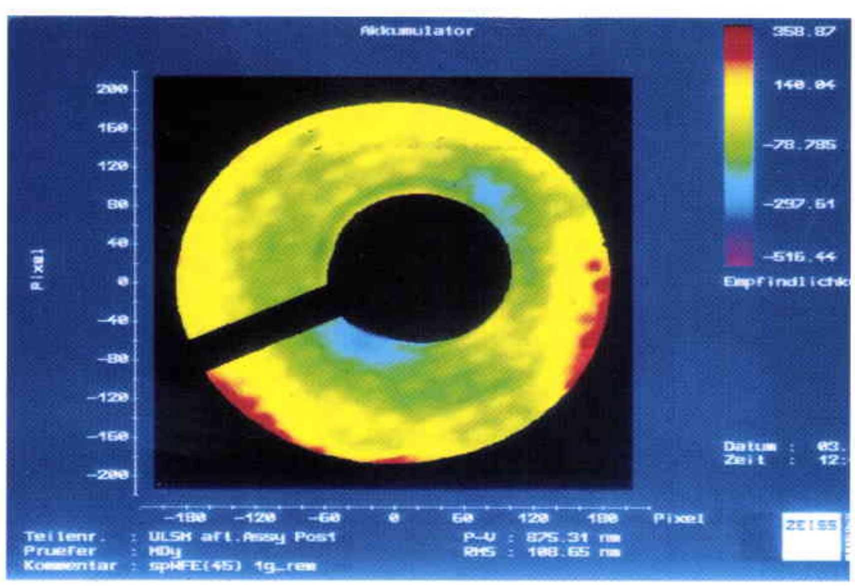


Figure 7 . Interferogram of the assembled 80 cm x 50 cm ULSM

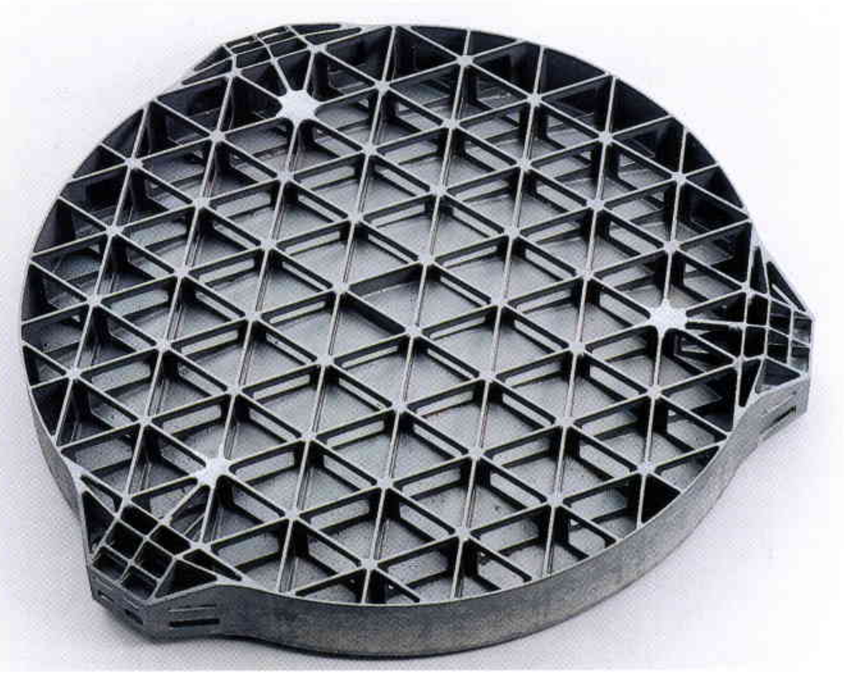


Figure 8. Rear of the 63 cm parabolic mirror for the ATLID application

Figure 9. Large verification structure for the SEVIRI thermal-stability test; the monolithic ceramic structure is 150 cm in diameter and 200 cm high

ATLID

Another example of highly efficient structural design is the ATLID (Atmospheric Lidar Experiment) parabolic mirror (F 0.9, aperture 63 cm). In the stiffening structure (Fig. 8), all unnecessary material has been removed in a trade-off between stiffness and mass, including in the area of the isostatic mounts. The triangular grid pattern with a rim thickness of only 1 mm and with internal cutouts is among the most complex ceramic structures of such size ever built. The mirror has been designed to have a first eigenfrequency of over 400Hz and a structural safety margin of 3.9 at 60 g static load.

After fine machining and lapping to 8 micron rms accuracy, the mirror surface was coated with a 150 micron CVD-SiC layer. Sample polishing tests have shown good homogeneity and that a surface micro-roughness of less than 1 nm rms can be achieved. The mirror exhibited no change in radius of curvature after the CVD coating. The "as built" mass of the mirror is just 6.2 kg.

Three-dimensional structures

The excellent "joinability" of the C/SiC material allows individually machined parts and structural elements to be combined to form complex 3D structure. The designer can therefore manufacture a ceramic telescope or instrument structures to final dimensions in the green-body state and then "infiltrate" them to form an integral ceramic component. C/SiC optical components can be used in combination with C/SiC structures to build athermal optical systems.

In addition, monolithic ceramic truss structures with better stiffness and thermo-mechanical properties than conventional all-aluminium or beryllium-type structures can be realised. Figure 9 shows such a large monolithic all-C/SiC reference structure which is currently being manufactured.

Conclusion

A process has been successfully developed that allows C/SiC ceramic materials to be used to manufacture highly complex, lightweight, high-stiffness mirrors and structures with excellent dimensional stability. C/SiC reflectors can be manufactured from a single piece of green-body or, for larger reflectors up to 3 m in diameter, as separate segments which are then joined whilst in the green-body state. This novel approach also allows one to realise closed-back designs, which result in improved structural efficiency. Different polishable surface coatings have also been developed for specific applications, which range from scanning mirrors to large telescope reflectors. Last but not least, this all-ceramic instrument technology delivers consistently high optical performance over a very wide temperature range.

ATLID: The Technology Development Programme for ESA's Satellite-borne Atmospheric Lidar

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The idea of deploying a lidar system on an Earth-orbiting satellite stems from the need for continuously providing profiles of our atmosphereís structure with high resolution and global coverage. Interest in this information for climatology, meteorology and the atmospheric sciences in general is huge. Areas of application range from the determination of global warming and greenhouse effects, to monitoring the transport and accumulation of pollutants in the different atmospheric regions (such as the recent fires in Southeast Asia), to the assessment of the largely unknown micro-physical properties and the structural dynamics of the atmosphere itself.

Introduction

An Atmospheric Lidar is an active instrument for profiling the structure of the atmosphere. Other types of lidar (acronym from Light Detection and Ranging) also exist — Doppler wind lidars, lidars to trace the concentration of chemical constituents, Raman lidars, etc. — but all of them work on the same principle. A lidar sends a laser beam into the atmosphere and collects and analyses the returned radiation (equivalent to the "echo" in a radar system), which is retro-diffused (back-scattered) by the molecules and the particles present in the atmospheric volume being probed. This returned light signal is collected by the instrument optics (typically a telescope) and detected, i.e. transformed in an electrical signal, by an opto-electronic receiver. In an Atmospheric (or back-scatter) Lidar, the signal is then sampled and processed to retrieve its intensity profile. The signal intensity is proportional to the back-scattering coefficient of the probed atmospheric volume, which in turn is a function of the density and type of particulates present. In this way, the concentration of the scattering media — whether aerosol, molecules or dust — can be measured.

Moreover, the retrieved information is intrinsically range-resolved, i.e. it is recorded as a function of the distance of the lidar from the target. In fact there is a one-to-one relationship between the time of flight of the light signal (the time that elapses between the emission of the laser pulse and the detection of the return "echo") and the location of the atmospheric sample which has back-scattered the light. If we consider a light pulse which travels through the atmosphere, each section of the atmosphere traversed by the pulse retro-diffuses a small portion of the light signal. The lidar receiver sequentially collects all of these contributions, which form an intensity-modulated pulse of longer duration than the transmitted one. By measuring the overall time-of-flight of the pulse and by "slicing" the pulse and assigning to each portion its own time of retrieval, the distance-resolved profile of the atmospheric path can be reconstructed.

For satellite-based measurements, the lidar instrument shoots its laser pulse to the Earth and the return signal contains samples "originating from" different regions of the atmosphere. Knowing the satellite's orbital height and the direction of travel of the laser pulse, one can retrieve a height-resolved profile of the atmosphere. These profiles contain valuable information about atmospheric features of interest, such as the density of particulates or pollutants, the structure of (thin) clouds or banks of aerosols, and possibly the concentration of air molecules. The resolution of the profile will be determined by the "timing" capability (the processing sampling bandwidth) of the detection system.

The lidar instrument consists of a laser source which generates the light pulses that probe the atmosphere, a telescope and optics to collect the back-scattered radiation, and a receiver which converts the light echo into an electrical signal. The direction of the outgoing path is co-aligned with the bore sight of the receiving telescope. If there is a need to probe many different regions of the atmosphere, a scanning mechanism can be added to steer both the telescope and the laser transmission axes in the required direction. In a satellite-based lidar instrument, other units are added to support the operation: a thermal-control system to extract the heat generated by the laser, a counter-inertia flywheel to compensate for the torque induced by the scanner, and a star-sensor to assist in the retrieval of the exact direction of the laser measuring path (Fig. 1).

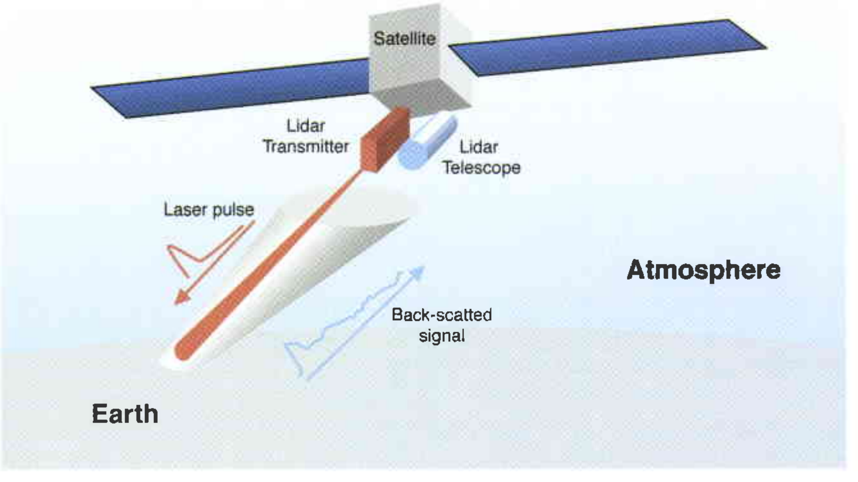


Figure 1. Schematic of the operating principle of a spaceborne lidar. The pulse sent to the atmosphere is back-scattered and the instrument collects and analyses the radiation, retrieving the profile of the measured parameters

ATLID: the European Atmospheric Lidar

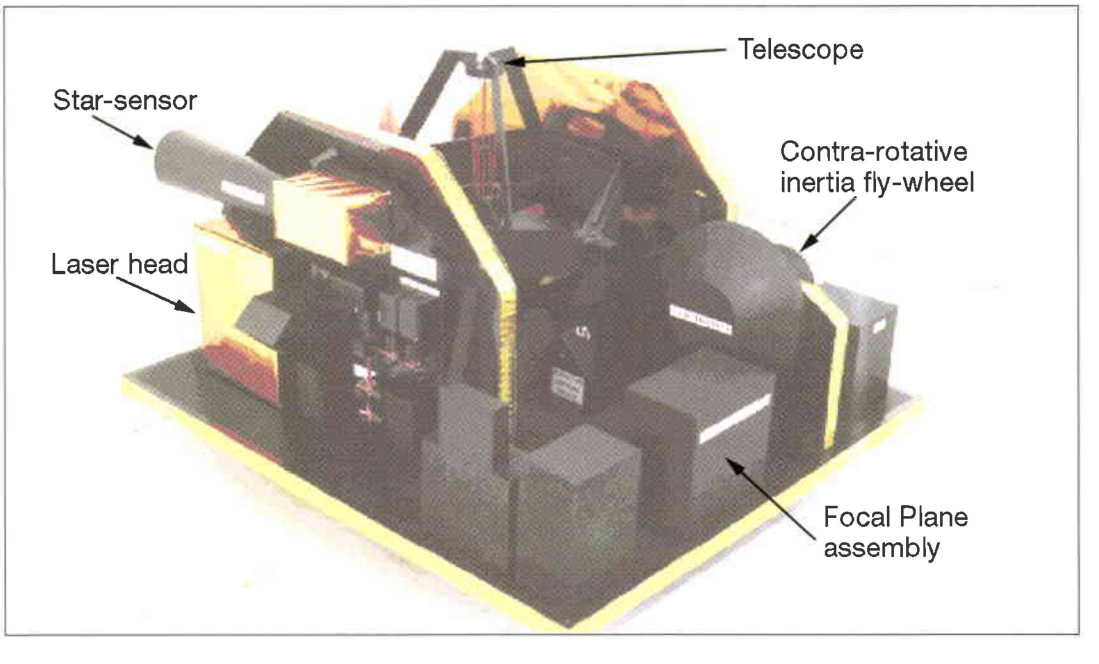
For more than a decade, ESA has been conducting studies and technology development efforts to evaluate the usefulness of lidars for remote sensing of the Earth's atmosphere from space*. These studies culminated in the definition of an Atmospheric Lidar concept known as ATLID, suitable for accommodation on the Agency's Envisat satellite.

ATLID is designed primarily to provide satellite measurements of cloud-top height both day and night. It is also capable of measuring the heights of cloud bottoms for thin clouds and the extent of the Planetary Boundary Layer (PBL) and of aerosol banks. These atmospheric features can be measured to an altitude of 20 km with a 50 m resolution in height and an accuracy of ± 100 m (3 σ). In order to provide 3-D mapping of atmospheric features, the ATLID telescope is scanned transverse to the spacecraft's flight direction. The scan angle of ± 23.5 deg at an orbital height of 800 km results in a swath width on the ground of 700 km. With a footprint 140 m in diameter, and operating at 100 pulses per second, the instrument can obtain more than 100 measurements within a 100 x 100 km^2 area.

ATLID is based on a pulsed diode-laser-pumped solid-state (Nd:YAG) laser, which delivers high-energy pulses in the near-infrared (at a wavelength of 1064 nm). The back-scattered light is collected by a lightweight 60 cm-diameter telescope, mounted on a single-axis scanning mechanism, which also provides the co-alignment of the outgoing and incoming light beams. The incoming radiation is filtered against the background light and sent to a receiver based on a high-sensitivity avalanche photo-diode. The torque generated by the scanning mechanism is compensated by a flywheel and the pointing is assisted by a star-sensor and fine-tuned by a so-called "lag-angle compensating mechanism". This device introduces corrections to the deviations that the beam suffers due to the scanning and spacecraft motions during the time of flight of the pulse. The variety of atmospheric targets which ATLID is called upon to measure requires a versatile electronic processing chain, able to handle signals with a large dynamic range.

As mentioned above, the present instrument design (Fig. 2) was tailored to its accommodation on the Envisat remote-sensing

Figure 2. Full-scale mockup of the ATLID instrument layout resulting from the design study (courtesy of MMS-F)



* See "Laser-Based Remote Sensing from Space", by E. Armandillo and H-P. Lutz, in ESA Bulletin No. 66, May 1991

platform. As a result of the workshop held in Granada (Spain) in 1995 for the assessment of the nine candidate Earth Explorer missions, recommendations were made to include an Atmospheric Lidar in the model payload of the Earth Explorer - Earth Radiation Mission, to provide height-resolved cloud-aerosol and planetary-boundary-layer height information for assimilation into a general Earth radiative model. A non-scanning ATLID design is presently proposed for the Earth Radiation mission, for which a different spacecraft concept is foreseen. The elimination of the scanning feature is dictated primarily by the need to achieve the best possible synergy between ATLID and the cloud radar, which is part of the satellite's basic instrument package.

The ATLID technology development programme

The study of the complete instrument was followed - starting in 1994 - by an extensive breadboarding programme. The instrument breadboards and assemblies realised in this programme were then tested to verify their functionality and also their compliance with environmental requirements. This activity was largely completed by the end of 1996, by which time most of the breadboard units had been tested and delivered.

The complexity and multi-disciplinary nature of the development work called for a joint effort by ESA, industry and several specialised institutions in the Member States. The ATLID development programme was therefore structured like a small project, with a team of experts drawn from the Directorate of Technical and Operational Support working in close consultation with Earth Science Division and Earth Observation Preparatory Programme Division staff. The industrial consortium, led by Matra Marconi Space France, included 25 companies from 10 different ESA Member States and Canada.

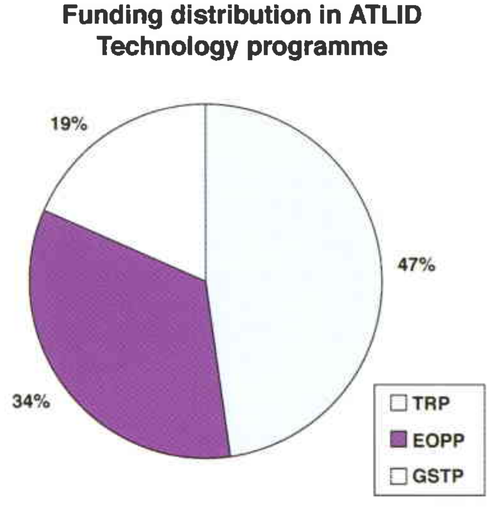
The development programme was financed through joint contributions from the ESA Basic Technology Research Programme (TRP), the General Support Technology Programme (GSTP) and the Earth-Observation Preparatory Programme (EOPP), totalling about 7 MECU (Fig. 3).

In view of the mission opportunities now foreseen within the Earth Explorer Programme, the scope of the ATLID Technology Development Programme has been enlarged to include the demonstration and early validation of the technologies for all key units and sub-systems. It is in fact recognised that ATLID is a very complex instrument relying on a variety of advanced technologies, ranging from high-energy laser sources to narrow-band optical filters, high-sensitivity detectors, large heat-lift thermal-control systems, lightweight optics and precise scanning mechanisms. With such a large and complex class of instrument, it is imperative not only to test the individual units, but also the sub-systems and their interfaces if one is to realistically assess the technology's readiness for such a satellite mission. The effort spent in analysing and testing the critical technologies and sub-system interfaces at an early stage will result in lower costs during the subsequent instrument development phases and hence in overall cost savings.

The ATLID sub-systems verification activity foreseen within the GSTP Programme (total envelope 3 MECU) focuses on the integration and testing of the laser head with the laser-diode power supply, the Q-switch and the thermal-control assembly, on the end-to-end verification of the detection process, and on the full integration and testing of the telescope and the optics.

Technical results to date

The technology-development activities so far



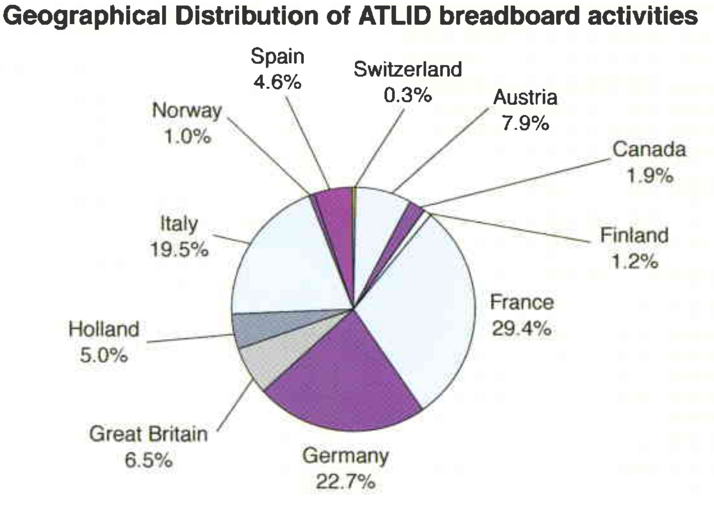


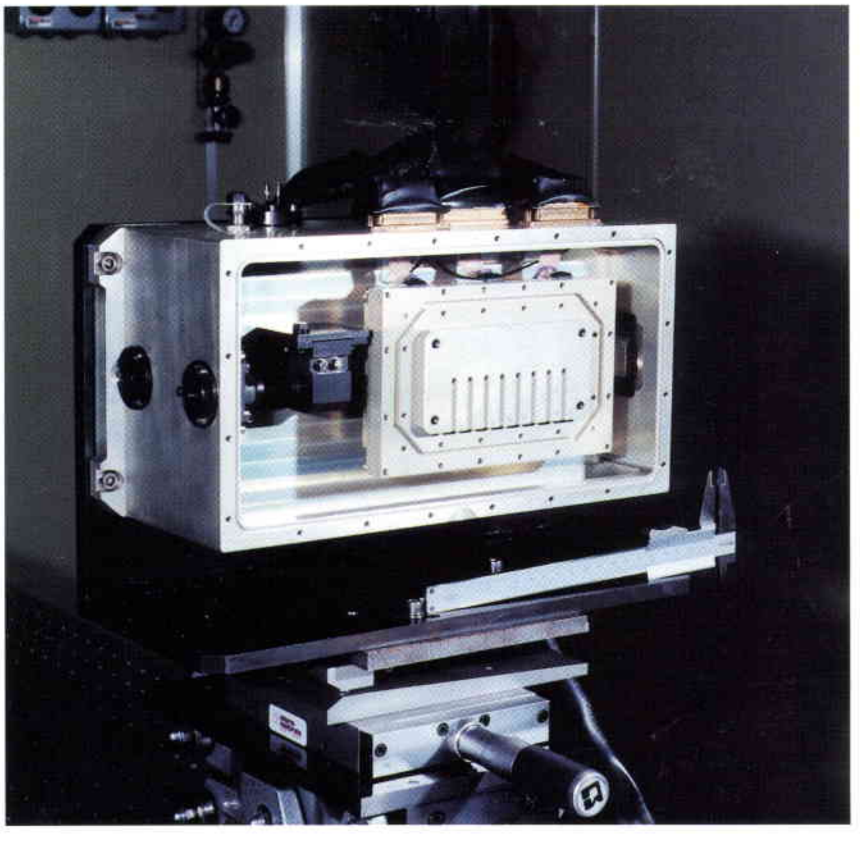
Figure 3. The ATLID funding shares, and geographical distribution of the technology-development activities

have been concentrated on the critical units of the three key sub-systems:
- the *transmitting sub-system*, composed of the laser head assembly, the laser thermal-control assembly and the beam-shaping optics
- the *receiving sub-system*, including the scanned lightweight telescope, the optical bench with the filter and the receiver
- the *pointing/scanning sub-system*, including the lag-angle compensating mechanism, the scanning mechanism with the contra-rotating inertia flywheel, and the star sensor.

Several of the critical technologies/units have already been breadboarded and tested, including the transmitter laser, laser Q-switch, laser diode power supply, thermal control, narrow-band filters and the optical coatings, detection chain, lightweight telescope and scanning mechanism.

The transmitter laser for ATLID is a 10-W diode-pumped Nd:YAG laser operating at a wavelength of 1.064 micron, which emits laser pulses with energies up to 100 mJ and lasting 20 ns, with a 100 Hz pulse repetition frequency (Fig. 4). The laser head is pumped by high-energy pulsed laser diodes and emits a beam of good spatial quality and high pulse stability with an electrical-to-optical efficiency (conversion ratio from prime power to laser radiation) of 6.5%. The generated heat of about 100 W is transferred to the thermal-control system by means of a conductance plate. The laser diodes are driven by a high-current pulsed power supply, which has also been breadboarded. The unit, which was tested in vacuum and with different thermal cycles, achieves 74% efficiency.

Figure 4. The ATLID laser head, with the heat-exchanger plate of the laser diodes visible in the foreground

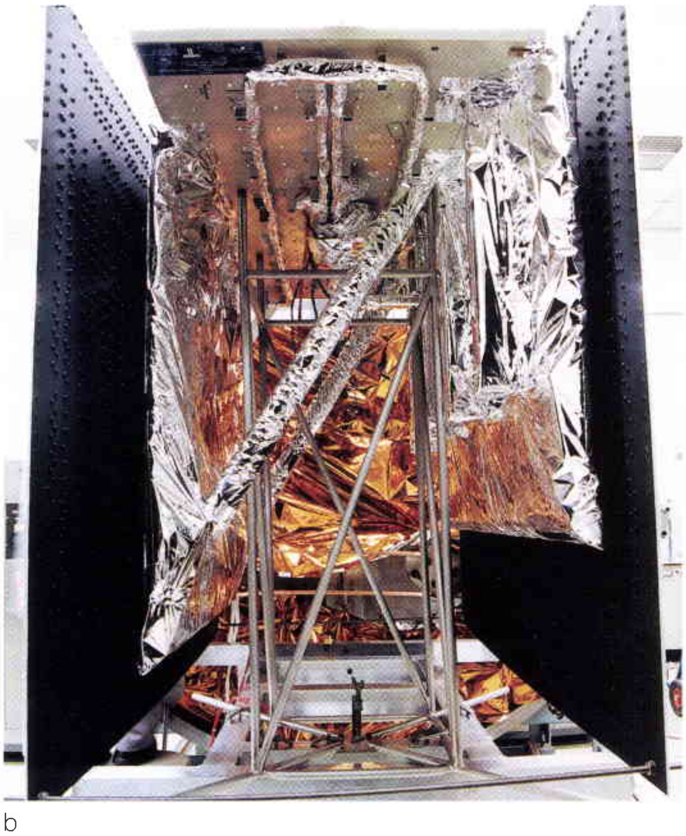


Another key element of the laser head, the laser Q-switch, is presently being breadboarded. It triggers the build-up and release of the laser pulse and consists of an electro-optic crystal, whose non-linear optical properties are modulated by a high-voltage pulse. Due to the very high energy flux of the laser beam, the Q-switch is subject to optical damage and therefore both accurate screening of the electro-optic crystal and a high-quality surface coating are required in order to produce a high-reliability device suitable for prolonged operation in space.

As already indicated, heat removal from the laser head is another key issue for prolonged operation of the laser transmitter. A high thermal load has to be dissipated under the extreme temperature conditions in orbit. A capillary-pumped two-phase loop has been selected for its high heat-lift capability and absence of moving parts. The fluid (ammonia) in the loop changes phase when in contact with the conductive plate to which the diodes are thermally coupled. The vapour expands via the ducts to the radiator, mounted on the satellite's anti-sunward face, where it returns to the liquid phase. The fluid is pumped by capillary effect through a sintered nickel wick and the fluid level is maintained constant throughout the whole range of thermal loads and operating cycle by a reservoir (Figs. 5a,b). The breadboard, including the large radiator assembly, has been submitted to both vibration and thermal-vacuum testing and the capillary pump was shown to still operate successfully even under 1 g conditions (i.e. when pumping against gravity).

The back-scattered radiation is collected by a 60 cm lightweight Cassegrain telescope, weighing less than 10 kg. The primary mirror is realised in C-SiC (Fig. 6), coated with a 100 micron SiC vapour-deposited layer, and supported by a non-hygroscopic CFRP structure. The large primary C-SiC mirror has already been breadboarded and polished to specification (surface roughness < 20 nm p-v) and the next step will be integration of the overall telescope.

The telescope is mounted on a single-axis scanning mechanism (Fig. 7), suspended between two liquid-lubricated bearings, designed for a lifetime of 1.8×10^7 cycles. The scanning-induced torque is compensated by a



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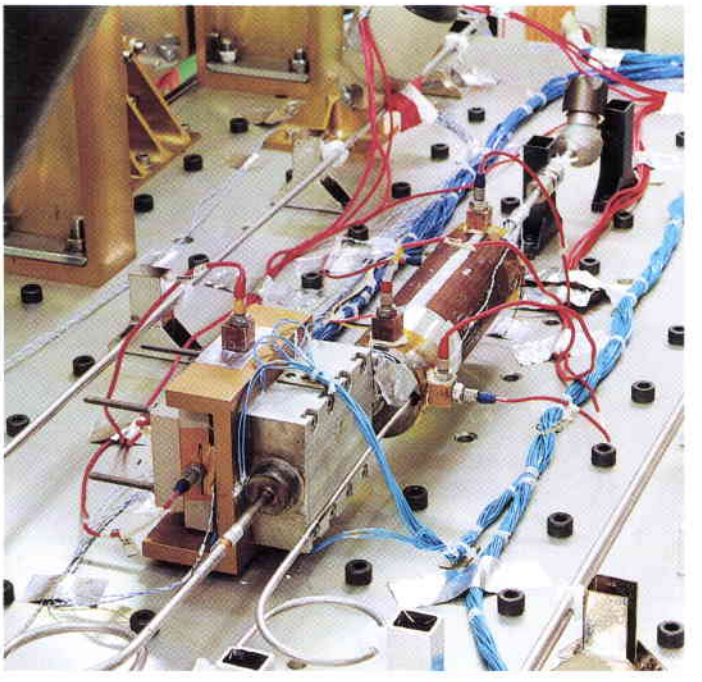

a

Figure 5. The laser thermal-control system: (a) evaporator/reservoir assembly with the ducts, ready for vibration testing; (b) overall breadboard assembly ready for thermal-vacuum testing

contra-rotating flywheel. The scan-mechanism breadboard includes the motor and bearing assembly and an optical encoder for angle restitution and monitoring, the electronic controller, the flywheel, and a locking device for the telescope during launch. The overall scan assembly, with a dummy mass for the telescope, has successfully passed its vibrational and thermal-vacuum testing. The bearings have also successfully completed an extended life-test in vacuum.

Focal-plane optics direct the incoming photons to the detection chain via an ultra-narrow-bandwidth filter for rejecting the background light originated by Earth albedo. The breadboarded filter is a Fabry-Perot device (Fig. 8), which has been shown to transmit up to 63 % of the return signal within a bandwidth as narrow as 0.21 nm. A Lyot filter was also breadboarded, but it proved less robust in meeting the accuracy and stability requirements.

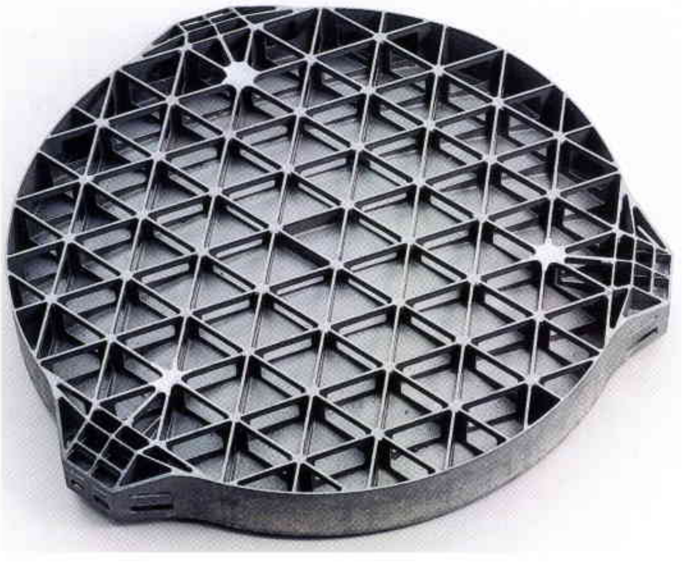

Figure 6. The ATLID telescope's C-SiC lightweight primary mirror (rear side)

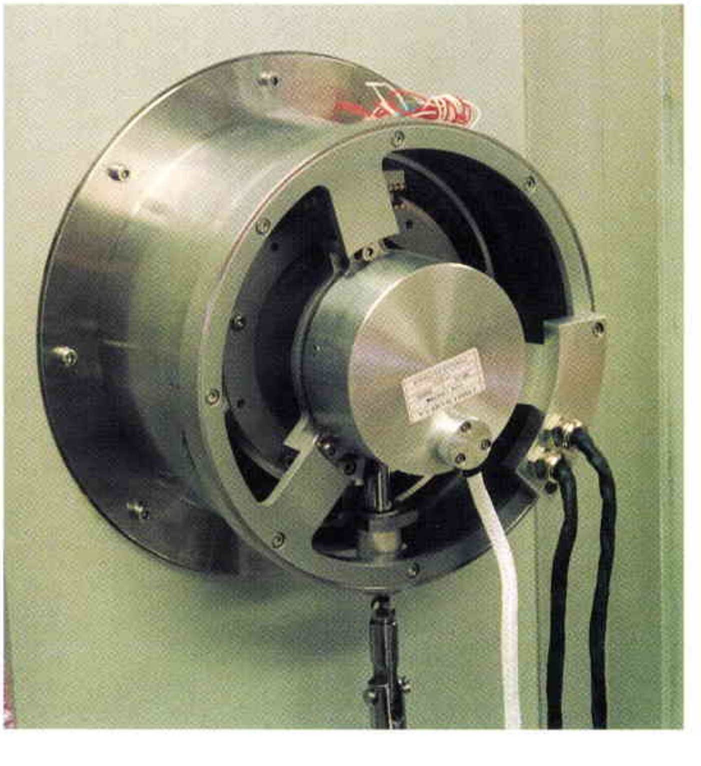

Figure 7. The scan mechanism, with the optical encoder in the foreground

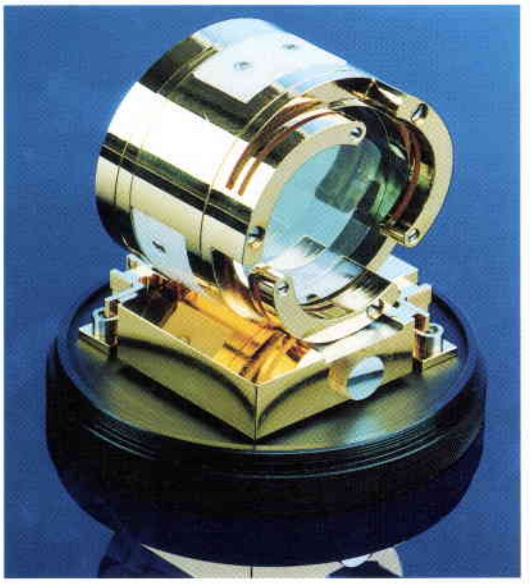

Figure 8. The hybrid front-end detector module of the ATLID receiver

The ATLID receiver consists of a detection module and a post-detection electronic chain. The detection module is based on a silicon APD, DC-coupled to a low-noise trans-impedance amplifier, integrated in a hybrid circuit. The latter has already been built to flight standard and provides an exceptionally low level of noise current. In order to perform the twin roles of cloud-top-height and aerosol-density measurement, the post-detection electronics is split into two parallel chains. The peak detection chain deals with high-intensity and sharp signals like those coming from the tops of thick clouds, and basically operates on a logarithmic amplifier. The radiometric chain is a high-gain high-linearity electronic assembly, able to trace minimum variations in the signal even at very low intensities, such as occur in the profiles generated by thin clouds or aerosol layers. The measured performances of the ATLID detection chain, in both day- and night-time operation, are outstanding: the measured signal-to-noise ratio meets — and more often exceeds — specification for all atmospheric targets, and the timing capabilities ensure a vertical resolution of 40 m, in a measurement range reaching to 25 km altitude.

On the basis of the architecture selected and the breadboard results, the estimated mass and power consumption of the complete ATLID instrument are 240 kg and 450 W, respectively.

The future of ATLID

As reported above, all of the key units have been successfully breadboarded and tested against their functional — and in most cases already also against their environmental — requirements. Although the focus has been on meeting functional requirements, the design standard of the units has permitted a substantial verification of the engineering performance against vacuum operation, temperature range and thermal cycling and random/sine vibrations and shocks. The availability of units of this standard will make the development and qualification of the future flight unit much more straightforward and efficient.

After subsystem integration and testing, following the programme of work planned for the years 1998 — 2000, the ATLID subsystem concepts and the maturity of the technology will be proven, in readiness for exploitation in the context of the Earth Explorer Earth-Radiation Mission.

All breadboarded models and units will then be available for further experimentation, either for further laboratory tests of specific lidar functions or to be assembled in a ground-based (or airborne) lidar model for supporting campaigns, ground-truth validation of other lidar missions and – possibly – for refurbishment and utilisation in flight tests.

Aside from the hardware heritage, the ATLID Technology Development Programme is providing a valuable return in terms of the day-by-day learning process, generating experience that can be exploited for other future technology developments. The ATLID work has also been a valid test-bench for the method of approaching the conception and initial development of complex innovative instruments like lidars. Rather than committing the R&D on single critical technologies to isolated specialists, a multi-disciplinary approach has been pursued to exploit throughout the synergies between the development of both the units and the sub-system, typical of a mature project environment.

The ATLID Programme can be seen as a successful R&D experience that has exploited the synergies between several different domains of space instrumentation technology in order to pave the way for the first European Lidar in space.

Acknowledgements

ATLID is the result of the joint efforts of many people, who have contributed over many years to ensure its success. The inputs of the following ESTEC colleagues who supported the development programme with their ideas and expertise are gratefully acknowledged: I. Arens, E. Armandillo, P. de Boer, A. Culoma, C. Garcia Marrirodriga, B. Harnisch, P. Ingmann, H-P. Lutz, R. Meynart and W. Supper. Nor would the programme have been so successful without the efforts and enthusiasm of our industrial partners, who actually realised the ATLID breadboards and units. In particular, the dedication and relentless efforts of D. Morancais, the ATLID Project Manager at Matra Marconi Space France, are gratefully acknowledged

ESACOM: The ESA Communications Network

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The goal of the ESA Informatics Department with respect to communications is to provide the Agency with efficient and reliable networking services to meet the users' evolving requirements at the best market conditions. It fulfils its mandate by offering a baseline for networking services targeted at the whole Agency, although networking support for spacecraft operations is not part of the Department's responsibilities. The general-purpose network engineered and operated by the Department is called "ESACOM". This article describes both the network and its basic service philosophy, as well as its potential role in a future ESA Corporate Highway.

Introduction

In accordance with the Agency's strategy regarding procurement of information services, ESACOM is based on an infrastructure offered by means of industrial contracts. Such contracts specify all services to be performed, the sites to be connected, the protocols to be supported, and all relevant service performance parameters. The delivery of the service parameters as specified in the contract is guaranteed on the basis of a Service-Level Agreement between the Agency and the industrial provider. Appropriate tools are provided to monitor the performance of the services and whenever necessary to initiate actions to restore service in the event of failures. This approach corresponds to modern established industry practice whereby a company concentrates its activities on its core businesses and leaves to industrial partners the provision of enabling services. The success of this approach is based on how well an intrinsically stable and static arrangement like a contract can capture the services expected by the customer and their dynamic evolution. The experience of the customer's staff responsible for the establishment and the maintenance of the arrangement, as well as the experience of the provider's staff responsible for its provision, are key to this success.

The experience gathered so far by ESA in its industrial partnerships has shown that the approach is feasible and can be used to successfully fulfil most networking requirements of a modern high-tech distributed organisation. The outsourced wide-area networks Data Dissemination Network (DDN) and Level 3 ESANet have been operating for almost three years with satisfactory performance. The expected cost reductions with respect to in-house provision have been achieved. The flexibility afforded by this approach enables the core corporate

Internal Organisation

Within the Informatics Department's Infrastructure Division, ADM-IT, responsible for the whole computing infrastructure, ADM-ITR, based in ESRIN, has the responsibility for the operations and the security of the ESA wide-area networks, as well as for the ESRIN Local Area Network. LANs at the other Establishments are operated by the respective infrastructure sections. The responsibility for network planning and engineering on an ESA-wide basis rests with the ESA Network Planning and Engineering Unit (ADM-ITN), which:
- Endeavours to be the centre of competence and expertise for networking in ESA.
- Continuously monitors the technology evolution.
- Defines the road map for the evolution of ESA networks, accommodating future user requirements.
- Procures the best services from industry at the best market conditions.
- Consults with projects on their telecommunications requirements and tailors the network infrastructure to satisfy them.
- Conducts studies to assess new concepts.

* Based at ESOC
** Based at ESTEC

requirements, as well as any project-specific connectivity requirements arising within ESA, to be catered for, with the beneficial effects of cost reductions deriving from synergy, avoidance of duplication, and economies of scale.

The network

ESACOM has a core (Fig. 1) that caters to the general-purpose data-networking requirements of the Agency by providing the following services, all based on the TCP/IP communications protocol:
- Local Area Network services.
- Wide-area data connectivity:
  - Interconnections between ESA Establishments and sites where the Agency has a permanent presence, such as the ESA ground stations (Redu, Vilspa), Brussels, Cologne, Washington, Moscow, Kourou, and Toulouse
  - Access to public networks: Internet, Public Switched Telephone Network (PSTN), Integrated Services Digital Network (ISDN), provided at all sites via different local providers.
- Protection and security according to ESA policy.
- Operation and monitoring of the above.

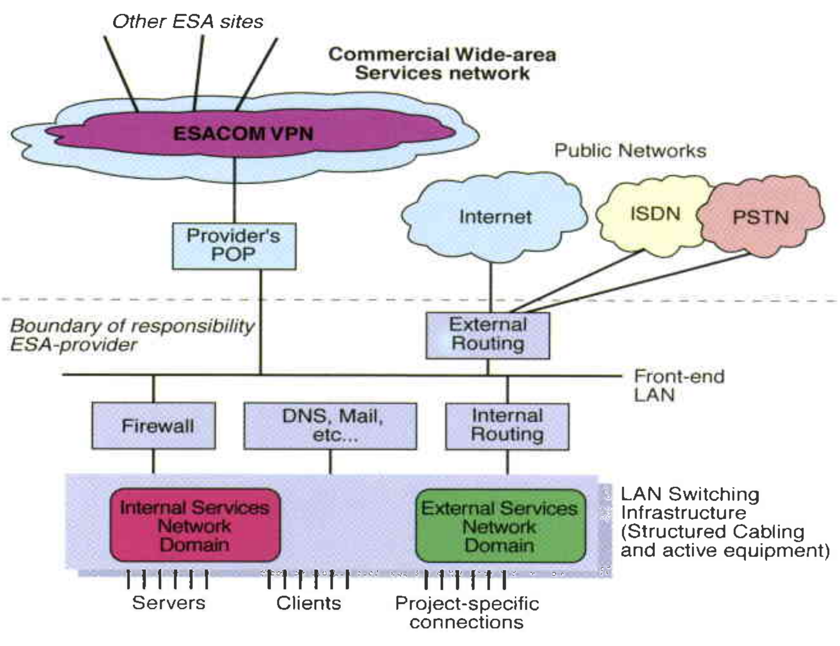


Figure 1. The ESACOM model

Additional communications services can be offered by ESACOM to cater to project-specific requirements, as described below.

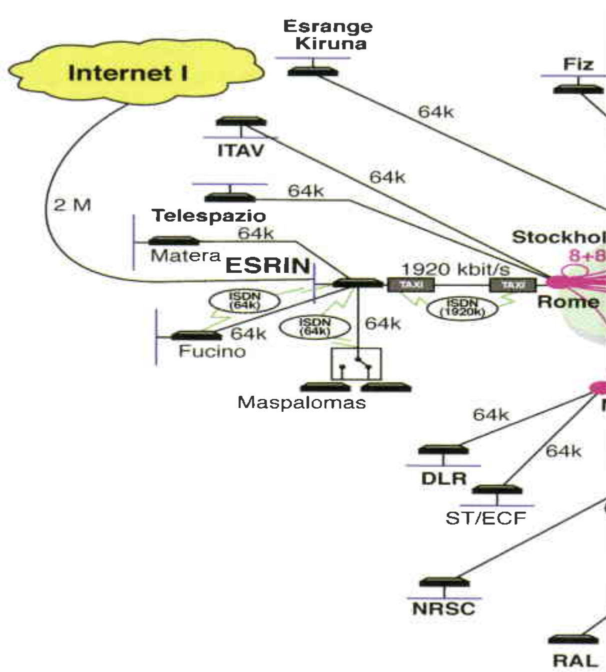
Local Area Network services

The Local Area Networks (LANs) at all main sites are organised according to a uniform criterion of structured cabling and LAN switching that allows optimal performance and maximum flexibility. Each wall outlet (in offices or computer rooms) can be associated to a different logical community, a virtual LAN, according to criteria like security (traffic isolation) and performance (traffic optimisation). The same cabling system can also be used to support telephone connections or special high-speed connections.

Wide-area connectivity

The wide-area data connectivity of ESACOM between ESA sites and stable project partners is provided by means of an outsourcing contract, where DDN, ESANet, and Level 3 have converged. The industrial telecommunications service provider, BT, offers connectivity all the way to the Customer Premises via dedicated routers used as Points of Presence (POP), connected via access lines to the nearest point of the provider's core network. The outsourced network is under the constant control and monitoring of the provider. ESA itself also monitors the status of the outsourced services, interacting with the provider to ensure that the service parameters are constantly met.

The model sketched in Figure 1 is instantiated in the five major ESA sites to provide wide-area connectivity via the commercial frame-relay network service offered by BT, CFRS (Concert Frame Relay Services), and via the external Public Networks. The dotted line in the figure indicates the boundary between the contractual responsibility of the providers and that of ESA (other network nodes follow a simpler model, without public networks).



Permanent Virtual Circuits pair-wise-connecting all major ESA sites constitute the ESACOM Virtual Private Network (VPN), realising a global ESA Intranet. ESA present and future Corporate Applications will all be supported by this network. Several other nodes of the network correspond to locations that are involved with ESA in the framework of a particular project, e.g. ERS or Envisat, as described below. The full structure of the ESACOM wide-area network, with the circuits interconnecting ESA sites and their partners, is shown in Figure 2.

Basic connectivity to the Internet for all ESA users at all ESA sites is considered part of the core network services. Internet is a fundamental business tool for dynamic access to information and to support both traditional and innovative types of human interaction. Internet is also fundamental, on the other hand, to making ESA's information and services generally accessible to the World. This implies that standard naming structures, levels of protection, and a fair share of the link capacity, are available without distinction to all users of the ESA corporate network.

The four ESA Establishments and Vilspa are connected to the respective national academic Internet Service Providers. The national networks, in turn, are interconnected via a high-speed international European backbone called TEN-34, which also provides a high-speed link to the United States.

A basic policy requirement is that no Internet traffic in any direction shall burden the Intranet links. To this end, major sites are visible to the Internet via their own national connection. As an exception to that requirement, minor ESA sites are attached to the major ones via secure tunnels, so that their Internet access will occur via one of the national connections described above.

A Remote Access Service to travelling or home-based users is provided via the Public Switched Telephone Network (PSTN), the Integrated Services Digital Network (ISDN), or a corporate account with a commercial Internet Service Provider, as appropriate. The same infrastructure also provides connectivity from ESA sites to remote users on public networks (dial-out).

Access to public networks is granted in all cases via the site's LAN and an external routing function, subject to the constraints of the security policy described later. Direct connectivity of a user's PC or work station located within any ESA premises to any public networks is not allowed, as this would bypass the whole security infrastructure.

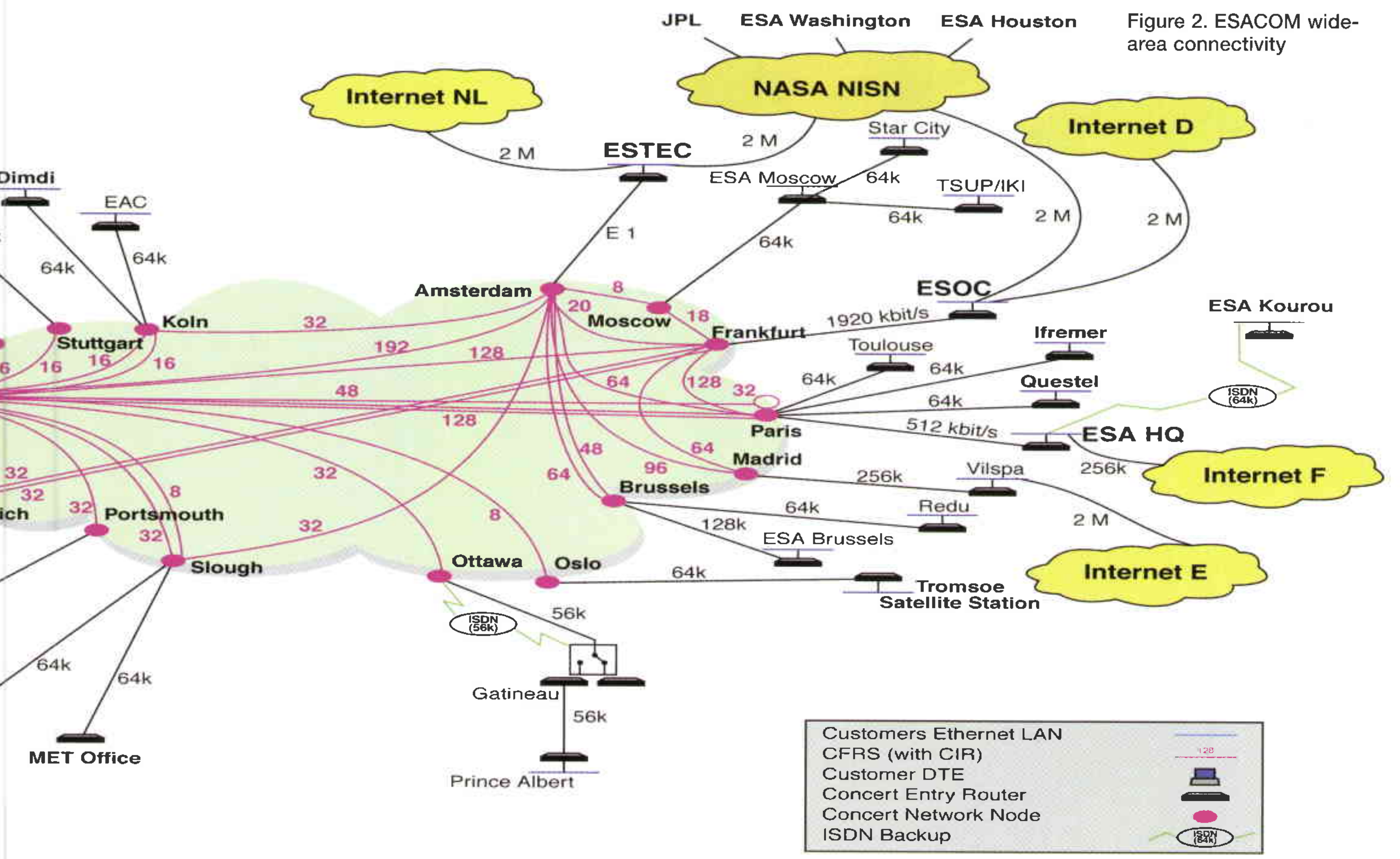


Figure 2. ESACOM wide-area connectivity

Network security

The ESA network infrastructure is subdivided from a security point of view into four network domains, as shown in Figure 3: the "External Networks", the "ESA External Services Networks", the "ESA Internal Services Networks" and the "ESA Restricted Networks".

At the boundary between the second and the third domain, as well as between the third and fourth, security facilities control all traffic. It is not possible for a single bit of information to enter or leave the ESA Internal Services Networks or the ESA Restricted Networks without passing through these facilities.

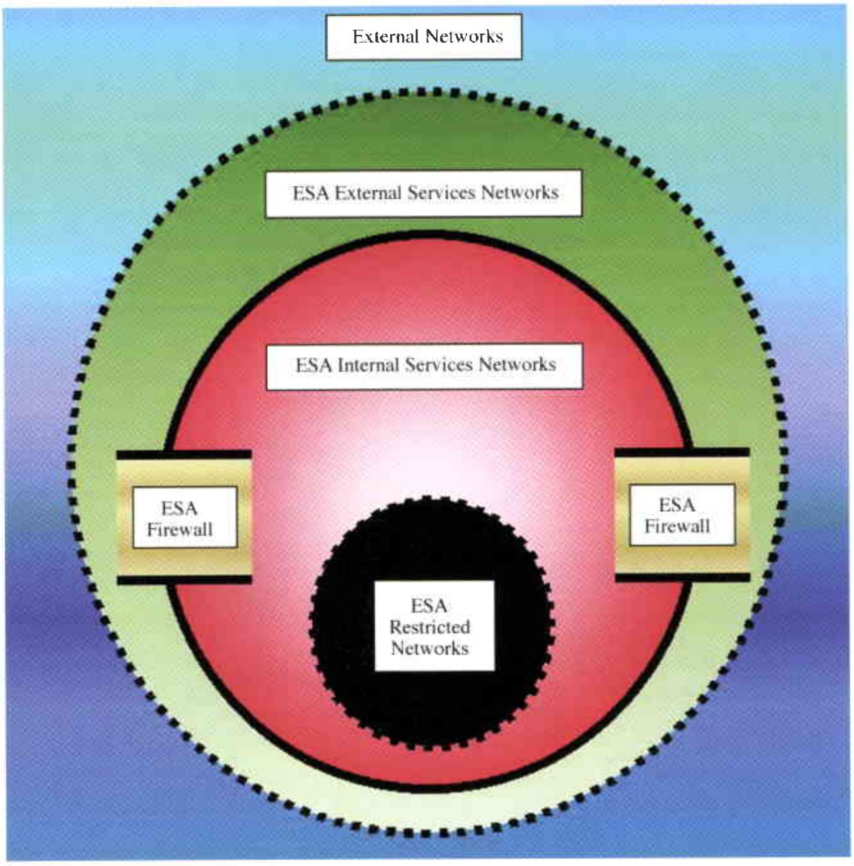


Figure 3. The ESA network security architecture

Each security facility comprises a set of mechanisms, implemented via one or more hardware components, that are individually tailored to handle the connectivity required within the scope of the involved classes. The mechanisms themselves are not static. They are established on the basis of available technology, the scope of the user requirements, and the overall ESA security and access policy.

- External Networks are networks supplied or owned by off-site industrial partners, national space agencies, or scientific institutes, national or international research networks and networks of Internet Service Providers as well as the Global Internet. Telephone networks used for data exchange, whether analogue (PSTN) or digital (ISDN), operated by any PTT or private provider, are also treated as External Networks.

- ESA External Services Networks are ESA networks that allow unrestricted access to and from the External Networks, in particular from the Global Internet. Connection to the ESA External Services Networks is foreseen for Information Servers that present the Agency to the World. For example, the ESA External World-Wide Web (WWW) Servers and ESA Public File Transfer Protocol (FTP) Servers are placed on the ESA External Services Networks.

- ESA Internal Services Networks include networks for the support of Software Development and those for the support of the Agency's Office Automation System. Software development users may typically need to access the ESA External Services Networks or External Networks, due to the frequent use of external contract support for software development and exchange of data with other space agencies and scientific institutes. Office Automation users typically need a high degree of connectivity to the outside world to support mail and data exchange with external bodies, in a controlled manner given the sensitivity of the data exchanged.

- ESA Restricted Networks allow access only to selected subsets of the ESA user community. They offer additional security mechanisms protecting against unauthorised access from the ESA Internal Services Networks. Typical examples of ESA Restricted Networks are those that support the Agency's Financial and Personnel Management Systems. The Mission Support Networks are implemented as ESA Restricted Networks. These networks support the mission-control systems and access is therefore restricted to a minimum and extremely carefully controlled.

The ESA Network Security Architecture described above is implemented by means of ESA Firewalls (Fig. 4), which strike a balance between open access from and to the External Networks and the ESA External Services Networks and the security requirement of the ESA internal communications. The ESA Firewalls control all traffic crossing this boundary on the basis of the principle that anything that is not explicitly permitted is denied. It is not possible for any traffic to enter or leave the ESA Internal Services Networks from or to the ESA External Services or External Networks, without passing through the ESA Firewalls and being positively authenticated or permitted. All accesses, successful and unsuccessful, are logged.

Operations and monitoring

The wide-area portion of ESACOM is operated from ESRIN by means of an industrial operations contract that provides monitoring, reporting, and management of the front-end equipment. The ESACOM Network Control Room is shown in Figure 5. The LANs are maintained and operated by the respective Establishments' infrastructure sections. The industrial contract, by also covering the WAN interfaces at all sites and their consistency, ensures smooth interactions with the respective sites' LANs. This function has proved invaluable in keeping the outsourcing firm constantly focused on the provision of an acceptable service level.

The outsourced network is monitored by the same ESA industrial contract via an off-the-shelf network management tool that is used also to monitor the site's LANs (Fig. 6). This tool is able to browse, in real time, the operational and statistical data contained in the network provider's equipment at any site (local and

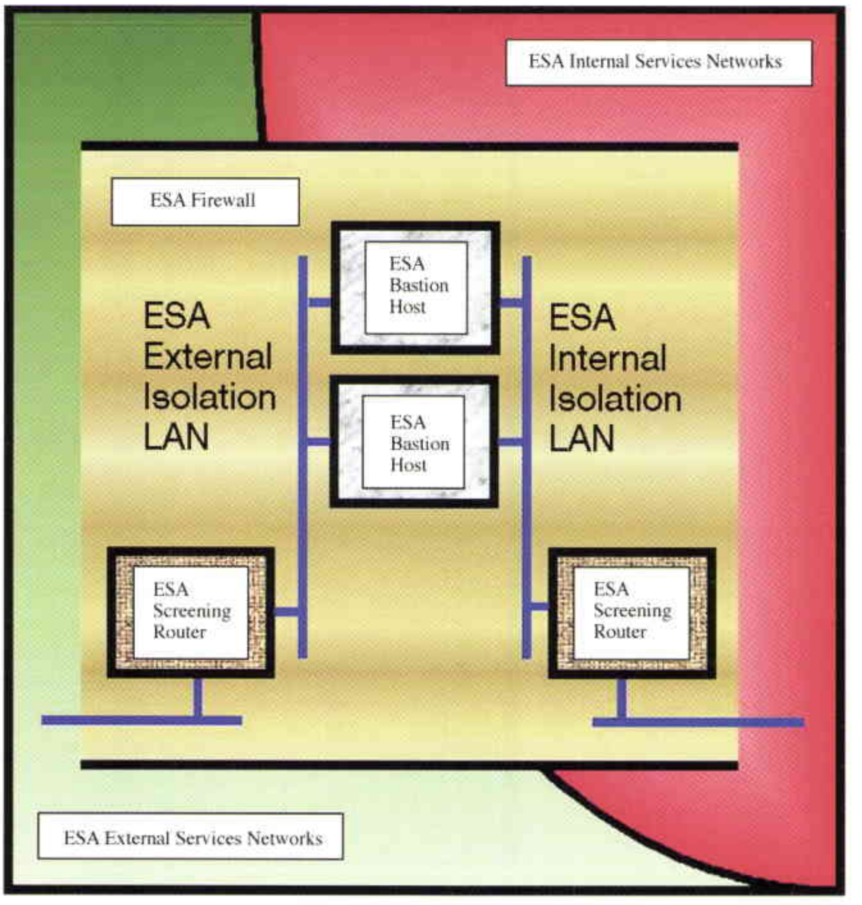
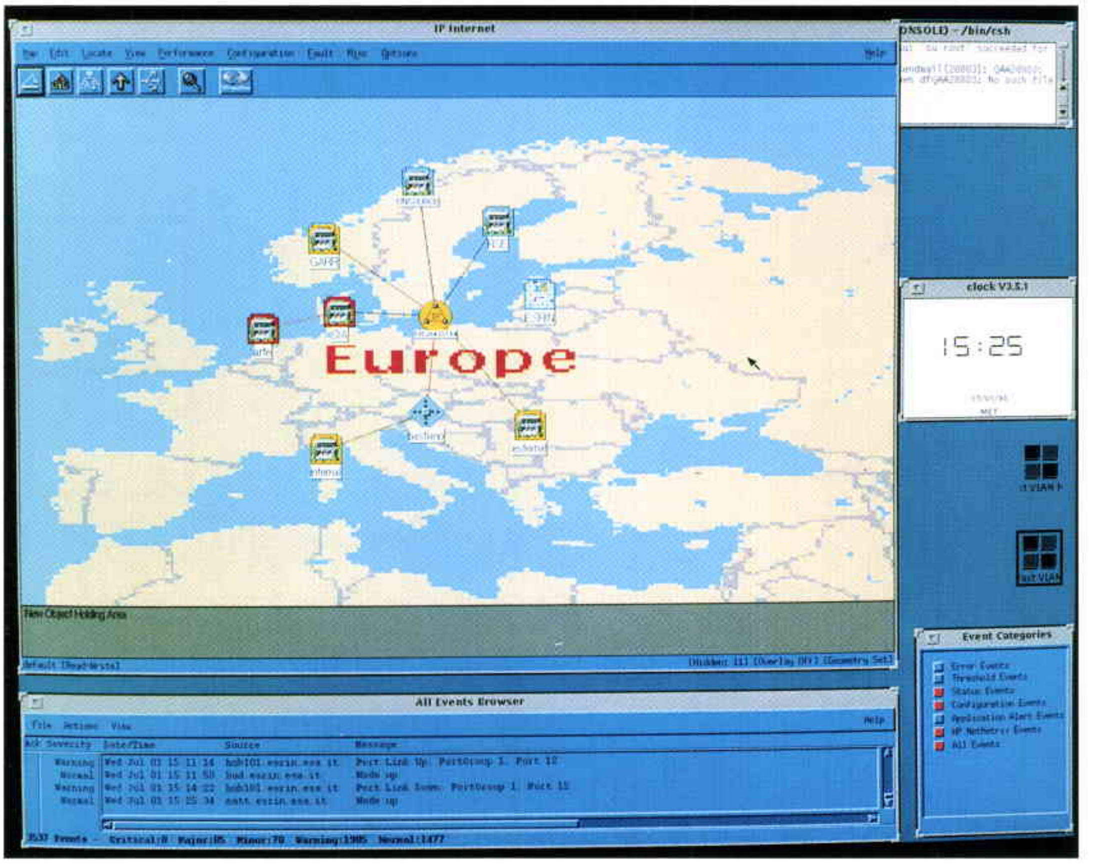


Figure 4. An ESA firewall providing high-level security

Figure 5. The ESACOM Network Control Room

Figure 6. The ESACOM network management tool



remote) of the network; the network operators can thus check the status of the network at any time and produce any statistics that they or the customer may require to check on the quality or the availability of the contracted service, such as the fulfilment of an internal service-level agreement.

Meeting project-specific networking requirements

In addition to the core services described above, ESACOM caters to specific project networking requirements based on the same core infrastructure, by providing customers with:

- network engineering efforts and consulting
- additional communication links directly related to the projects
- dedicated LAN connectivity throughout a site
- networking equipment at project-specific locations
- ISDN and PSTN on-demand connections
- dedicated access to public networks (e.g. Internet)
- extra security arrangements (e.g. access control lists)
- project-specific operations and maintenance (e.g. round-the-clock support).

For example, additional components to support specific project requirements can be easily and economically added to the basic building blocks of the outsourced WAN. The way in which the service is structured within the outsourcing contract allows for modification of the service parameters and of the hardware structures on demand, in order to cope with changes in requirements. A typical example would be a project requiring additional IP capacity. In this case, the speed of the access line can be increased and additional virtual circuits can be contracted. The capacity of such circuits can also be appropriately modified, whereas any desired service availability can be achieved by adding redundancy to the routers' configuration and requiring the access lines to be backed up with ISDN.

Additional requirements for Internet connectivity may also arise from specific projects, for which the basic access provided as part of core services may not be satisfactory in terms of link capacity, response times, security or even location of the connection. Such requirements can be addressed by contracting a dedicated link to the Internet with the appropriate capacity with a telecommunications services provider, to be used exclusively by the requesting project, although this service would be available at any location within the requesting site via the normal LAN connections. The provider of such service may or may not be the same provider as for ESACOM, according to the best market conditions. One such example is at ESRIN, where an Internet connection with guaranteed bandwidth has recently been contracted for Earth Observation public data servers and the ESA Home Pages.

Whenever a modification to the current network set-up is requested, as in the above examples, the new services can be gracefully accommodated on top of the current set-up. In those situations where a component of the core infrastructure already exists, the price increase is only marginal. This proves how the synergy with an existing infrastructure may benefit the users, compared with makeshift procurement of the services directly from the industry by each specific project.

The evolution of ESACOM

The stated aim of the Informatics Department is to provide efficient and reliable networking services to all of ESA according to the users' evolving requirements. The latter must be constantly monitored and validated against the latest technological offerings in order to fine-tune the available resources.

Two apparently contradictory drivers are influencing the evolution of the Agency's communications infrastructure today: the need to keep the IT and communications budget in line with the down-sizing of the Agency's overall expenditures and, pulling in the other direction, the steadily increasing demand for network bandwidth and performance as new network computing paradigms emerge to support ESA's business processes.

The objective of the ESACOM evolution is to respond to both of these categories of requirement with the realisation and continuous optimisation of a network infrastructure, the ESA Information Highway:

- ensuring the minimum cost per unit of traffic exchanged, while offering fully satisfactory communications services to its users
- integrating all the different communications services and therefore capable of exploiting to the maximum extent possible the synergy effects of such integration.

ESA is by nature a distributed organisation with a strong need to improve the efficiency of its operations. This can be achieved especially through the enhancement of its internal and external information exchange capabilities. One possible scenario is the realisation of working environments where the project activity is not constrained by the physical location of its resources (staff, knowledge base, support facilities, partners) inside and even outside the Agency. This presupposes the adoption of a networked enterprise organisational model based on the presence of an efficient and flexible communications infrastructure.

On a general-purpose network like ESACOM, it is reasonable to expect the existence of different classes of traffic that may come up with different, more or less stringent, performance requirements. For example, the interactive traffic of a financial application like AWARDS (strict real-time requirement of the financial officer sitting in front of a screen waiting for a response) may require a higher priority than an offline file-transfer application that can be launched in background. These requirements imply the prioritisation of traffic travelling on the same circuit, or of traffic on different circuits travelling from the same source to the same destination. Modern routing protocols supporting link prioritisation and resource reservation are being explored and acquired to that end.

The distributed computing applications (like the official ESA office automation system Lotus Notes, AWARDS, WWW), the newly emerging tools for computer-supported co-operative work, including desktop video/voice conferencing, and the potential shift towards a fully fledge network computing scenario pose additional challenges to the network infrastructure. The extra requirements will appear not only in terms of the pure increase in data transmission capacity, but also in terms of the ability to support different services with different Quality of Service (QoS) guarantees (like bandwidth, delay, priority, etc.).

Today, different networks are supporting different wide-area services in ESA: ESACOM as it stands today for data communications based on a frame-relay Virtual Private Network (VPN), a recently implemented ISDN-based Virtual Private Network for voice telephony between ESA sites, public ISDN for H.320 video conferencing between ESA sites and with external partners, and the public Internet for generic data communications with external partners.

As a first step in the integration of services, the frame-relay network will be enhanced with QoS provision; in this way, in addition to data applications, IP-based desktop voice/video conferencing applications will also be supported (now standardised in the ITU H.323 framework). IP-based telephony will be introduced for pilot users in order to evaluate its performance and usability.

In the longer term, the consolidation of all services over a single infrastructure will be realised, at a date depending on the maturity of

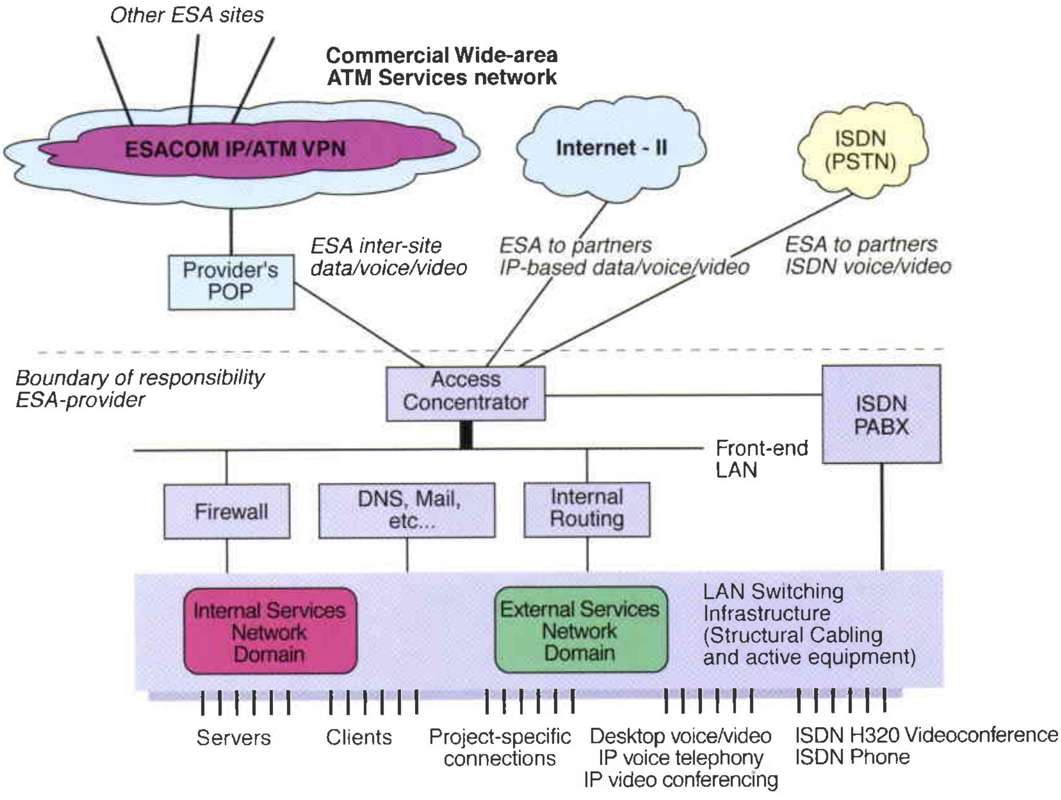


Figure 7. ESACOM Information Highway

the technology and on the availability of competitive offerings from the service providers.

It can be anticipated that a single ESACOM Information Highway will carry all the inter-site data, voice, and video services, as portrayed in Figure 7. This network will be based on IP and ATM (Asynchronous Transfer Mode) technologies. The Public ISDN (possibly, also PSTN) connectivity will be kept for off-net voice and video conferencing with external entities. The public Internet will most likely also be offering QoS guarantees (Internet II) and could be exploited for additional services with external partners and as back-up to the main ESACOM wide-area connectivity.

In the preparatory phase, a number of technologies and tools have to be investigated, evaluated, and then put in place as the building blocks of such an infrastructure. Examples are:
- new service offerings from the VPN providers, especially those geared towards service integration
- new compression and transport schemes for voice and video
- tools for end-to-end QoS management, enabling the establishment and monitoring of different classes of service
- applications measuring resource utilisation at user community/project level, to be used for capacity planning and to enable the implementation of charge-back schemes (should this need arise).

Regarding the cost aspects, while maintaining the classic financial objectives of maximising the return on capital investment and reducing recurring expenses, a new cost model for the network should be put in place. This model should enable the evaluation of the introduction of new services and technologies into the network as a business case, allowing a fair comparison between alternatives. This also implies viewing the computing and networking infrastructure more strategically; i.e. not only as a support facility with certain associated costs, but as an asset for improving ESA's efficiency and effectiveness in the future.

Conclusion

This article has described the current configuration and the expected evolution of ESACOM, whilst also trying to capture the spirit behind the endeavour. The main challenge now is to accommodate present and future Agency-wide networking requirements and show that they can be fully satisfied in the most efficient and cost-effective manner by this infrastructure and the evolution thereof.

The Project Test Bed and Its Application to Future Missions

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This article presents the concept of the Project Test Bed (PTB) and its application in support of two ESA missions — the PROBA (Project for On-Board Autonomy) technology mission and the Land Surface Processes and Interactions Mission — during their early project phases. As a multi-purpose simulation and verification platform, the PTB includes a system simulator, an Electrical Ground Support Equipment and Monitoring Control System (EMCS) and real flight hardware like the on-board computer. It therefore has the potential to support systems-engineering activities throughout the spacecraft-development life cycle and of being reused from one mission to another, as reported here.

Introduction

In ESA projects, a number of different simulation and test facilities have traditionally been used in support of different activities like mission analysis, design and development, assembly, integration and verification (AIV) and flight-operations preparation and training. Simulation is used extensively in design verification and operation preparation, but it is also required for test benches involving real flight-hardware elements. The Electrical Ground Support Equipment (EGSE) is used to verify the spacecraft's functionality whilst still on the ground, by stimulating it with test signals/ procedures and analysing its responses.

Simulators are normally developed to support specific tasks during the various phases of spacecraft development. The different simulation requirements at the different stages and the often different responsibilities for procurement mean that simulators still tend to be developed in isolation and with little or no reuse foreseen. Simulation in the early phases is normally not carried forward to later phases, and verification test benches often include their own simulation systems. Simulators supporting mission operations and training are developed independently of those used during the development. Flight operations procedures are developed and tested using these simulators, which in turn are not applied for validating the test procedures.

The PTB concept

The PTB concept seeks to rationalise the development of ground simulation and test facilities within a space project and to minimise duplication of effort. The new approach consists of establishing an infrastructure early in the project, which can evolve and be adapted to the needs of the different development and verification tasks along the way.

The PTB is thus a space-engineering development and test facility that, whilst including specific components for a particular project phase or mission, has a general design such that it can be used across many project phases and for different missions (Fig. 1).

The PTB is composed of three main elements (Fig. 2):

- The real-time simulator, containing models of the spacecraft hardware and environment. At the start of the project the models are fairly simple, but are able to provide an overview of the complete mission to assist with the systems-engineering tasks related to mission and system definition.
- The EGSE and Monitoring Control System (EMCS), consisting of telemetry, tele-command and special command interfaces, a master test processor and a suite of test/operational procedures.
- A hardware emulation of the On-Board Computer (OBC) running the flight software.

Some of the specific components may be reusable for other projects depending on the degree of similarity between the two missions. At the beginning of the project, the system prototype is composed mainly of the software simulation and reusable components from other projects, but in the later phases other components can be added. In order to allow the different components to be developed independently and in parallel, it is important to ensure an early and accurate definition of the interfaces between PTB components.

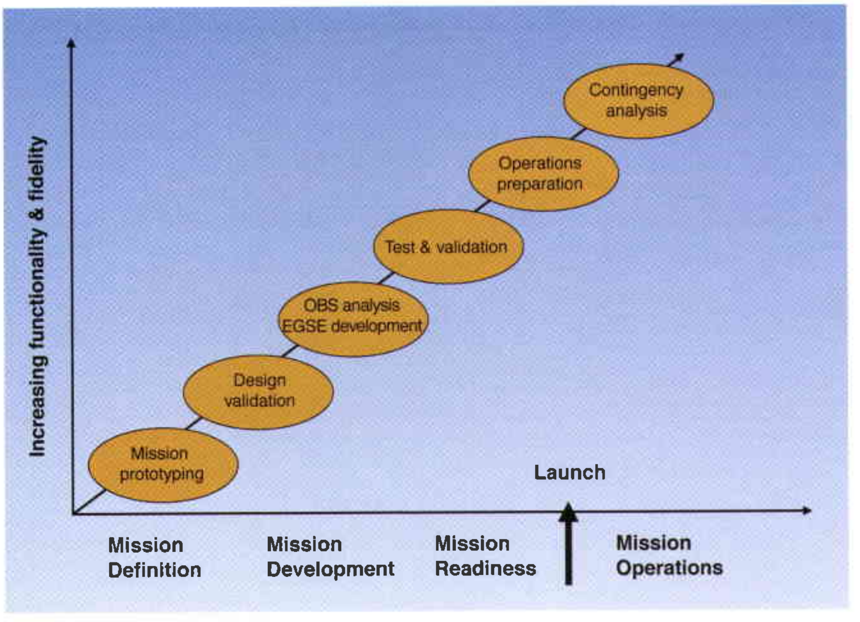


Figure 1. Evolution of the Project Test Bed (PTB)

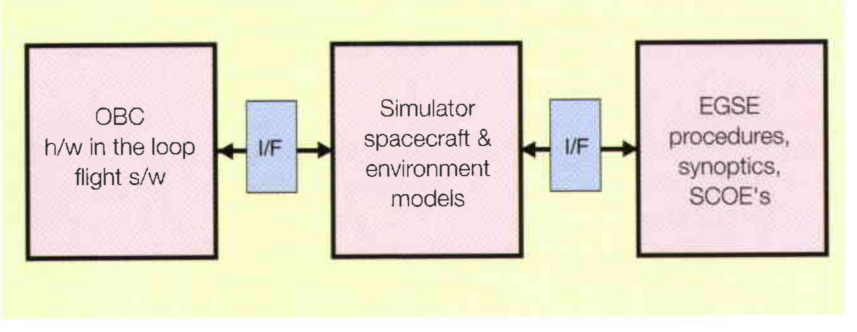


Figure 2. The PTB concept

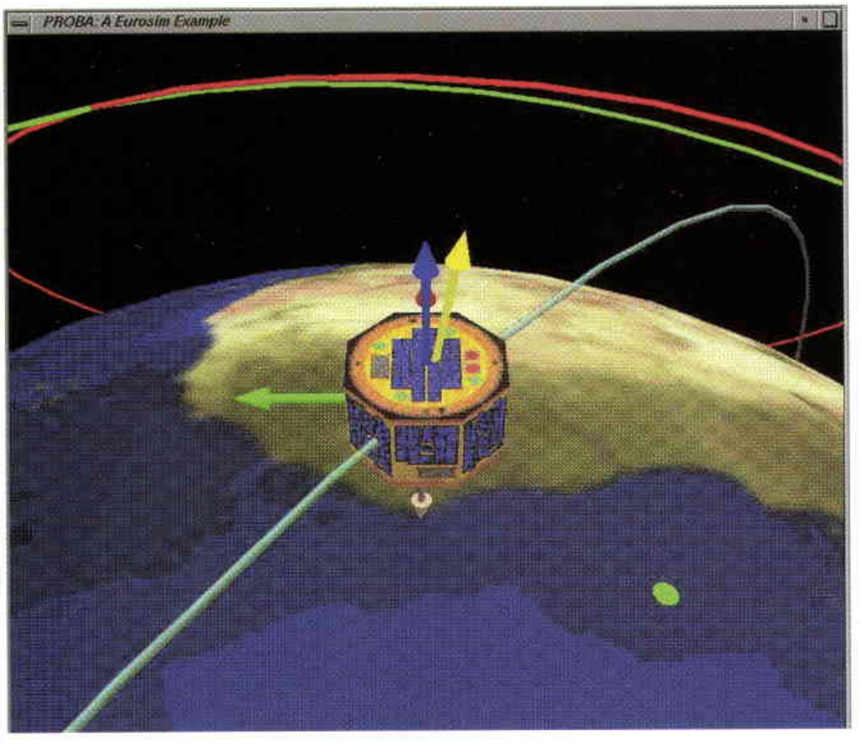


Figure 3. The PROBA mission

PTB applications

A first version of the PTB concept, covering only the simulation element, has been developed at ESTEC for the PROBA (PRoject for On Board Autonomy) mission and then partially reused for the Land mission PTB prototype. The purpose of such a simulation is to support early project phases by providing:

- Mission simulation to monitor the performances of the chosen platform and its predefined control system, to verify in a visual and intuitive way that the mission requirements are fulfilled at system level, and to identify feasible control strategies.
- System simulation to achieve a better understanding of configuration options and to support trade-offs at system level by providing quantitative performance results for different spacecraft options.

The PROBA mission

The PROBA mission (Fig. 3) is an ESA Technology Demonstration Programme conceived to prove the feasibility of a small and low-cost mission optimising operational autonomy. It will therefore fly advanced technologies which can contribute to enhanced autonomy for satellite systems. The baseline orbit for the 100 kg (approx.) spacecraft is Sun-synchronous, with an altitude of 817 km and an inclination of 98.7°. Its main scientific payload will be the Compact High-Resolution Imaging Spectrometer (CHRIS). The baseline satellite attitude will be Earth-pointing, with a roll and pitch/yaw steering capability allowing BRDF (Bi-Directional Reflectance Distribution Function) images to be taken repeatedly of the same Earth scene. The ground station will be at ESTEC, with the multiple user stations at a variety of sites.

The Land mission

The Land Surface Processes and Interactions mission (Fig. 4) is one of the proposed future generation of Earth-Explorer missions. It is dedicated to the study of land-surface processes and interactions with the atmosphere, including the energy and water fluxes and the biomedical fluxes like photosynthesis and plant respiration.

The mission features a single hyper-spectral imaging instrument known as PRISM (Process Research for Imaging Space Missions). The mission calls for the acquisition of directional measurements over a scene (site), thus requiring across-track (roll) pointing performances of ± 30° and along-track (pitch) pointing performances of ± 60°, in order to measure the BRDF of the observed site.

Pre-Phase-A analyses have demonstrated the advantages of an instrument concept without a pointing capability, accommodated on an agile spacecraft allowing the required pointing to be achieved with the platform itself. According to the preliminary studies, the spacecraft will have a mass of about 700 kg. Its configuration features fixed solar arrays, and its baseline attitude is Sun-pointing. It will use yaw steering in order to minimise image distortion due to the pointing and the Earth's rotation. The baseline orbit is a Sun-synchronous polar orbit (97.8°) with an altitude of 670 km. The main ground station is to be located at Kiruna, in Sweden, and the options for 'local users' are also being studied.

PTB prototype implementation

The PTB simulator has been designed with a modular approach in mind such that in the later phases of a project not only can additional mission-specific software and hardware be added to the PTB, but the existing subsystem models can be independently upgraded with minimal impact on the rest of the PTB.

The simulator contains models of the spacecraft, its subsystems, the spacecraft environment and the ground segment. Its purpose is to provide a virtual spacecraft and environment in which to refine the mission concepts and to assist system design and later verification and validation, mission operations and training. Its design must be flexible enough to support changes in and the evolution of performance requirements. In fact, the simulator models the overall system (space and ground) to such a level of detail that the mission objectives can be demonstrated, with the option of incorporating the actual flight software.

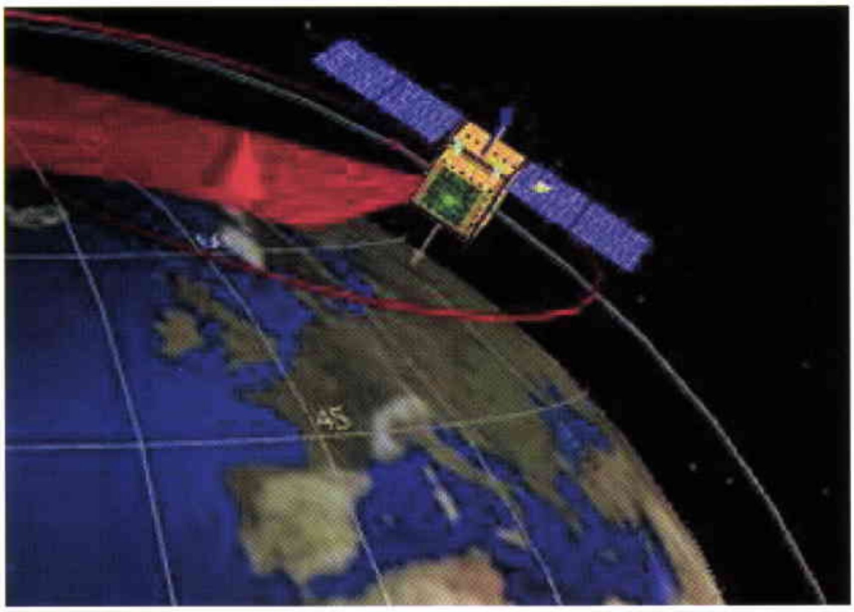


Figure 4. The Land mission

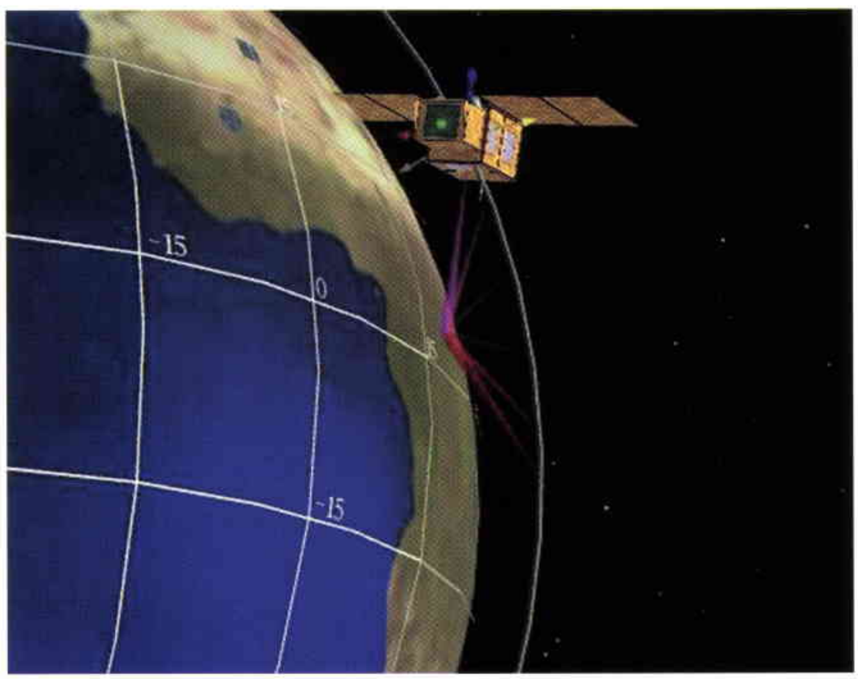


Figure 5. BRDF imaging

Capabilities of the PTB Mission Simulator

- Uplinking of telecommands and downlinking of housekeeping data when the spacecraft is in contact with the ground station
- Downlinking of user-requested images
- Maintenance of an event table containing the housekeeping history from the last ground-station contact (Fig. 11)
- Computation and 3D display of spacecraft position, orbital track, ground-station visibility zones and transmitter and imager coverage
- Realistic geometric modelling of the spacecraft, overlaid with its body vectors as well as Sun and Earth pointing vectors
- Simulation and 3D display of pointing manoeuvres required during the mission lifetime, such as Earth-pointing and BRDF manoeuvres (Fig. 5)
- Computation and 2D display of an Earth map with spacecraft position, ground stations, target images and image swath with zoom capability (Fig. 8)
- Simulation of electrical power generation and consumption
- On-board scheduling of image requests/downloads to the user station

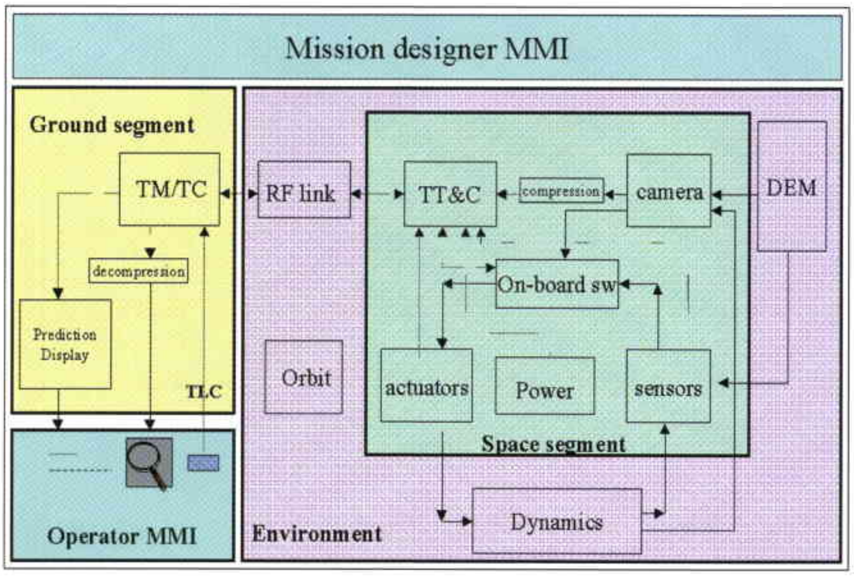


Figure 6. Simulator architecture

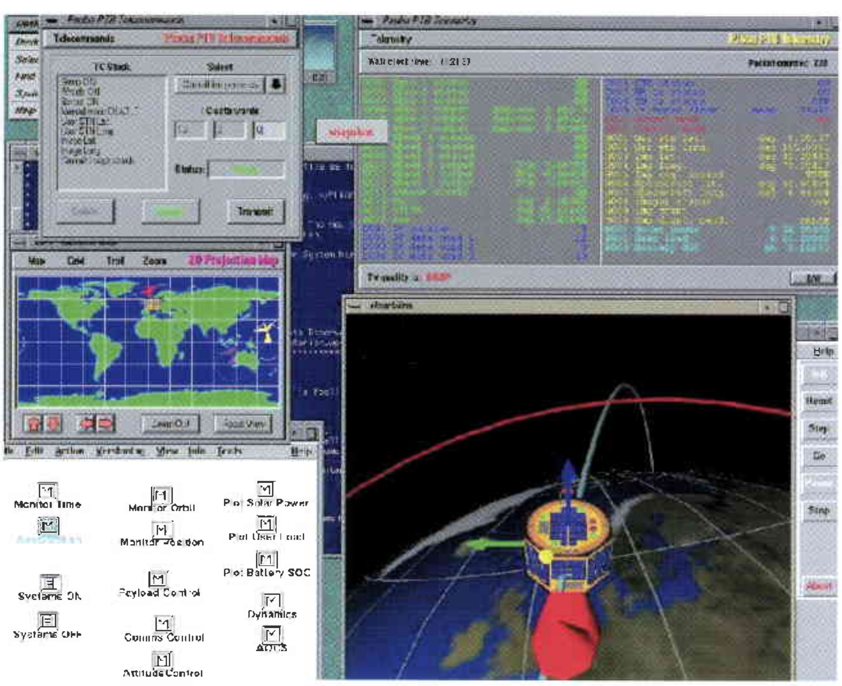
Simulator architecture

The simulator is based on the EuroSim real-time simulation environment, which supports model development and integration, simulation execution and analysis of results. The basic components (Fig. 6) of the PROBA and Land mission PTBs are the same, except for the spacecraft graphical models and the operational scenarios.

The simulator's four main components are:
- the spacecraft models
- the environment models
- the ground-segment models
- the display.

The spacecraft models implemented are:
- TT&C, which models the communications link between the spacecraft and the ground station
- OBSW, which models the telemetry and telecommand handling, the control laws and the autonomous payload-management software (different models for the two missions)
- POWER, which models power generation via body-mounted solar panels, battery state of charge and loads during the mission
- AOCS, which models the sensors and actuators
- Camera model.

Figure 7. Typical PTB user interface



The environment models are:
- the orbit model (PEM), developed by ESOC, which supports Keplerian orbits with first-order perturbations, (terrestrial spherical mass distribution, residual atmospheric drag, solar radiation pressure and Moon gravitational influence)
- the dynamics model, using a simple single rigid-body approximation of the spacecraft structure.

The ground segment models are:
- estimation algorithms (tbd)
- prediction algorithms (tbd).

The display capabilities of the PTB consist of a 3D Image Generation System (IGS; Figs. 3 – 5), 2D map and telemetry/telecommand man/machine interfaces (MMIs). A typical PTB user interface (Fig. 7) also includes the test conductor MMI provided by EuroSim.

Two commercial tools are used for the graphical implementation: MultiGen and Vega. MultiGen is used to create new models and edit existing ones, and Vega was employed to animate the models. A number of highly detailed models were required, including a texture mapped Earth, a textured spacecraft model and transmitter cones that can be switched on and off. BRDF sequences are shown in terms of past and present viewing angles.

Vega has also been used to provide the simulator user with different viewing options, including a ground- or user-station view, tracer view and overall view of the Earth and orbit

The 2D Map (Fig. 8) consists of an Earth map, displaying ground stations, target images, and spacecraft position, with the possibility of zooming in on the computation of the image swath to be taken by the instrument.

Three MMIs – one for telecommanding (TC) and two for telemetry (TM) – have been developed using Xforms, a public-domain tool kit. The TC MMI (Fig.9) presents the user with a list of telecommands which can be selected and stacked for later uploading. The transmission of the spacecraft telemetry data is handled in two different ways:

- when a link is established with the ground station, the spacecraft transmits the instantaneous housekeeping data, which is displayed by the TM MMI (Fig.10)
- when the spacecraft is not in contact with the ground station, it stores a history of major events, which it downloads when next in contact with the station (Event MMI) (Fig.11).

Further work

The analysis and implementation of the interface between the PTB simulator and the on-board computer is still in progress. The development of a full PTB and its application in the context of end-to-end validation and operations preparation for a real mission is foreseen as the next step. Application of the PTB concept to the SMART-1 mission (described elsewhere in this Bulletin) is presently being investigated via the development of an appropriate prototype.

Conclusions

The prototype version of the PTB implemented for the PROBA and Land missions is proving to be a useful tool. It has been designed using a modular approach, so that in the later phases of a project not only is it possible to add mission-specific software and hardware, but also the existing subsystem models can be independently upgraded with minimal impact on the rest of the PTB. Although the two PTBs developed so far are only prototypes for early mission phases, they have served to demonstrate clearly the validity and benefits of the concept of test-bed reusability across projects.

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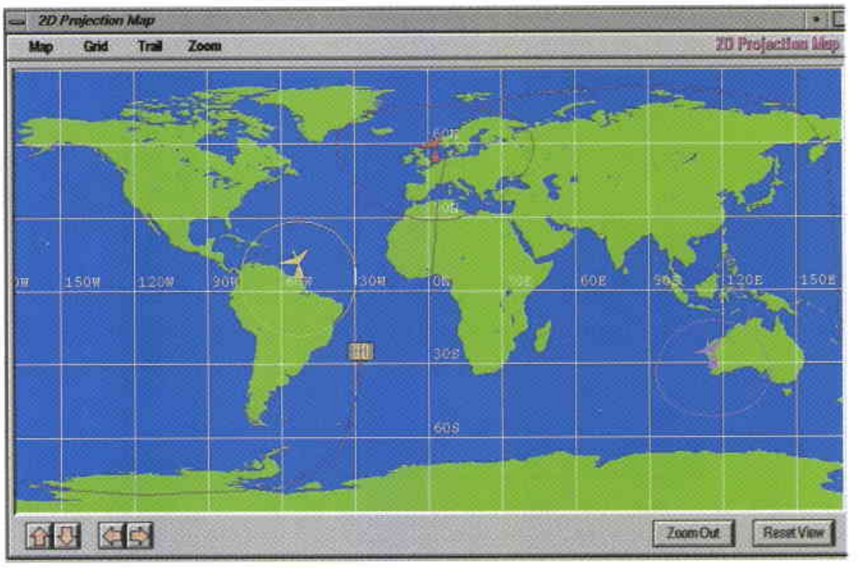

Figure 8 . The two-dimensional map

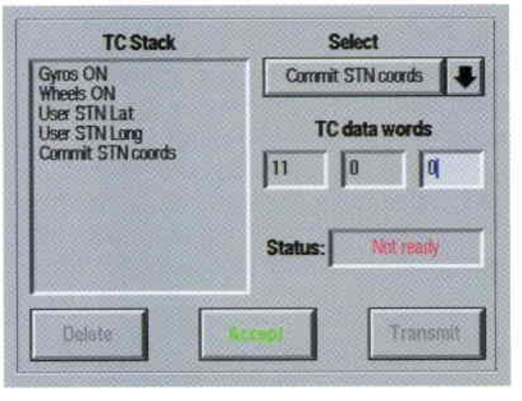

Figure 9. The telecommanding (TC) man/machine interface (MMI)

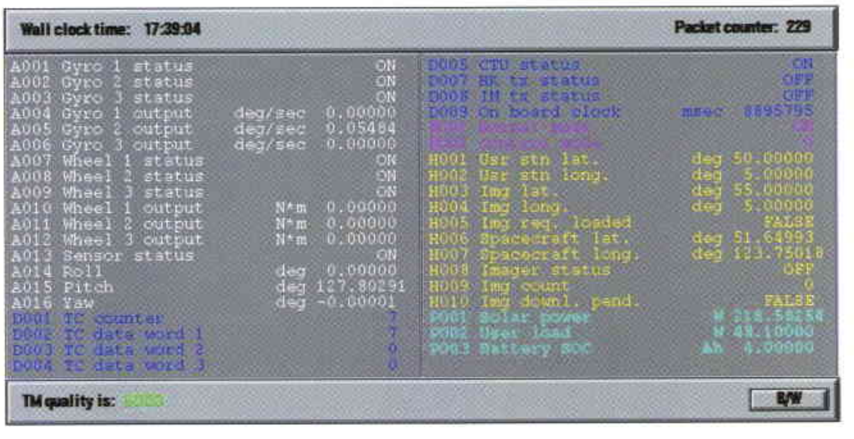

Figure 10. The telemetry (TM) man/machine interface (MMI)

Figure 11. The event man/machine interface (MMI)

The TEAMSAT Experience

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TEAMSAT was the first satellite delivered to orbit by the Ariane-5 launcher on its second qualification flight on 30 October 1997. The name of this unusual project was derived from Technology, science and Education experiments Added to Maqsat. The 350-kg satellite, which was embedded in Ariane-5's upper instrumented test platform Maqsat-H, carried five experiments provided by various European universities.

The entire project, from the initial idea to the end-of-mission, lasted exactly one year. The development, integration and testing were executed at ESTEC in the record time of seven months. Spare parts from previous projects were used to save time and reduce costs. The fast, cheap and unusual implementation included the 'hands-on' involvement of young graduate trainees, to exploit the project for educational purposes. The short but intense mission provided excellent scientific and technological results of relevance for future space missions.

This article provides an overview of the TEAMSAT project and explains some peculiarities which resulted in a unique experience for all of the participants.

The challenges related to the mechanical and electrical engineering, the On-board Data-Handling System, and the Test and Operation Control System are addressed by the other TEAMSAT articles in this issue of the Bulletin.

Background

The second qualification launch of Ariane-5 (A502) originally included two instrumented platforms, Maqsat-H (the upper passenger) and Maqsat-B (the lower passenger), built by Kayser-Threde (D) (Fig. 1). The role of the two mock-ups was to represent in mass and volume typical Ariane-5 payloads, in order to simulate a realistic launch and orbit injection. Furthermore, they were equipped with sensors to measure acceleration, vibration, acoustic noise and shock at different locations during the launch phases. Maqsat-B was to include a specific bearing structure to launch the radio-amateur satellite Amsat P3D.

Maqsat-H had to have a mass of 2300 kg and a height of 5m, but most of its internal volume was empty. Its mission would have terminated once the data recorded on board during the launch had been transmitted to ground, i.e. shortly after separation from the launcher. There was therefore space to install other experiments which could have a longer mission life. This consideration was discussed in the ESA Council of 25 October 1996 and it was decided that this opportunity should be exploited 'for scientific and educational purposes'.

The APEX office (of the ESA Directorate of Launchers) asked ESTEC whether any experiment was readily available to take advantage of a free flight on board A502. In a matter of days, five interesting experiments were proposed and offered for integration by European universities and ESTEC itself. Four experiments (AVS, Fipex, VTS and ODD) were potentially available, but needed to be adapted to the specific mission. In addition, they required collective mechanical and electrical integration to form a self-contained spacecraft (the 'TEAM' part). The fifth experiment (namely the Young Engineers' Satellite – 'YES'), proposed by a group of ESTEC Young Graduate Trainees (YGTs) and stagiaires, was actually a complete and independent tethered

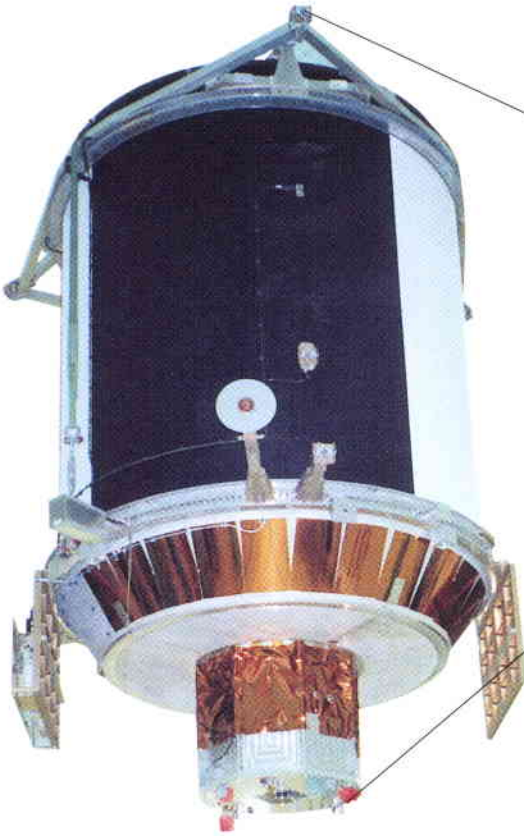


Figure 1. Cut-away view of Ariane-502. The payload, from top to bottom, consisted of two platforms, Maqsat-H and Maqsat-B. TEAMSAT is installed beneath Maqsat-H (courtesy D. Ducros/ESA)

satellite pair to be deployed in Geostationary Transfer Orbit (GTO). This, in itself, was an ambitious and challenging project because at that time only a conceptual design of the satellite was available, although the tether system did exist and had already been demonstrated in previous space flights. YES had to be newly developed as an integral part of TEAMSAT, taking into account that it would eventually be ejected with its counter-mass to become a free-flying tethered pair.

To limit the impact of the presence of TEAMSAT, the original design of Maqsat-H was modified to reduce the mass by 350 kg and assign this budget to TEAMSAT. A space suitable for a last minute integration was identified in the Maqsat-H lower cone: a cylindrical envelope with a diameter of less than 1m and a height of max. 75 cm was available and accessible through the separation ring.

The experiments
The five experiments offered by European universities and ESTEC were:

- *Autonomous Vision System (AVS) - Technical University of Denmark.* AVS is a star-tracker system based on a Charge Coupled Device (CCD) camera and a central unit that can automatically recognise specific stars and determine the attitude of the host spacecraft for navigational purposes. Its on-board memory contains the model of more than 11 000 stars and constellations. The AVS camera can also acquire images and identify non-stellar objects (such as satellites). The system had already been flown on sounding rockets and it was in the process of being upgraded for future missions.

- *Flux Probe Experiment (FIPEX) - University of Stuttgart.* FIPEX measures the low concentrations of atomic oxygen up to altitudes of 1000 kilometres. Atomic oxygen is known for its erosion effect and degradation of optical surfaces on spacecraft in low Earth orbit. The perigee passes of the GTO offered particularly favourable altitude profiles to study this phenomenon. FIPEX had already been flown on the TEXUS sounding rocket. The configuration foreseen for the TEAMSAT mission included one electronic unit plus five sensor units to be mounted around the Maqsat cylinder.
- *Visual Telemetry System (VTS) - MMS/ IMEC/ OIP.* VTS is a new on-board visualisation technology for monitoring spacecraft activities such as solar array deployment. It was initially designed for Envisat and other future ESA projects. This was its first flight opportunity. TEAMSAT hosted an existing engineering model consisting of three cameras and a master unit that provided compressed, buffered image sequences. The VTS cameras were positioned around the Maqsat-cone to capture image sequences of events that occurred during the launch phases, from the jettisoning of the fairing to the separation of the Speltra. Later, during the mission, the system was reprogrammed to take images of stars, the Sun and the ejection of YES from TEAMSAT.
- *Orbiting Debris Device (ODD) - Automation & Informatics Department, ESTEC.* The Maqsat-H cylindrical body was painted with a high contrast pattern (75% white and 25% black) to support test and calibration of ground-based optical and radar stations in Europe. The main goal of these systems is to track and identify space debris. Before becoming operational they need to be calibrated using reference objects with well-defined characteristics. The contrasting paint would also allow detection of the rotation or tumbling of Maqsat-H.

Members of the TEAMSAT team in Kourou, during the early Ariane-502 launch preparations

Additionally, surface paint degradation will be observed and studied in the coming years.

- *Young Engineers' Satellite (YES) - Technical University (TU) of Delft.* YES is a free-flying sub-satellite that was intended to deploy a 35-km tether attached to an inert counter-mass (known as TORI), to study the dynamics of tethered satellites. The idea was based on the thesis work of two students at TU-Delft. It was designed, assembled and integrated in record time by young graduates and stagiaires at ESTEC with the support and assistance of ESTEC staff. A GPS receiver was installed to evaluate the use of GPS for navigation, especially above the GPS satellite constellation, and provide more information on tether dynamics. YES also contained technology validation experiments for measuring radiation, acceleration and the solar angle. An on-board main computer controlled the tether experiment and the other on-board instruments. This computer, known as 'JORIS' was entirely designed, assembled and programmed by stagiaires as part of their work/study programme at ESTEC. A second computer, based on commercial technology (PC104), provided back-up functions to the main computer and the interface to a commercial camera (QuickCam) for the acquisition of images during the YES ejection. In the event, the tether deployment had to be disabled as a result of the Space Debris Committee decision of June 1997, as explained later.

The constraints

The main purpose of A502 remained the qualification of the launcher, so the advantages of a free flight were counterbalanced by the constraints imposed by the qualification launch. TEAMSAT had no influence on launch dates and times. The main consequences of this were a very tight development schedule and an unexpectedly long launch campaign.

At the beginning of the project, the Ariane-502 launch was planned for 15 April 1997, which would have left only 10 working weeks to develop the entire system. This is normally the time that is needed to select the industrial partner to perform the work. Furthermore, as the TEAMSAT project had not been planned, it was difficult to organise resources in such a short time.

The presence of TEAMSAT could not endanger nor interfere, in any way, with the A502 launch. It was decided that TEAMSAT could not have any direct mechanical contact with the launcher, or electrical interface with either the launcher or with Maqsat. From the mechanical point of view, the solution was to design a box providing guaranteed containment of all internal parts under the most severe launch conditions. The potential weak point was the YES release system. This had to be designed to meet the highest safety requirements, in particular with regard to the pyro-cutter circuits and the bolts holding the lid (and YES) to the box. Electrically it meant that, once on the launcher, YES had to be dormant (not powered) to avoid accidental firing of the pyros due to commands or faults, no matter how they occurred. Furthermore, no RF transmission and no live connection outside the TEAMSAT box were allowed until after Maqsat separation when the launch operations were terminated. The only signal available to TEAMSAT was given by a separation switch that would open when Maqsat-H separated from the launcher. This signal was used to 'wake-up' YES and to re-synchronise the other experiments. Unfortunately, other events which occurred before separation, such as the fairing jettisoning, could not be adequately monitored by the VTS cameras because of this lack of synchronisation between the launcher and TEAMSAT. Other safety aspects included the integrity and reliability of the batteries.

TEAMSAT underwent and passed four safety reviews.

To avoid the impact of a possible TEAMSAT late delivery, the Launcher Authority requested the production of a 'dummy' model mechanically representative of the spacecraft. After the qualification programme, it could have been used for launch should the flight model not be completed on time. This actually happened for Amsat P3D, which could not be readied on time and was replaced at the last moment by an equivalent 550-kg ballast mass in Maqsat-B.

Figure 2. Two stagiaires installing the electrical harness on the TEAMSAT Flight Model at ESTEC

The TEAMSAT flight model had already been qualified when the international Steering Committee for Space Debris gave its no-go decision on the deployment of the YES mission's 35-km long tether. The risk of its remaining too long in the Ariane-5 GTO before re-entering the atmosphere was judged too high. This risk was further increased by the mandatory morning launch (A502 baseline) which meant a less favourable effect of solar pressure on the tether re-entry.

The approach

The tight schedule and the other constraints did not permit a conventional approach. Since the project was a last-minute flight opportunity not foreseen in any budgets, there was little money available for parts, equipment and manpower.

The only viable solution was to make it an in-house project and utilise the available trainee workforce (Fig. 2) under the supervision of ESTEC specialists. For all the contractual activities and to adapt the experiments, ESA allocated 600 kECU from the General Studies budget. This amount corresponds to less than 1/10th of the cost of a small satellite.

Those involved were very creative in finding unused or spare equipment. Several parts could be used (free of charge) from previous projects since they always have spare critical parts or engineering models for test purposes. At the end of a mission, these parts are generally considered obsolete or too risky to be reused for subsequent missions. But for us, this was the only choice and we decided to take the risk and the equipment!

After a good dusting off and testing, the following equipment was considered flightworthy:

- three Nickel-Cadmium (NiCd) batteries, manufactured in 1983 for ECS-2 and preserved for several years at –8°C
- two transponders from Olympus and Eureca
- the pyrotechnic devices to release the lid and eject YES, from the ERS programme (their quality was not in question)
- other small components, such as relays, connectors, cables (these items had to be adapted to suit specific purposes and interfaces).

Part of the ground equipment and software was also re-used and adapted:

- the Checkout Terminal Equipment (COTE), including battery conditioning, from the Cluster mission
- the in-orbit Mission Control System based on ESOC's SCOS-II.

The experiments were generally available from previous developments or missions and the Principal Investigators (PIs) were eager to exploit or to test them in a GTO orbit. The project offered them a financial contribution to adapt the mechanical and electrical interfaces and, of course, the complete integration, testing, ground infrastructure and operations.

Equipment that was not so readily available had to be procured or developed. Fortunately, some of the industrial partners and the ESTEC research laboratories were glad to provide their state-of-the-art developments or research items in exchange for a unique opportunity to test, demonstrate and/or validate their equipment in a real mission. This was the case for:

- the Data-Handling Systems in which recently developed chipsets were used to design and build the telemetry (TM) and telecommand (TC) systems for both spacecraft
- the TM and TC ground equipment loaned by the development companies
- the S-band antennas: three pairs were procured for testing and to establish the best combination. Two European industries offered their latest developments against some cost reimbursement and the results of the tests and in-orbit behaviours. The third pair (cross-dipole type) was designed, built and donated by one of the radio amateurs of the AMSAT organisation.

Another cost-saving factor was the simplification of the system and related internal and external interfaces, and of the mission. Compatible with the objectives of the experiments, the mission was planned to last approximately five days to limit operating costs. This was consistent with the available battery power source without using solar arrays.

The real key to the success of TEAMSAT was the human factor: the enthusiasm and the motivation of many young engineers and the experience, dedication and hard work of ESA staff and technicians. This work force even included some retired ESA staff members who 'came back' to share their expertise with the new generation of engineers. There was a level of 'hands-on' involvement not seen at ESTEC since the time of sounding rockets!

The implementation

The design and development of the system and of the operations had to be simple. Fortunately, all the experiment objectives were compatible with GTO and with the attitude provided by the launcher, and hence it was decided to avoid the implementation of an Attitude and Orbit Control System. On-board thermal control was reduced to the minimum: no active system was implemented, only passive thermal protection. Special thermal materials were applied on each electronic device.

The model philosophy adopted included the development of a Structural Model (StM) and a Proto-Flight Model (PFM). The StM was the representative model used for mechanical qualification of TEAMSAT and of the Maqsat-H/TEAMSAT composite. It then became the 'dummy' requested to ballast Maqsat, should the PFM not be delivered on time. A closed aluminium box of octagonal form (755 mm high and with a maximum diameter of 944 mm) was designed to integrate the electrical system, the experiments and the ejection mechanism for YES. Two identical 'boxes' were produced: one to contain the StM and one for the PFM.

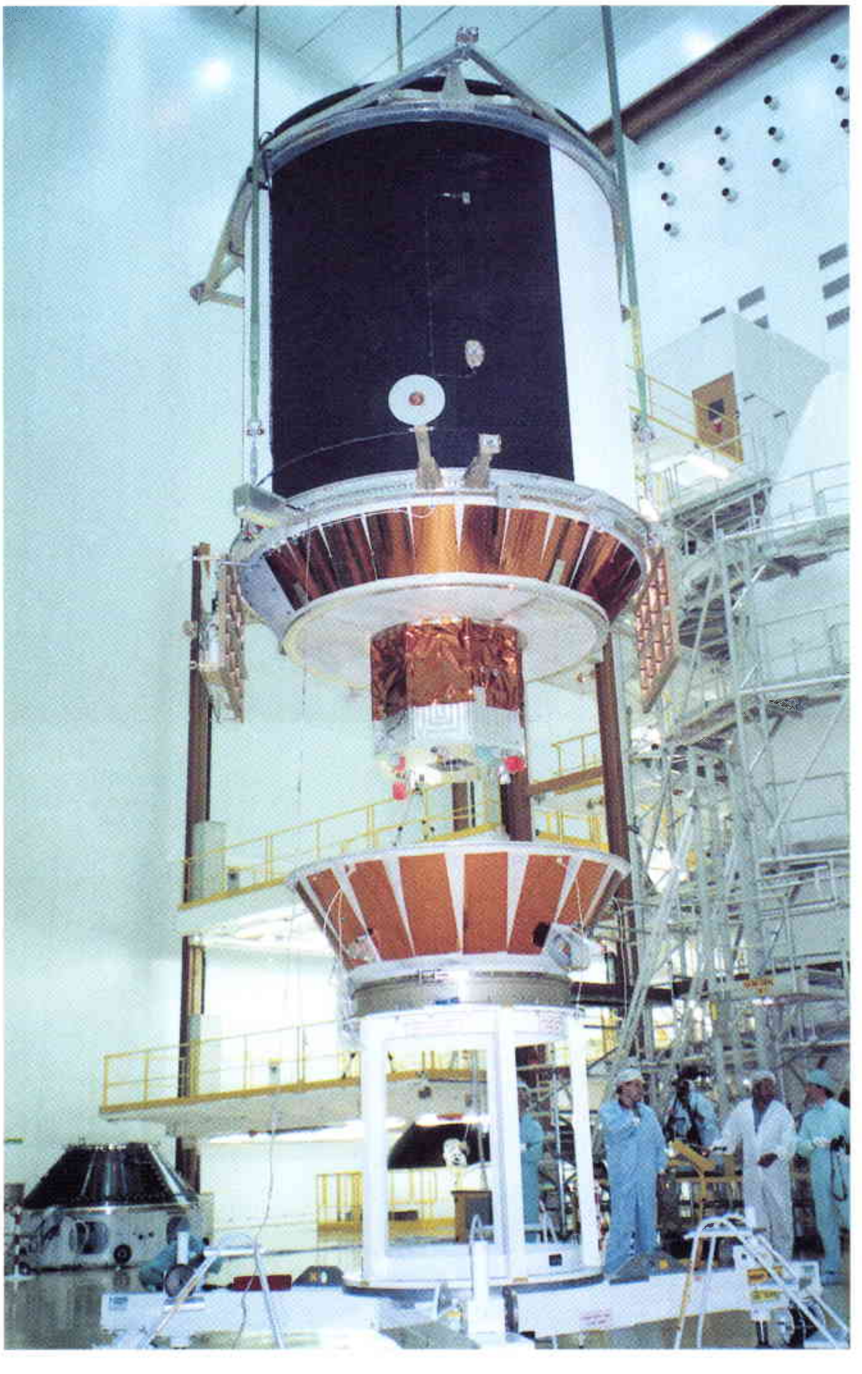
ESTEC facilities were used to test the satellite, in particular the 70 kN 'shaker' which exposed first the StM (Jan.1997) and then the PFM (May 1997) to the vibration conditions to be experienced by the system during launch (Fig. 3). Due to budget and time limitations, the testing performed was reduced to a minimum. For instance, it was decided not to perform any thermal/vacuum testing at system level. The results of the tools for thermal modelling were considered sufficient. One of the ESTEC laboratories was adapted and equipped as an integration and test hall. The same area was later rearranged as the Experiment Control Centre (ECC). In both cases nearly all of the equipment was borrowed and subsequently returned, so the actual cost to the project was insignificant. The facilities for the system mechanical and electrical integration and testing, and experiment flight operations were provided by ESTEC with the involvement of the YGT's for the software customisation.

Figure 3. TEAMSAT Proto-Flight Model on the 70 kN shaker in the ESTEC vibration testing facility

The design and manufacturing of the various subsystems were highly interrelated, e.g. the basic mechanical structure was designed and then adapted to accommodate the installation of the thermal protection and of the electrical harness. Ad-hoc solutions were found using a concurrent engineering approach and documentation was kept to a minimum. These were natural consequences of having an integrated team in which each member could directly follow the evolution of the total design and its implementation.

The most demanding experiment was YES, for which only a conceptual design existed at the beginning of the project. Particular care had to be devoted to the design of the ejection mechanism. The bolts holding the lid to the box had to be strong enough to withstand the static and dynamic loads of YES and of the ejection springs during launch, whilst still being 'easy' to cut for the pyro-cutters at the moment of ejection. The thrust for the ejection was provided by four springs compressed inside the box.

Figure 4. Integration of TEAMSAT into the lower cone of Maqsat-H in Kourou



The mechanical design and manufacture was performed in the ESTEC Mechanical Workshop, relying heavily on the years of experience and workmanship of the ESA technicians and engineers. The participation of the experiment PIs in the development effort at ESTEC included the delivery and acceptance testing of their equipment (flight and ground) by the project (Feb. 1997) followed, a few weeks later, by participation in the Integrated System Test.

At the end of June 1997, the flight and ground systems were ready for shipment to the launch site. On 15 July, the TEAMSAT launch campaign was officially started. The experiment sensors and the antennae for TEAM were installed externally around the Maqsat-H cone. The Maqsat cone was covered with large strips of reflective aluminised kapton tape. YES was covered with a thermal blanket to protect it after ejection. Finally the TEAMSAT PFM with its on-board experiments was interchanged with the dummy and mated to Maqsat (Fig. 4). From this point on no further internal hardware intervention was possible.

The launch and operations

The main mission operations were conducted from a dedicated Mission Control Centre (MCC) at ESOC and in close co-operation with the ECC in ESTEC. Two ground stations ensured the link to the two spacecraft: Perth (Australia) and Kourou. Communication links were established between the European sites, MCC and ECC, with the EGSE in Kourou. This allowed the mission control team, the sub-system specialists and the PIs to monitor, and in some cases (e.g. for the final boost charge of the batteries) to interact directly with the spacecraft and the experiments in preparation for the launch. Due to the limited travel budget (further restricted by two previous interruptions in the A502 launch campaign), only two TEAMSAT engineers travelled back to Kourou for the actual launch at the end of October 1997. Generous support was provided on the launch site by the APEX office.

The final countdown for Ariane-502 started during the night of 29 October, nine hours before the nominal lift-off time. Everything remained nominal for TEAMSAT and the procedures ran smoothly throughout the countdown including the recycling due to the launch hold. Eight minutes before ignition, the external power supply was disconnected and the last telecommand was sent to VTS to initialise its internal time-line in order to take pictures of the fairing ejection.

The Ariane-502 Vulcain engine ignition (H_0) sequence began at 13h 43min 08s (UT). The actual lift-off occurred 7.5 s later.

At H_0 + 1690 s (some 28 min later), Maqsat-H carrying TEAMSAT was released into GTO. Due to the launcher roll anomaly, not all of the injection parameters were as expected:
- perigee altitude: 525 km instead of 581 km
- apogee altitude: 27 000 km instead of 36 000 km
- inclination: 7.76^{o} as specified
- spin rate: almost zero instead of 0.5 rpm.

Due to the off-nominal orbit, Mission Control and Ground Station staff had to exercise emergency search and command procedures to acquire and lock onto TEAM over the Perth ground station. This delayed the down-linking of the VTS camera data and activation of the experiments by a few minutes.

The major consequences were that the new orbit had a period of 7h 40min instead of 10h 30min. As the experiment activation and operation periods depended on the spacecraft orbital position, the mission had to run faster! The mission timeline had to be replanned immediately, and extensive ranging had to be performed to establish the new orbital parameters and station tracking elements. With no spin stabilisation and varying spacecraft attitude, telemetry acquisition was not always possible and, when acquired, the signal level often dropped to a level where data was lost. By tuning the space and ground segment operations, it was possible to optimise the experiment operations and the mission data.

The mission was rescued but with heavy consequences on the power and thermal conditions. The external thermal protection, for instance, had been designed for a different attitude, resulting in internal temperatures dropping more quickly than expected. Nevertheless, this confirmed the predictions of the mathematical models. During the following 3 days of operations, the spacecraft provided a wealth of exciting data.

The ejection of YES (Fig. 5) was performed during the 8th orbit after the apogee pass on 2 November, 0:22:24 UT. The ejection speed was calculated as 1.7 m/sec. Unfortunately, at the time of ejection, the link to YES had already been lost and so the event could not be monitored as expected.

The TEAMSAT mission ended on 2 November, at 10:30am EST when, after 3 days of intensive operation, the energy in the batteries had been consumed.

Figure 5. Artist's impression of YES ejection

Results achieved

- *AVS (Autonomous Vision System)*
  The on-board CCD camera took pictures from various positions in orbit and automatically recognised star constellations and non-stellar objects (Fig. 6). In particular, this system was actively used from the initial phases of the mission to determine the (non-nominal) attitude and orbit of the spacecraft to a very high degree of accuracy. The AVS has confirmed its high potential as a star-tracker. This has enhanced its position as a navigation instrument for future spacecraft. It will be used by the NASA Pluto-Kuiper Express mission as the primary pointing instrument during its interplanetary mission.

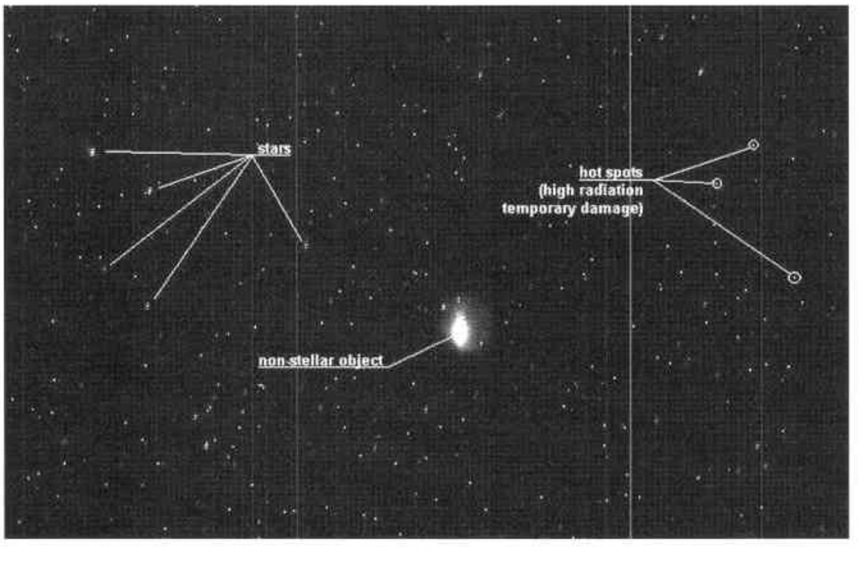


Figure 6. The AVS on-board camera automatically recognised star constellations and non-stellar objects (the object in the centre appears very bright due to its closeness)

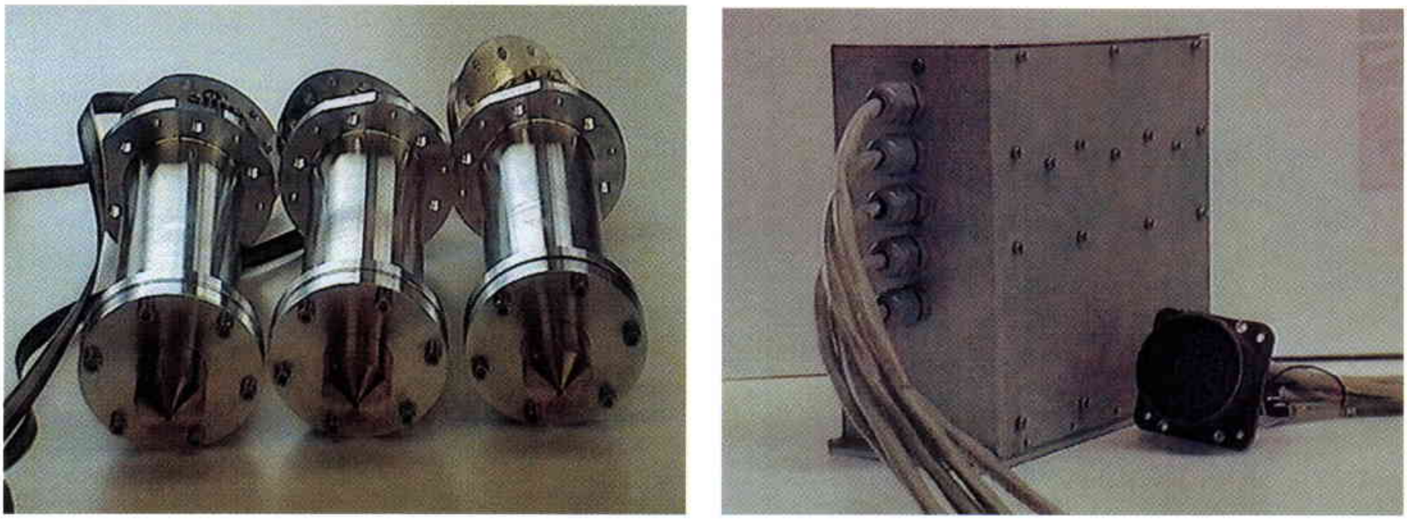


Figure 7. The FIPEX configuration for TEAMSAT included the electronic unit (right) and the atomic oxygen sensor units (left). Five of these sensors mounted around the Maqsat cylinder measured the atomic oxygen concentration at different orbital altitudes

– *FIPEX (Flux Probe Experiment)*
FIPEX (Fig. 7) achieved its objective of measuring the concentration of atomic oxygen at different orbital altitudes. The five sensors acquired excellent data during five perigee passes and even one apogee pass (used for calibration purposes). The GTO enabled FIPEX to obtain an atomic-oxygen concentration vs. altitude profile which will be of great value in the prediction of oxidation effects (e.g. degradation of optical surfaces) for future missions. The preliminary results can be found on the ESTEC/TEAMSAT web site (http://www.estec.esa.nl/teamsat/). The scientific results will appear in various publications of the IRS University of Stuttgart. FIPEX has been planned to be one of the instruments for the International Space Station (ISS).

– *VTS (Visual Telemetry System)*
The images acquired were spectacular, particularly the sequence of the Speltra separating from TEAMSAT with the Earth in the background (Fig. 8). The mission confirmed the validity of the system and provided technical information with

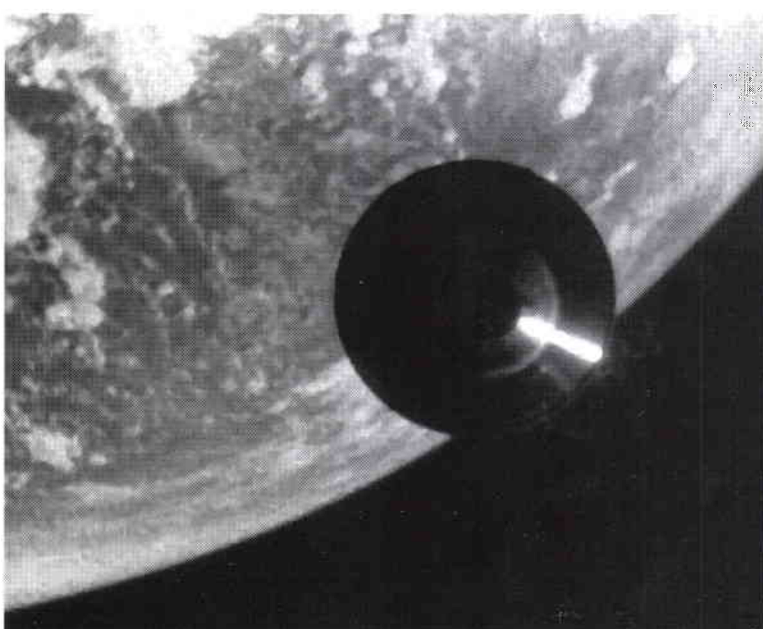
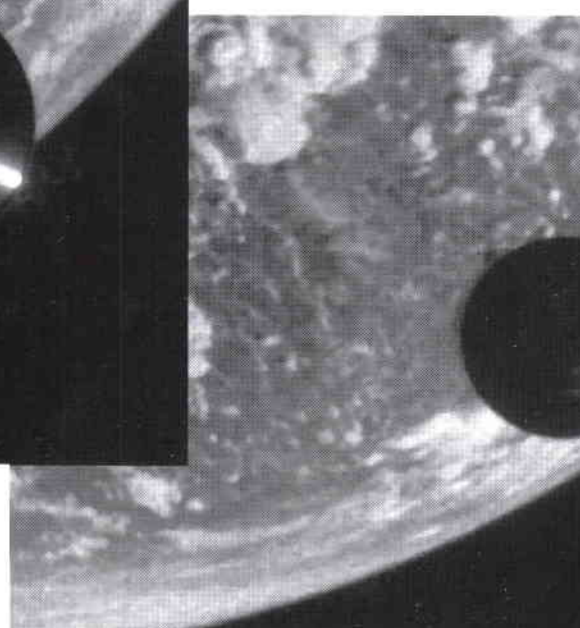
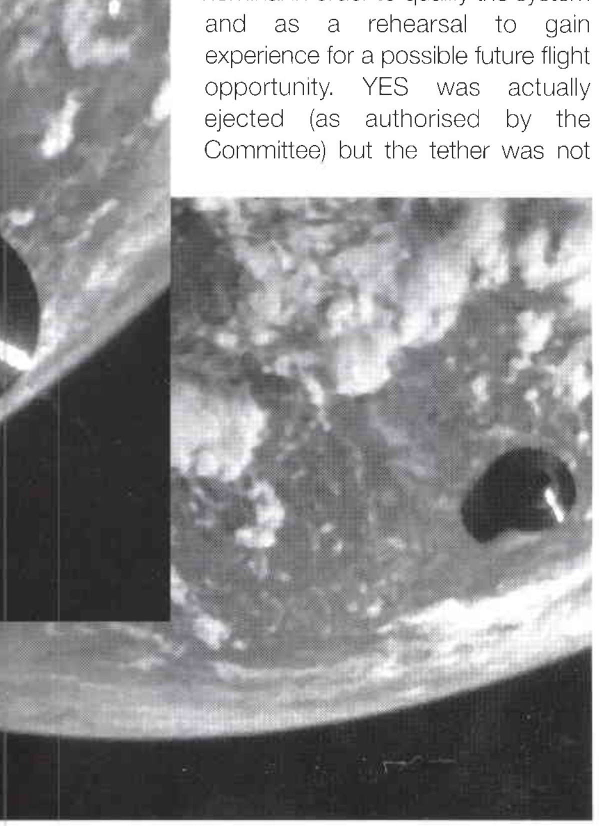




Figure 8. This image sequence, taken by one of the VTS cameras 19, 29 and 64 seconds after separation of Maqsat-H/TEAMSAT from the launcher, shows the (Ariane) Speltra encapsulating Maqsat-B and, in the background, the African continent some 600 km below

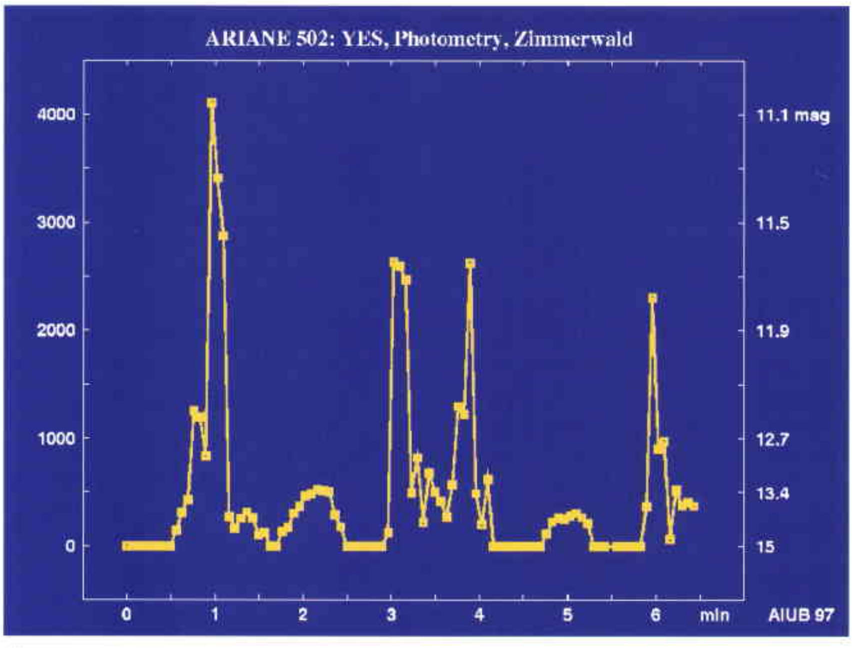
which to improve the VTS cameras and on-board software. The VTS images acquired during launch contained details useful for the Ariane-5 qualification analysis. Upgraded VTS camera modules will be used on future missions, such as XMM, and possibly Integral and Cluster-II. VTS has been confirmed to fly on PROBA.

- *Orbiting Debris Device (ODD)*
  This experiment is actually still in progress. A few days after launch the ground-based optical and radar instruments of various institutes detected, tracked and took pictures of four objects in GTO (Figs. 9a-c). Thanks to their reflection patterns they could be recognised as: Maqsat-H/TEAMSAT, YES, the A502 Speltra and the A502 upper stage with Maqsat-B. The observations will continue throughout the coming years and will allow the calibration of these ground based instruments for the observation of other objects in space whose sizes and reflectivity are not known. The observations and measurements will also provide information about the degradation of paint and other materials in space.

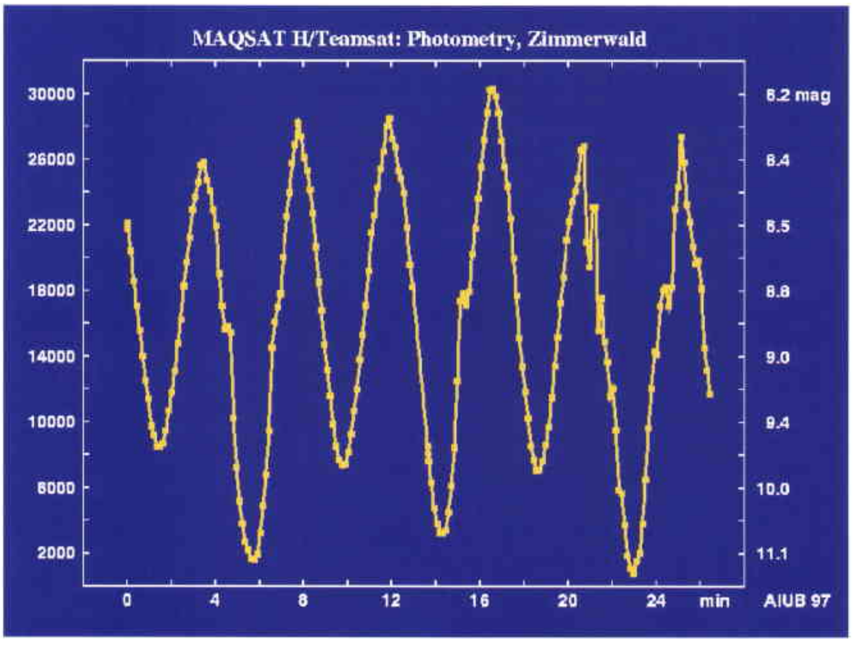
- *Young Engineers' Satellite (YES)*
  The ultimate goal of YES – to study the special and unexplored behaviour of a tethered system in a highly elliptical orbit – was not achieved due to the Space Debris Committee decision. However, the mission was executed as if it had been nominal in order to qualify the system and as a rehearsal to gain experience for a possible future flight opportunity. YES was actually ejected (as authorised by the Committee) but the tether was not



(a)



(b)



(c)

Figures 9a-c. Illustrate the ODD experiment (courtesy University of Bern). Figure 9a shows the tracking of YES and Maqsat-H performed by the 1 m Zimmerwald telescope. The photo was taken from a distance of more than 20 000 km on 3 November 1997 (22:30 UT). The two stars appear blurred because they move more slowly than the tracked objects YES and Maqsat-H, which could be recognised thanks to their refectivity patterns shown in Figures 9b and 9c, respectively.

deployed and the counter-balance mass remained mated to TEAMSAT. Despite these restrictions, the mission provided many useful and interesting results (see http://www.delta-utec.demon.nl) and, above all, served the purpose of training several young engineers. The success of the YES mission was enhanced by the excellent performances of other on-board experiments and instruments: the new technology Scintillating Fibre Detector, the GPS and the Sun-sensors.

From a technological point of view, TEAMSAT provided a first in-flight demonstration of such newly-developed items as:

- VTS and AVS: two important instruments with great potential for future missions
- fully asynchronous ESA/CCSDS standard packet telemetry (TM) using the recently developed ESA chipset for TM transfer frame generation
- dynamic TM bandwidth allocation concept implemented without the use of an on-board computer
- first-time reception of GPS signals above the GPS satellite constellation (~6000 km)
- first flight of new scintillating fibre detectors, together with other types for comparative evaluation
- investigation of three different S-band antenna technologies in combination with performance prediction:
  - quadrifilar helix antenna, for links in the bands 100 MHz to 3 GHz to be flown on Metop
  - micro-strip (double tuned) patch
  - cross-dipole.

Last, but not least, TEAMSAT contributed significantly to the knowledge gained during the A502 qualification flight.

The educational achievements

TEAMSAT enabled Young Graduate Trainees (YGT's) and Spanish Trainees at ESTEC to gain valuable experience in designing, building and integrating a satellite and its payload. In total, 43 young engineers from these schemes, as well as stagiaires from Dutch universities and schools, were involved at various stages during the project. Considerable spare-time effort was required from ESTEC and ESOC staff to guide them.

TEAMSAT: the major events

Event	Place	Date
ESA Council decision	ESA/HQ - Paris	25 October 96
Experiment proposals for Ariane-502 (APEX)	ESTEC	30 October 96
Financial support granted	ESA/HQ - Paris	4 November 96
Kick-off (750 kECU available)	ESTEC	15 November 96
DG decision for TEAMSAT on A502	ESA/HQ - Paris	28 November 96
TEAMSAT/Maqsat-interface meeting	CNES (Evry)	14 January 97
Internal oritical design review	ESTEC	16 January 97
Mid-term review	ESTEC	24 January 97
Structural model (Dummy) vibration test	ESTEC	29-31 January 97
Experiment delivery and acceptance testing	ESTEC	February 97
TEAMSAT/Maqsat-fit-check	IABG – Munich	24-25 March 97
TEAMSAT/Maqsat-composite vibr. test	IABG – Munich	May 97
TEAMSAT flight-model qualification	ESTEC	30 May 97
Flight Readiness Review	CNES – Evry (F)	5-7 June 97
Space Debris Steering Committee – YES review	ESA/HQ – Paris	11 June 97
Delivery acceptance (pre-shipment) review	ESTEC	20 June 97
Sensors shock test	Dassault Av. (F)	10-11 July 97
Shipment flight and ground systems to Kourou	ESTEC	12 July 97
Start TEAMSAT launch campaign	Kourou	15 July 97
Integration into Maqsat-H	Kourou	25 July 97
Launch campaign interruption (1^{st})	Kourou	3 August 97
TEAM/YES Mission Operation meeting	ESTEC	20 August 97
POC	Kourou	9 September 97
Launch campaign interruption (2^{nd})	Kourou	29 September 97
Launch Readiness Review	Kourou	27-28 Oct. 97
Ariane-502 launch	Kourou	30 October 97
TEAMSAT End-of-Mission	ESOC	3 November 97

TEAMSAT combined the experience of the 'old' with the enthusiasm of the 'young', creating the link for a natural transfer of know-how. The validity of such training was further confirmed by the fact that various European space companies have since made job offers to many of the young engineers.

Following the TEAMSAT experience, the two PIs of the YES/Tether experiment have started their own company (called Delta-Utec) in Holland, acting as consultants for small space missions and tethered systems.

Conclusions

TEAMSAT largely achieved the scientific, technological and educational objectives set for it, often matching the most optimistic expectations, in a very effective 'faster, cheaper' manner. From the educational point of view, TEAMSAT represented a unique 'hands-on', 'end-to-end' experience for many YGTs, trainees and stagiaires. It also provided a flight opportunity for several ESA technologies developed in-house and under industrial contracts. TEAMSAT also gave several universities the opportunity to fly experiments at very low cost.

From the operations and ground segment points of view also, TEAMSAT was a successful experience. In spite of its injection into a non-nominal orbit, the mission was fully recovered thanks to the professional intervention of the ESOC and Ground Station personnel.

On the project management side, the lack of contractual or political pressure, coupled with the short chain of command and the highly integrated team, enabled fundamental decisions to be made very quickly. The instant access to the unique pool of expertise available within ESA was a key factor in the project's success.

Acknowledgement

The success of TEAMSAT is the result of the dedicated efforts of many young engineers, ESA staff and technicians, and supporting universities and companies. The authors wish to thank all of those who have contributed their time and resources to the project. Without them this unique experience would not have been possible.

The names of all of the project participants and supporters are engraved on the side of the TEAM satellite and will be in space for the lifetime of its Geostationary Transfer Orbit around the Earth.

TEAMSAT is indebted to the Ariane-5 programme for the flight opportunity.

Additional information, including an animated sequence of photographs taken during the mission by the on-board cameras, can be found on the ESTEC/TEAMSAT web site at:

http://www.estec.esa.nl/teamsat/

Information relating to YES and to the tether experiment can be found on the Delta-Utec home page at:

http://www.delta-utec.demon.nl

esa

Engineering TEAMSAT — From Concept to Delivery

A. Bradford, F. Müller-Stute & B. Sarti
ESA Directorate for Technical and Operational Support, ESTEC, Noordwijk, The Netherlands

The role of the ESTEC Engineering Section in the design and manufacture of TEAMSAT grew from the design phase, when only a few individuals were involved, to the manufacture and assembly phase, when almost all of the staff in the Section became involved in the project.

Designing TEAMSAT

In the early phases of the TEAMSAT project, much of the mechanical and spacecraft configuration design work was carried out by two Young Graduate Trainees (YGTs) working in ESTEC's Mechanical Design Office and Structural Design Section (A. Bradford and A. Hedqvist)

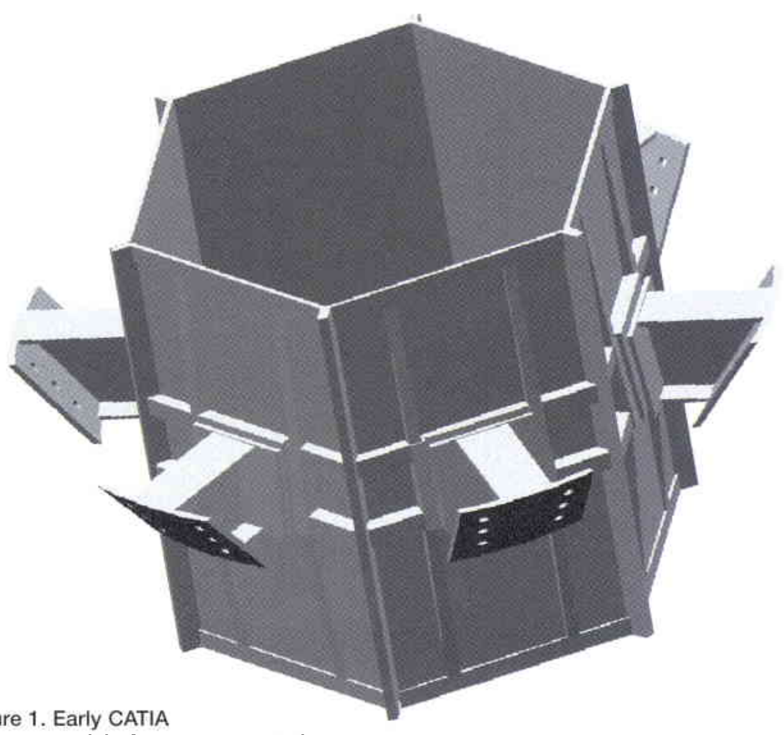


Figure 1. Early CATIA concept model of a cone-mounted option for the TEAMSAT box

The TEAMSAT Structural Model (StM) and Proto-Flight Model (PFM) – along with the Maqsat-H structure, for representation of the TEAMSAT mechanical interfaces – were entirely modelled using the CATIA 3D facility. The resulting 'Master Model' rapidly became a source of reference for most of the sub-system designers and project representatives.

A very early system concept is shown in Figure 1. In this design, the TEAMSAT box is a hexagon, the original concept before internal volumetric requirements demanded a change to an octagonal shape. The method of attachment to Maqsat-H shown is also an early concept, since at this stage attachment of TEAMSAT via the lower cone was being considered.

Detailed information on all of the existing components (e.g. transponders, batteries, and TEAM experiment master units) was gathered to form a kind of central archive. Such information was obviously vital to ensure that the CATIA model was updated with the correct mass and dimensional data for all the components that were to make up the internal design of the spacecraft. Additionally, new components were first checked against the Master Model in order to define a volume envelope and a possible location in the spacecraft. Further examples of the advantages of building and maintaining an accurate 3D model of the complete spacecraft are as follows:

- The spacecraft rapidly became a very complicated system and it was important to model the system in three dimensions to ensure that all components would fit correctly.
- Vital simulations of the separation of the two elements of the YES sub-satellite were

possible using the model. This ensured that changes and modifications would not compromise the fact that YES would be able to eject without damaging either of the two systems.
- The CATIA 3D software was extensively used to manipulate the spacecraft configuration to ensure that the mass properties of the system remained favourable, i.e. within the Ariane-5 given limits, as new items were added to the internal configuration. This software automatically calculated mass properties (centre of mass, mass moments of inertia and principal axes of inertia) for the system model. The mass properties defined and calculated for the PFM ensured that these could be matched when designing the 'Dummy' (Structural Model).
- For the design of new components, especially at system level (e.g. OBDH boxes, PC104 computer unit), the CATIA software facilitated 'automatic derivation' of the detailed engineering drawings directly from the 3D model.

Figures 2 — 4 show the CATIA 3D Master Model of the system as well as a sub-system assembly drawing generated directly from the model.

Manufacture and testing of TEAMSAT

Due to the incredibly tight schedule for the project, the design phase rapidly began to overlap with the manufacturing phase. Manufacture and testing of the Dummy was required before the configuration of the PFM was even finalised. At this point, the involvement of the Engineering Section increased dramatically. Although the manufacture of the primary structure (octagonal box, cover and lid) for both the Dummy and the PFM was contracted out, there was still significant preparation work to do at ESTEC. The Mechanical Workshop staff was charged with the manufacture of approximately 230 kg of dummy masses, which were low cost, but mechanically fully represented the spacecraft. As was the case with the project as a whole, the work was required very quickly and the experience of the workshop technicians was evident as time constraints were met. The staff's enthusiasm throughout the project was reflected by their willingness to work long hours (often evenings and weekends) to get the job done on time.

While manufacture/assembly of the Dummy was still in progress, work had already begun on the building of custom-designed flight model components with, once again, Engineering Section involvement (Fig. 5). As

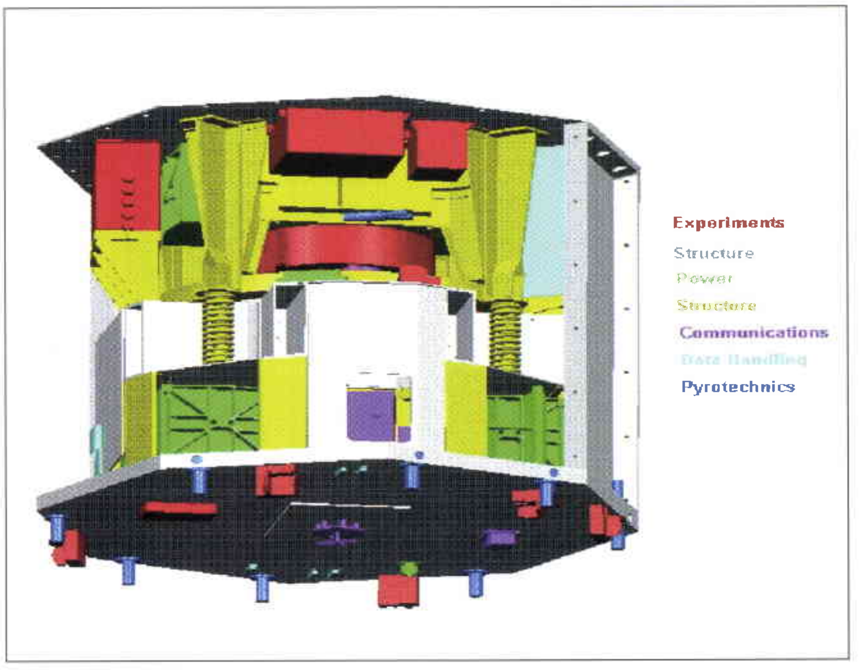


Figure 2. Final CATIA Master Model of the TEAMSAT system, colour coded to identify sub-system groups

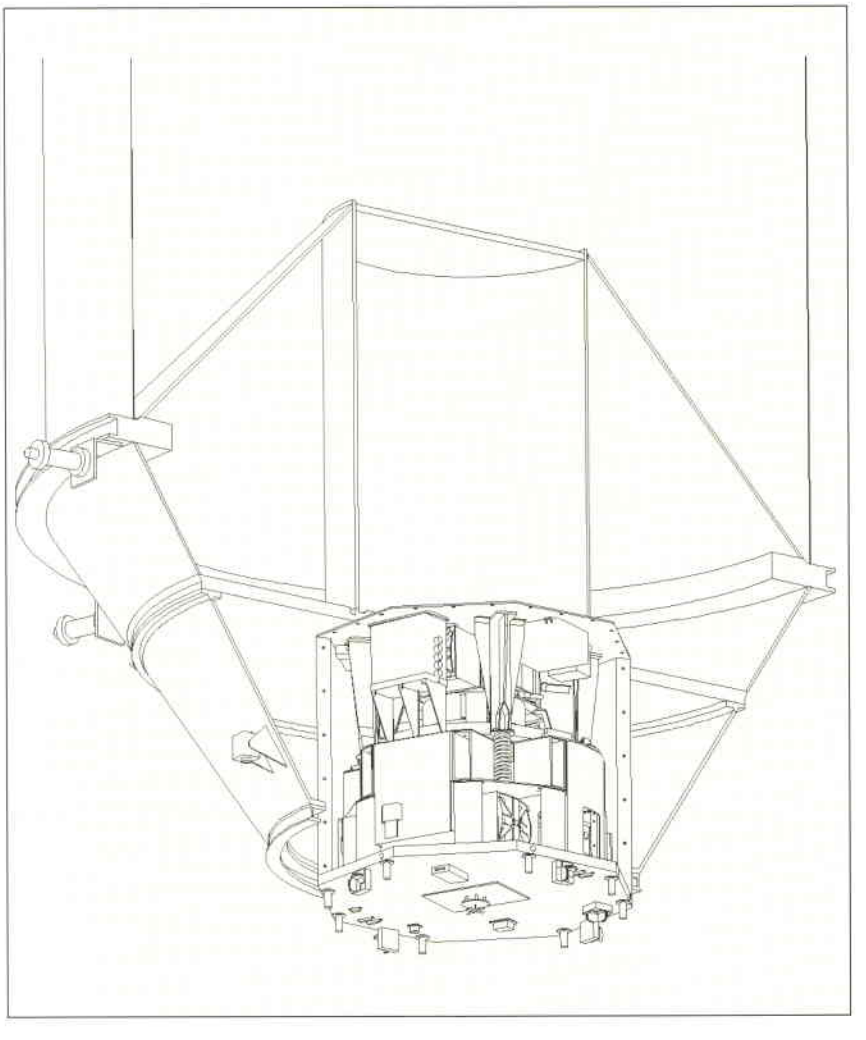


Figure 3. Cutaway view (CATIA model) of TEAMSAT mounted in Maqsat-H, including TEAMSAT cone-mounted sensors

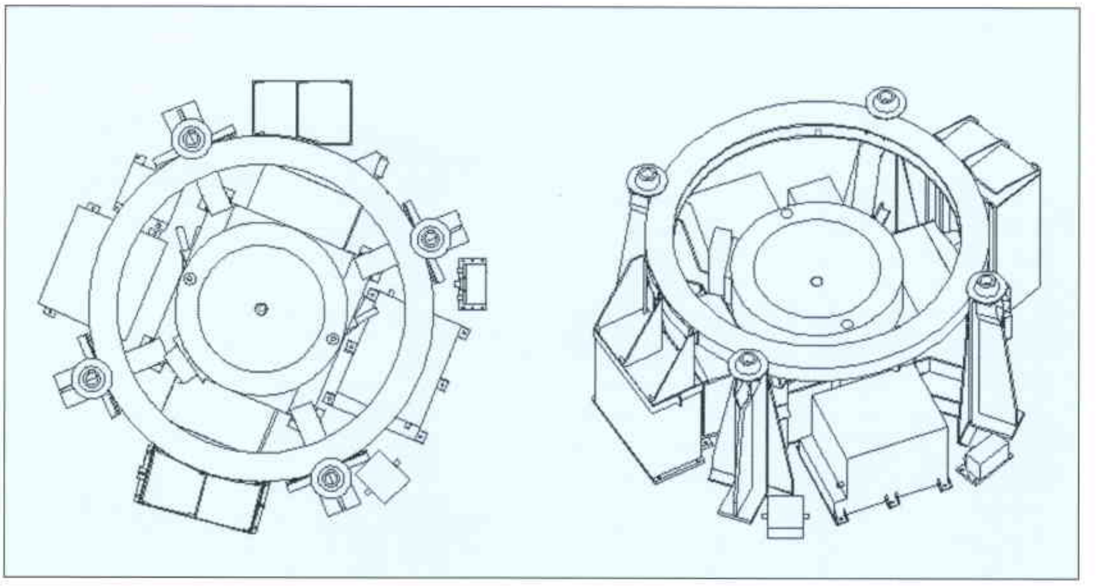


Figure 4. Production assembly drawing of the TEAM sub-system, generated from the CATIA system Master Model

Contribution of the ESTEC Engineering Section

Mechanical Design
- all primary & secondary structure elements (StM & PFM)
- internal configuration & layout
- OBDH mechanical enclosures
- PC104 computer unit mechanical enclosure
- 'JORIS' flight computer mechanical enclosure
- MGSE & test support hardware.

Mechanical Manufacture/ Production
- TEAM and YES structural support elements, including complete manufacture of TEAM and YES secondary structure and ejection system support structure (mainly rivetted and welded sheet-metal elements)
- manufacture of dummy masses for Structural Model
- significant modifications to spacecraft primary structure (to meet ever increasing fixation/ support requirements)
- production of aluminium machined enclosures for two complete OBDH units, 'JORIS' flight computer, JANE power conversion unit, two 'Quick Cam' units
- production of over 50 small machined and turned parts, including ejector system components, pyrotechnic catchment devices
- production of many support platforms for sensors, including solar aspect sensors and GPS antennas
- various MGSE elements

Electrical Manufacture/ Production
- manufacture of complete flight harness for spacecraft
- flight-qualified soldering of PCB boards & components for two OBDH units (two boards per unit), JORIS flight computer, JANE power conversion unit, solar aspect Sensors
- refurbishment/ manufacture of GPS antennas and LNA assembly
- manufacture of various semi-rigid RF cables.

It can be seen from this list that many of the manufactured elements were produced with input from both the Mechanical and Electrical Workshops, as the Engineering Section worked to produce complete components, manufacturing both the metal enclosure and the electronic elements.

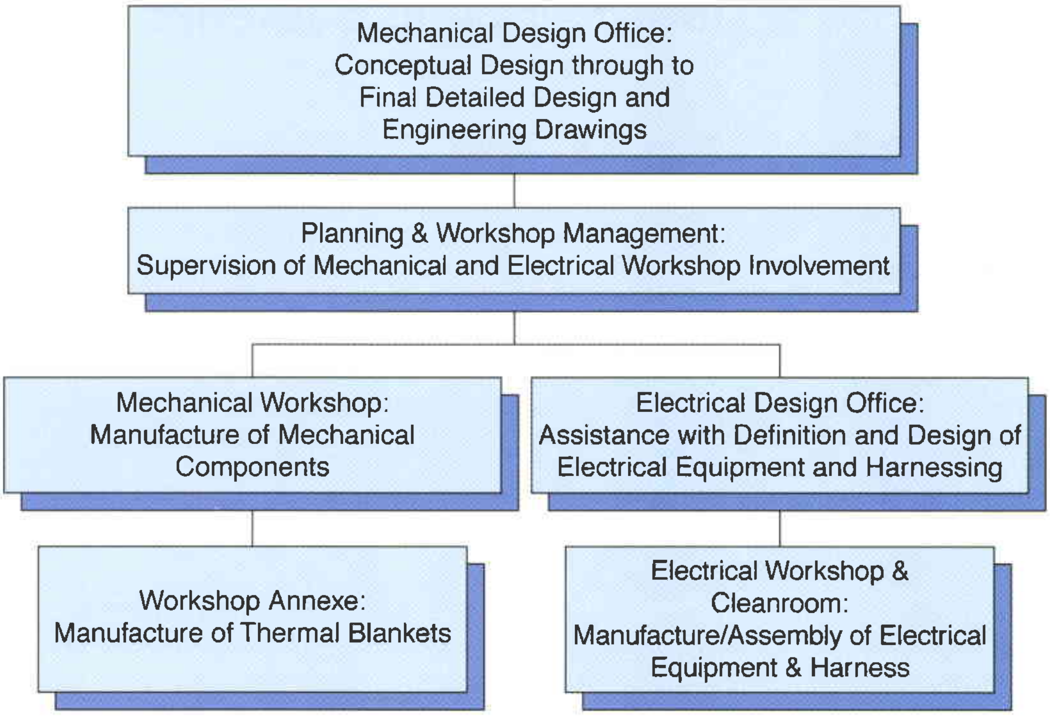


Figure 5. Progressive involvement of the Engineering Section in TEAMSAT

time went on, the estimate of required workshop support increased and the manufacture of the PFM became a major Engineering Section effort. The Electrical Workshop became involved during the manufacture of the printed circuit boards (PCBs) for the on-board computers, data-handling systems and other small electrical devices. The Mechanical Workshop began work on the secondary structural elements, and the manufacture of various boxes and enclosures for the many custom-built electrical devices included in the spacecraft.

The Mechanical Workshop consisted only of ESA staff. The Electrical Workshop, however, required additional outside help to support the large number of tasks entrusted to it. This was particularly the case for the manufacture of the harness. One ESA staff member was even persuaded to come out of retirement to help supervise the production of the harness. The remainder of the harness work was done by three stagiaires, recruited especially for the project. These three young engineers were given a truly 'hands on' training experience whilst producing the flight-qualified harness. As the harness was readied for integration on the spacecraft, two of the three stagiaires began to concentrate more on the spacecraft itself, housed in the Erasmus Building High Bay at ESTEC.

Throughout the manufacturing and assembly phases of the project, there was close cooperation between the Design Offices and the Workshops. With time constraints as tight as they were, this cooperation was vital. It was also helpful that the areas were in the same vicinity, which fostered easier access and face-to-face discussions concerning engineering drawing details or the resolution of technical discrepancies.

This interface was sometimes stretched to the limit. Situations arose several times in which a component was required very quickly, often before a completed engineering drawing could be provided. In these cases, the Design Office would release a preliminary drawing with only the overall exterior dimensions. Once manufacturing of the component was started, more detailed drawings were provided in time for the Workshop staff to complete the task. This approach may not have been ideal, but it did ensure that optimum use was made of all resources.

Conclusions

This unique project showed how productive close co-operation between the different disciplines represented in the ESTEC Engineering Section can be.

The on-site design and manufacturing capabilities provided an essential contribution to the success of TEAMSAT.

TEAMSAT's Data-Handling Systems

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Twenty-five weeks from project approval to the delivery of two working, flightworthy spacecraft data-handling systems did not, during the feasibility study, seem possible to fulfil. However, due to staff dedication combined with some calculated risk-taking and the availability of the ESA Telemetry and Telecommand chipset, a working data-handling system including ground segment was already available six weeks prior to TEAMSAT's shipment to Kourou.

Introduction

The highly restricted budget dictated the use of old flight spares and engineering models wherever possible. Thus, for the RF link, we used transponders from Olympus and Eureca. However, size and lack of adaptability of other parts such as a Central Data Management Units made them unsuitable, so we opted to design a new system from scratch. Not only did the system have to be much smaller, but it also had to accept the event-driven, asynchronous experiment data outputs 'as is', since there was no time to adapt the experiments or their existing test and development systems.

Fortunately, we had a small stock of Application Specific Integrated Circuits (ASICs) for building on-board telemetry and telecommand core systems compliant with the ESA subset of the recommendations of the Consultative Committee for Space Data Systems (CCSDS). These standards support asynchronous data delivery. The availability of this chipset and the fact that the system built from it did not involve a processor or software made the otherwise impossible task feasible.

Another advantage the telemetry/telecommand (TM/TC) chipset conferred was the 'Very high speed integrated circuit Hardware Description Language' (VHDL) models that came with it. The use of VHDL enables devices and whole systems to be designed and simulated down to very fine detail. Models of other components were already available, including the whole ground segment, in sufficient detail to exercise all the TM and TC protocols at an early development stage. This was instrumental in our successfully flying the data-handling system 'straight off the drawing board' without a prototype and with debugging restricted to relatively minor user interface issues.

Another essential element was an in house Field Programmable Gate Array (FPGA) design facility. There were two FPGAs in each spacecraft, supporting TM and TC functions respectively. They also controlled house-keeping packet generation (including control of the analogue subsystem) and provided programmed delays for command pulses. The FPGA design process also produced VHDL models.

Data-handling system design features

Our requirement to accept user interfaces and data structures 'as is' meant we had to provide a 'byte stream' rather than a packet service for both up- and down-links. In effect, the data-handling system provided a transparent path between experiments and their respective test and monitoring equipment. However, ESA/CCSDS packet structures were used to send the main power switching and configuration commands, and carry the platform housekeeping data. With no recognisable packets, delimiting between users was done by allocating different Virtual Channels (VCs) and Multiplexer Access Points (MAPs) on the TM and TC links, respectively. This is not necessarily a strategy we would advocate in other circumstances since VCs and MAPs are intended to primarily delimit different levels of service and/or address redundant paths in the transport layer. A given VC or MAP may then carry packets with different sources and destinations, as identified by the packet Application IDs, but with compatible requirements for bandwidth and latency. The ESA TM chipset was designed to support simultaneous byte stream and packet modes on different VCs.

We decided to include all the central power switching and housekeeping functions in the On-Board Data-Handling (OBDH) box, thereby creating one self-contained service unit for

* SERCO BV, The Netherlands

each spacecraft with the following characteristics:

Dimensions	310 x 170 x 110 mm^3
Weight	3.2 kg
Power	7 watts

The boxes were designed and manufactured in the ESTEC Workshops and contained one TM board and one TC board, each weighing about 450 g. They also contained relays, power regulators modulation filters, thermistor matching networks, etc. The housekeeping system provided 32 single-bit digital channels and 16 analogue channels with 8-bit resolution. Configuration switching telecommands were decoded by the Packet Telemetry Decoder (PTD) and, after amplification, used to operate the power-switching relays.

Self-adapting, asynchronous TM service

TM systems of earlier designs obliged users to adapt their data production to a lock-step regime imposed by the fixed-format TM transfer frame. Although the frame generated by the VCM/VCA chipset has a fixed size, its internal format adapts itself dynamically to user activity. This met the requirement to accept user data as randomly occurring squirts of various sizes or as fully asynchronous individual bytes. The useful bandwidth available on the TM link was 28 259 bits/sec (overheads removed). The system shared this among individual users such that each got a guaranteed share (which could be re-specified in flight), but any bandwidth not taken up by one user would be offered to other users in proportion to their guaranteed share. If users failed to exploit all the bandwidth offered, the generator itself completed frames with filler.

The AVS star-finder experiment on TEAM is a good example of a sporadic data producer. In quiescent mode, it produced a small squirt of housekeeping data from time to time, but when an image was taken a more prolonged squirt would be produced. The experiment had no flow control, so the TM system had to accept the data as it was produced at 19.2 kbaud from its PC-type asynchronous serial interface. It was guaranteed a share of the TM bandwidth matching this peak requirement, but this was only taken up occasionally due to the nature of experiment operations. The FIPEX experiment, also on board TEAM, was somewhat similar in its data-production characteristics.

The third TEAM experiment, the Visual Telemetry System (VTS), produced small amounts of housekeeping as a background activity, but it also had a 128 Mbyte buffer for video information. Its output interface was flow-

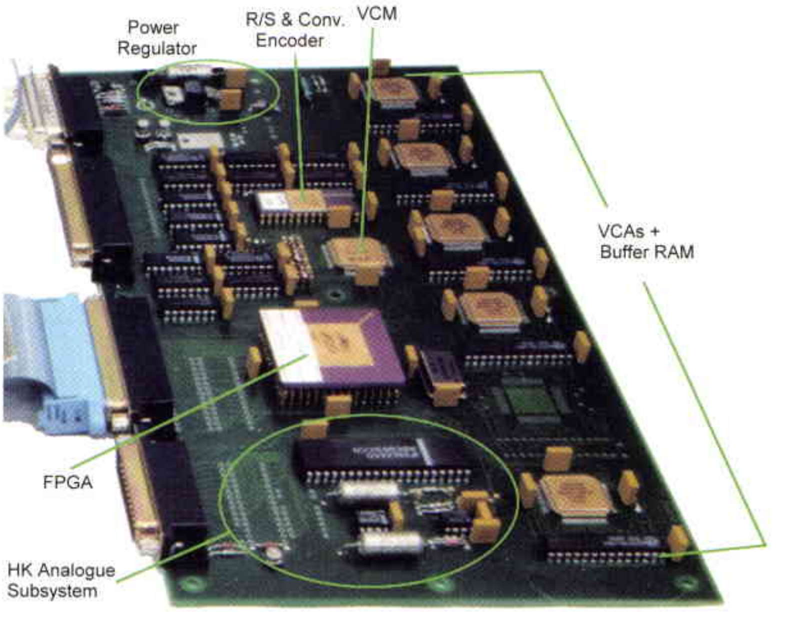


Figure 1. TEAM telemetry board

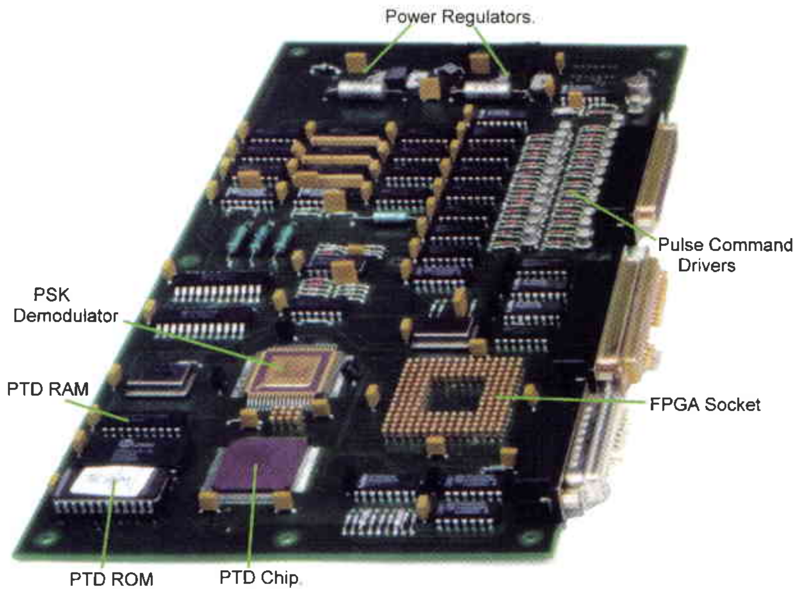
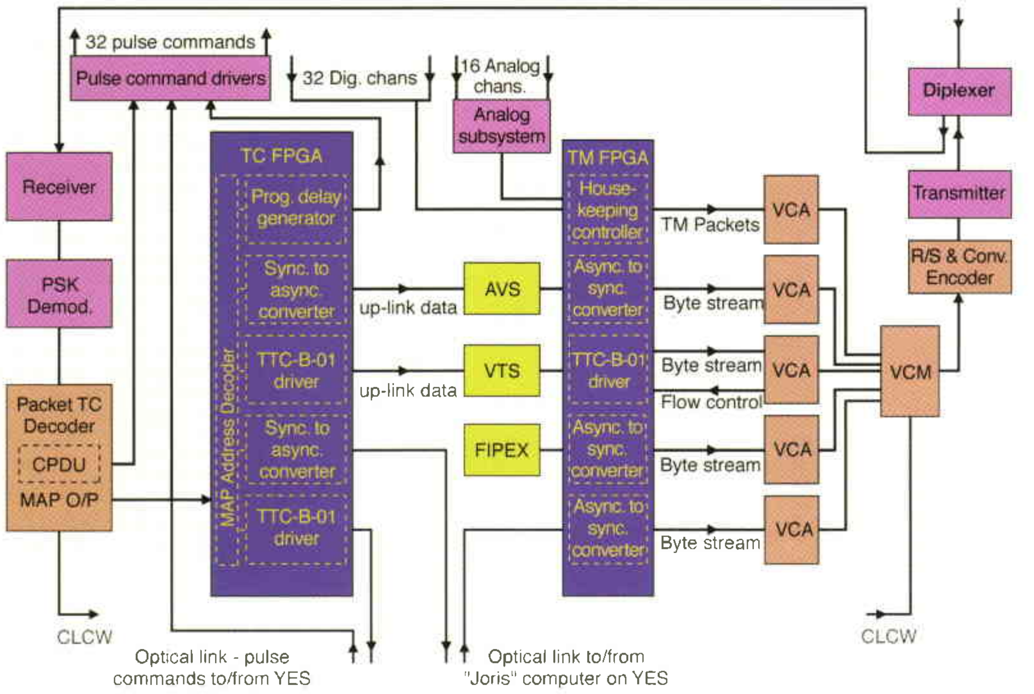


Figure 2. TEAM telecommand board

controlled so the VCA only accepted data when there was space in the transfer frame. This made it an ideal companion for AVS and FIPEX, since it could soak up the substantial bandwidths allocated to them but not used most of the time. In effect, the flow control applied by the TM system emptied the VTS buffer as fast as the total link bandwidth and current activities of the other users would allow.

In addition, we had platform housekeeping data being produced in ESA/CCSDS packets of fixed size and format every 4 sec. In that case, bandwidth was used consistently because of the constant data production rate.

Figure 3. The TEAM On-Board Data-Handling System (OBDH)



The housekeeping system was similar to a classical ESA fixed-format approach. It made very inefficient use of the bandwidth it occupied (constant values reported in successive packets, etc.). However, the bandwidth in question was only a small proportion of the total, so the inefficiency could be tolerated in the interests of simplicity.

The ground segment

The ground segment had to be ready in time to support spacecraft integration and testing. Additionally, everything concerned with terrestrial- and space-link compatibility and procedures had to be resolved with ESOC during this period.

The transparent TC and TM links reduced the work required to implement the ground segment by ensuring that existing PC-based experiment development sets and software could be used for experiment control and processing during testing and flight. In this way, a comprehensive experiment control centre was created at very low cost.

System performance and conclusions

TEAMSAT is the first ESA spacecraft to be flown with TM and TC systems both fully compatible with ESA/CCSDS standards, and the first spacecraft to exploit the adaptive asynchronous TM capabilities they support. The performance and ease of use delighted everybody. There is also no doubt that the short, relatively trouble-free design and construction phases resulted from the use of the TM and TC ASICs, which implemented all of the tricky core functions and protocols.

The failure of the YES TM transmitter to command on after a routine short battery-saving hibernation period towards the end of the mission was the only blemish on an otherwise faultless performance. The YES transponder was an ex-Olympus engineering model that was over 16 years old. Its use was one of the many calculated risks we had to take.

Optical links between the two spacecraft before separation enabled essential TC and TM of one to be routed via the RF links of the other to overcome the expected effect of antenna pattern holes. One such link providing a redundant TC path via TEAM to YES was discovered to be unreliable during testing and could corrupt the intended command. By that stage there was no time to correct it, so an extra safety interlock was placed on the path by removing such commands from the ESOC database. In any case, given the pre-launch official disabling of the Tether experiment, it was no longer required. As a last-resort 'nothing-to-lose' action, the safety interlock was deliberately removed to make a final attempt to switch on the YES transmitter towards the end of the mission. The command corruption on that occasion resulted in the premature ejection of YES. At that time, all other principal objectives having been achieved, this did not further degrade the mission in any way other than to deprive us of some pictures of the separation via VTS that we might otherwise have had.

The efficient, adaptive behaviour of the TM system in accepting asynchronous, event-driven inputs without involving a processor is of particular note. It is a mode of operation that, considering it too complex, project groups and industry have so far mostly avoided. If attempting to implement it in software, there is probably some justification in this point of view. However, in successfully flying such a system 'straight off the drawing board' after ultra-short design and construction phases, we have demonstrated that by using the TM ASICs such misgivings are unfounded.

There was no mission requirement for the authentication process supported on the TC chip, so it was not used. The only other ESA/CCSDS capability not demonstrated in flight was the COP-1 protocol. TEAMSAT was the first ESA spacecraft to support this capability, but there had been no time to verify ground-station compatibility. However, its functionality on board had already been verified during integration and testing and its effectiveness in flight had already been demonstrated in 1994 by the low cost STRV-1 A and B satellites built by DERA, UK. These used an earlier prototype telecommand decoder chip, very closely related to the one we used.

The TEAMSAT project has proved that a spacecraft data-handling system of high performance and guaranteed compliance with standards can be designed and built quickly and cheaply by using commercially available, space-quality ASICs and supporting VHDL models. These ASICs are mutually compatible, come with all the complex protocols frozen into their silicon, and so enable the radically new system capabilities and standards they support to be implemented with no risk. They are outputs of an on-going ESTEC development activity exploiting VLSI technology to reduce costs and improve performance within the framework of the new ESA/CCSDS standards. Currently, more than ten projects are already committed to using them.

Acknowledgements
Virtually all ESTEC Departments provided generous assistance in one way or another. However, the excellent and enthusiastic support given by the Workshops deserves special mention.

ASIC Descriptions

All ASICs used latch-up-free, Silicon-On-Sapphire (SOS) technology have a footprint of about 8 cm^2 and weigh about 15 g.

Telemetry ASICs

Virtual Channel Assembler (VCA): Assembles data into one of up to eight VCs on the TM link (one VCA per VC). Applies flow control (optionally) to match the data source production rate to the bandwidth available to that VC. Accepts data as ESA/CCSDS packets or byte stream.
TEAM used five VCAs and YES used four.

Virtual Channel Multiplexer (VCM): Multiplexes outputs of up to eight VCAs on to one TM link. An inflight-programmable Bandwidth Allocation Table guarantees minimum portions to each VC. The VCM completes the transfer frame header (spacecraft ID etc.). Also provides interfaces for the Command Link Control Word (CLCW) from the TC decoder chip, and to the Reed-Solomon and Convolutional Encoder chip.
Each spacecraft used one VCM.

Reed-Solomon Convolutional Encoder: The on-board segment of a forward error detection and correction system providing a coding gain of about 7dB on the link budget. Its use is optional, but a tight link budget for TEAMSAT made it mandatory.

A complete TM frame generator core comprises one VCM, one VCA for each VC and an optional Reed-Solomon and Convolutional Encoder chip. Power (5V) is typically about 30 mW per chip, but depends mostly on clock rate and output loading.

Telecommand ASICs

PSK Demodulator: Demodulates the noisy PSK subcarrier from the TC receiver and recovers the NRZ data, bit clock and a 'signal present' indicator when the signal-to-noise ratio exceeds a predetermined value. One chip was used on each of the two spacecraft. Belongs to the physical layer and is not strictly part of the data-handling chipset.

Packet Telecommand Decoder: On-board segment of an ESA/CCSDS compatible up-link providing error-free delivery of packets or arbitrary data structures via up to 62 addressable MAPs. Also hosts an authentication check (not used for TEAMSAT), and a Command Pulse Distribution Unit (CPDU) which decodes multiple bi-level commands delivered in a packet.

Power (5V) is typically about 30 mW per chip, but depends mostly on clock rate and output loading.

Sources for more information:

Data-Handling System: TEAMSAT Website
http://www.estec.esa.nl/teamsat/

ASICs: TOS-ES Microelectronics Website
http://www.estec.esa.nl/wsmwww/

TEAMSAT's Low-Cost EGSE and Mission Control Systems

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The decision to launch, on Ariane-502, a number of experiments on a satellite developed by young engineers and students required new approaches to the development of Electrical Ground Support Equipment (EGSE) and the Mission Control System (MCS). This article describes how the systems were implemented through the combined activities of students, young engineers, experienced ESA staff and industry, in a short time and at low cost.

Introduction

Electrical Ground Support Equipment is used to check out spacecraft and payloads during their development prior to launch. A Mission Control System is used to monitor and control the spacecraft and its payload after launch. Traditionally the EGSE and MCS are separate systems, but in the case of TEAMSAT the baseline approach was to have a low-cost, portable EGSE/MCS system, suitable for both the TEAM and YES satellites. It would be used in Europe for satellite development and then moved to Kourou to support launch and mission operations. This philosophy was driven primarily by the lack of resources (people, budget and time), but also provided an opportunity to test the principle of commonality across the development and operational phases. This article describes what happened in practice.

The Electrical Ground Support Equipment (EGSE)

Evaluation of the EGSEs available from previous projects showed that for a small mission the resources needed to commission and sustain any available equipment and software far outweighed the advantages of their availability. The only exception to this was the battery conditioning and monitoring equipment plus Check-Out Terminal Equipment (COTE) already qualified for use with Ariane-5 launches, which was generously loaned by the Cluster project.

It was decided to adopt a more radical approach and to base the EGSE on PCs running Windows 95, using any available prototypes for specialised interface needs. This decision also allowed easy integration with the experiment test equipment, which was already PC based.

The minimum requirements were that the EGSE must:
- receive, separate, deliver and process telemetry data
- command the spacecraft.

Moreover, the ESA packet telemetry and telecommand standards had to be supported. These standards are based on the recommendations of the Consultative Committee for Space Data Systems (CCSDS). In fact, use of these standards was an advantage, because of the availability of industrial products to support them. The company Satellite Services (SSBV) offered free use of their prototype PC-based telemetry and telecommand equipment in exchange for technical feedback on its use; the company De Lande Long offered its telecommand packet preparation and transmission software, also free of charge, to operate the SSBV telecommand equipment.

For processing of the telemetry data, a software package offering packet telemetry parameter calibration, display, graphical representation and archiving was purchased from Micro Scitech. This left only one problem to solve: separation of the virtual telemetry channels, their archiving and their distribution to user PCs. For this no existing product was available and the decision was taken to develop this software in the EGSE laboratory at ESTEC. It was treated as an exercise in 'object-oriented' development using the software environment 'Delphi'. The result was a set of basic software units which were used by students to build their experiment software in record time and with minimum training.

The overall EGSE integration and testing was done in the EGSE laboratory prior to its use with the spacecraft. The resulting architecture used both in spacecraft development at ESTEC and for launch-site operations in Kourou is shown in Figure 1.

As TEAMSAT comprised two satellites, TEAM and YES, it was in fact necessary to have two systems to perform testing if time was to be used efficiently. Unfortunately, it was not possible to acquire enough equipment to build two systems. At times when parallel testing was required, it proved possible to use the flight operations equipment (SCOS, NCTRS and NDIU described later in this article) as a second command and display facility. This proved invaluable in speeding up the testing process and certainly contributed to having the complete spacecraft integrated and delivered on time to Kourou. Using the flight operations equipment in this way was a good demonstration of the potential for commonality between the two domains.

Concerning cost, it was possible to build the test system for 20 kECU and one man-year of engineering effort. However, it must be remembered that without the generous offers of free use of equipment and the use of EGSE laboratory equipment this would not have been possible.

The Experiment Control Centre (ECC)

In the original baseline, the ECC was to be co-located with the Mission Control Centre in Kourou using the hardware and software of the EGSE. Once again, economic considerations dictated a change in policy which had significant technical impact. Due to the high cost of maintaining an operations team in Kourou comprised of experimenters, young graduates, ESA staff and contractor's engineers, it was decided to re-locate the experiment operations activity to ESTEC. This eliminated the need for travel and subsistence expenditure.

Since all EGSE was located at the Guiana Space Centre (CSG), Kourou and was needed for the launch campaign, it became necessary to duplicate most of the EGSE, including the experiment EGSE. The software was not a problem, but twelve PCs were needed. This time the office automation programme came to the rescue with the loan of 12 new PCs which were installed and commissioned in only 2 days by ADM-IS staff. Reliable communications were also needed between ESTEC and ESOC for receipt of telemetry and transmission of telecommand packets. This facility was also designed, installed and tested by ESOC personnel in record time. The whole ECC was designed, built and tested in only 4 weeks, this being the time available from the taking of the decision until the planned launch date in late September.

The ECC consisted of two complete systems, one for TEAM and one for YES. Each had a virtual channel demultiplexer/archiver connected to ESOC via ISDN. Serial data links passed telemetry data to the PCs used for data processing for each experiment. Some PCs also had the capability to generate telecommand data packets, which were then forwarded to ESOC for transmission to the spacecraft. Each spacecraft also had a housekeeping display PC for monitoring of its health.

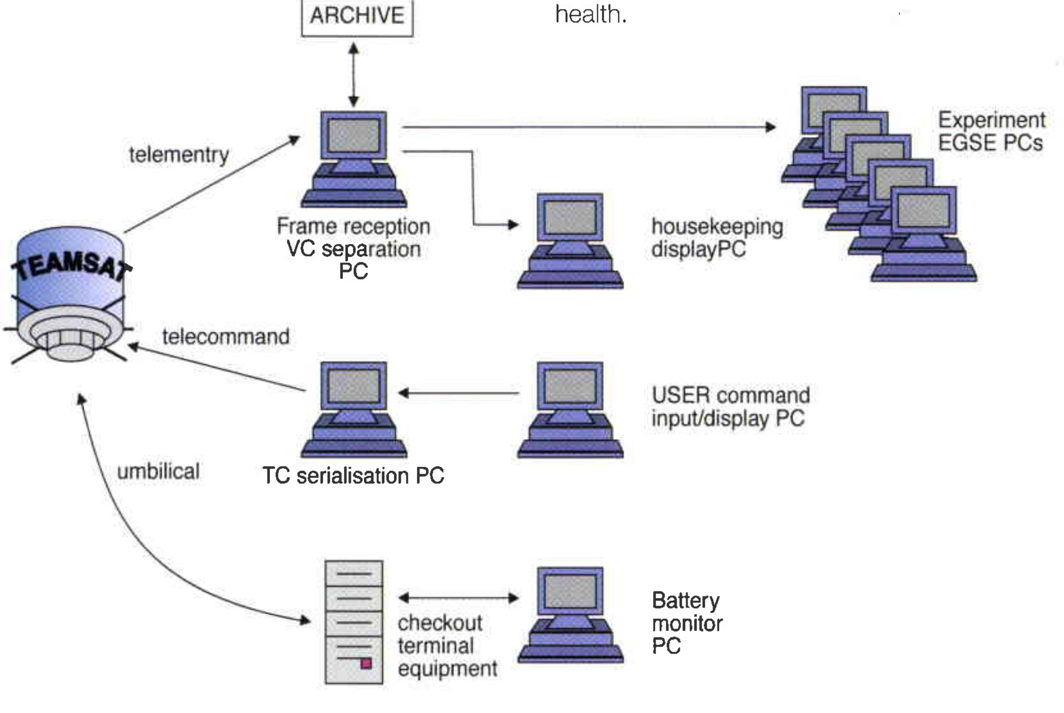

Figure 1. TEAMSAT EGSE configuration

A complete mission simulation consisting of a graphical presentation of the Ariane-5 launch sequence followed by simulation of the TEAMSAT orbit was also provided in the ECC. This proved to be extremely useful during the mission operations, to visualise the spacecraft orientation and to plan operations which could only be carried out in specific parts of the orbit. The simulation was supplied free of charge by the company Silicon Worlds and ran on a workstation provided by the Simulation Section of ESTEC. The ECC is shown diagrammatically in Figure 2.

The Mission Control System (MCS)

Following the principle of commonality, the initial intention for the MCS was to re-use the EGSE, including the experiment test equipment which would be used for experiment monitoring and control. This decision proved to be overly simplistic when faced with the needs for interfacing to an existing ground-station network and providing additional services such as ranging, orbit determination and operational flight-procedure development. Closer examination revealed that deviation from the commonality principle in order to re-use the Agency's existing facilities managed by ESOC brought significant advantages – multiple ground stations, a proven infrastructure and most of all, support from teams with vast experience and fully familiar with configuring, operating and using them. This led to the decision to use the ESA ground-station network and the SCOS-II Mission Control System together with a core team from ESOC to support the mission operations. The work to prepare for operations is covered later in this article.

MCS requirements

In terms of overall flight control, TEAMSAT required:

- access to two ground stations to provide adequate orbital coverage
- spacecraft control facilities
- flight dynamics support, in particular to provide accurate orbit prediction for both spacecraft, essential to plan the signal acquisition by the ground stations; this support was particularly important as the two spacecraft were not provided with an on-board attitude and orbit control capability
- mission planning support, to schedule experiment operations, with emphasis on power conservation
- transmission of the experiment telemetry data to the ECC
- a mission control system providing the usual capabilities needed by operations staff:
  - spacecraft database setup
  - telemetry receiver/packetiser
  - raw data distribution, archiving and retrieval
  - telemetry processing, including at least parameter extraction, parameter validity checks and parameter engineering value calculations

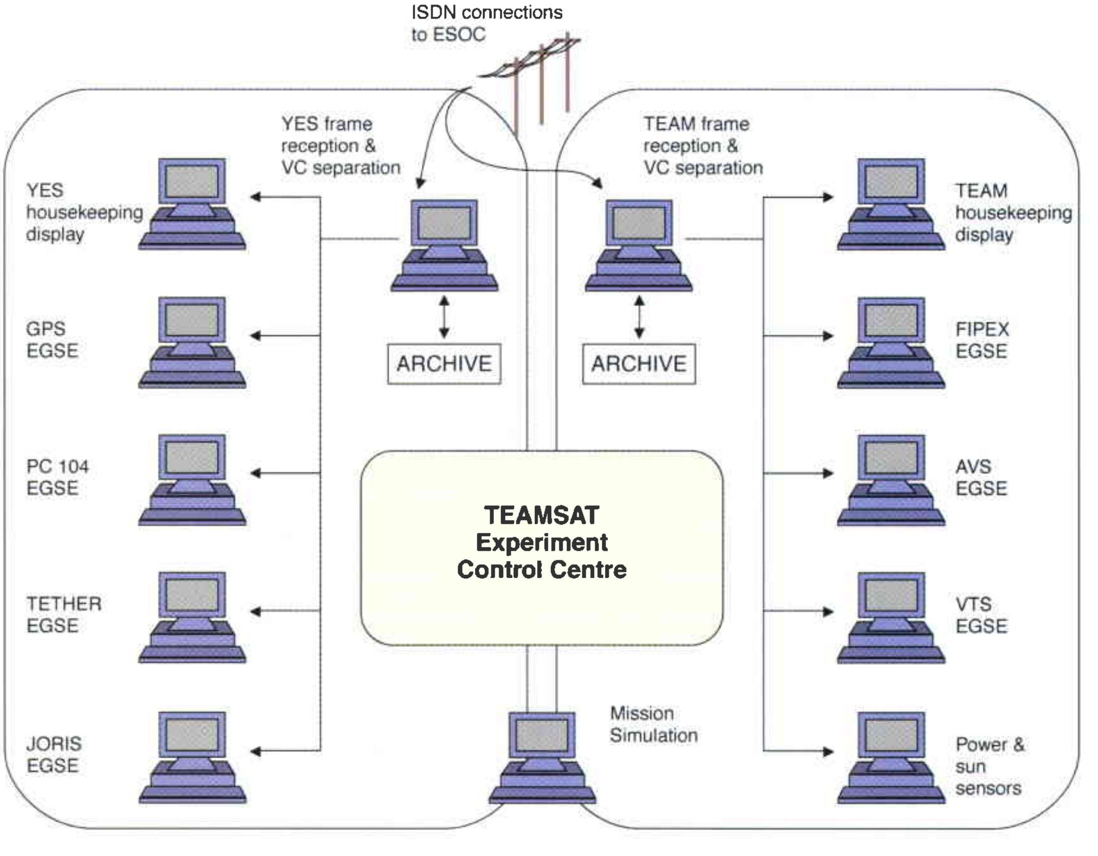

Figure 2. TEAMSAT Experiment Control Centre configuration

- time correlation
- telemetry displays
- commanding. including preparation of commands on a manual stack, uplinking, verification, and maintenance of a command history
- ranging-data acquisition and processing
- mission event logging (e.g. uplinking of a TC).

In addition, there was a late requirement to display images from one of the YES on-board cameras.

Operations ground facilities approach
The following ground facilities were provided:
- ground stations: ESA ground stations at Kourou (French Guiana) and Perth (Australia) were used together with the ESA ground station communications network (OPSNET)
- spacecraft control facilities
- flight dynamics support: based on ESOC facilities and expertise
- mission planning: no specific facilities were developed, but a mission-planning specialist (from the ERS-2 project) performed the task using commercial off-the-shelf (COTS) tools (spreadsheet and word processor).

Selection of the operations control system
The time available was very short. When it was decided to investigate an alternative to re-use of the EGSE for operations, there was no choice but to base the system on existing facilities. In addition, it was known that the hardware would have to be installed successively at three sites: initially at ESOC, then at ESTEC, and finally at Kourou. Thus, equipment compactness and portability were essential features. ESOC's older infrastructure, SCOS-I, was considered unsuitable since it was cumbersome to modify and configure and in addition would have required a considerable amount of expensive, and not particularly portable, hardware.

In February 1997, ESOC's newest configurable control system, SCOS-II, was in use for one mission – the SOHO monitoring and data retrieval system, installed at NASA Goddard Space Flight Centre (GSFC). It was also being prepared for two other missions, Meteosat-7 (launch and early orbit phase) and Huygens. SCOS-II subsequently supported both of these missions very successfully, in September and October 1997 respectively.

The SCOS-II hardware architecture comprises a network of Sun workstations, running the Solaris 2.5 operating system. A key feature of SCOS-II is that it is scaleable, i.e. workstations can be added according to the size and demands of the mission being supported. For instance, a mission control system can be provided on a single workstation, the so-called 'SCOS-in-a-box' configuration. By contrast, the operationally demanding Meteosat-7 launch and early orbit operations (LEOP) used a configuration of 26 workstations. The approach for TEAM/YES was that of 'SCOS-in-a-box', with essentially one Sun workstation (namely a Sun/SPARC 10) dedicated to each spacecraft.

Another recent development in ESOC's control centre approach is the use of a standard 'front-end' to the ground-station network. This 'front-end', called the NCTRS (Network Control and Telemetry Routing System), takes care of the ground station network protocol (OSI, X.25) and the specific interfaces to the various types of equipment in the ground stations. The control system uses the widely supported TCP/IP protocol for its various interfaces, including those to the NCTRS for telemetry, telecommand and tracking data. The NCTRS also runs on a Sun Solaris workstation, one of which was used for each spacecraft. A simplified block diagram of the overall control and data-processing system for a single spacecraft is shown in Figure 3.

Project-specific additions to SCOS-II
As SCOS-II provided most of the required functions, it was necessary to make only small additions to the system. These were in the areas of:
- TM virtual channels and packetisation handling
- TC packet protocol handling
- real-time experiment image displays.

SCOS-II assumes it receives telemetry data in the form of SCOS-II packets, whereas the data received from the ground station was in the form of transfer frames containing virtual channels. These in turn contain source packets. A TM receiver/packetiser was therefore developed (based on an available example) to select virtual channels and convert the transfer frames into SCOS-II packets (essentially the source packets, with a special header added).

A problem for the MCS was that there was no ground-station equipment available that supported the TC packet protocol. The equipment did in fact exist, but at the time it had not been deployed at the stations, nor was the necessary NCTRS interfacing supported. The approach adopted was to write special software to convert the TC packets generated by SCOS-II data units of the TC packet protocol. The older generation (Mark II) of

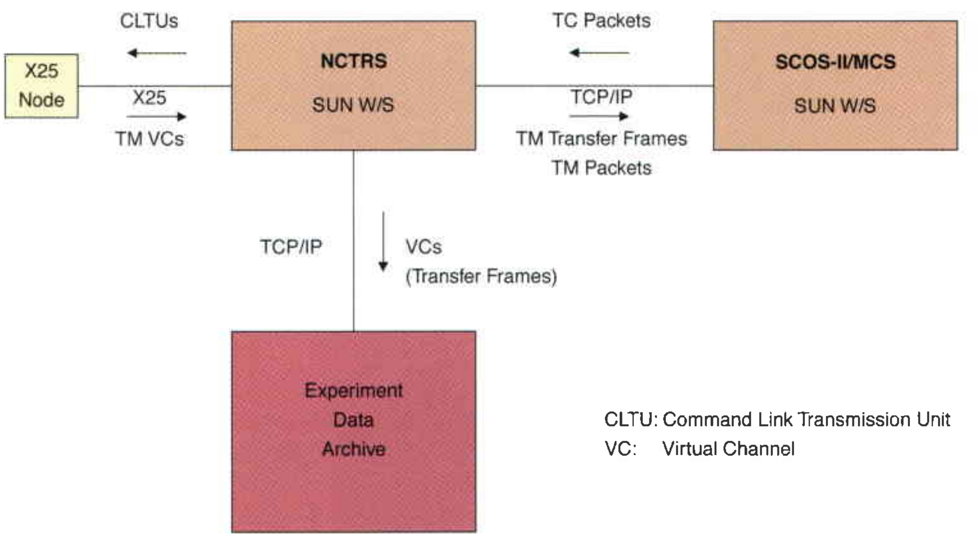

Figure 3. Overall control and data processing system

telecommand equipment was then used in 'transparent mode' to up-link the command data.

A display of the data acquired by one of the YES on-board cameras was developed using the SCOS-II data processing and 'mimics' display capabilities. In SCOS-II, 'mimics' displays are normally used to present block diagrams of spacecraft subsystems. A mechanism was therefore devised to use them to display camera data, with decompression and display of the JPEG data triggered on receipt of the data packets. Subsequent images coming from the same camera refreshed the image on the mimic display in real time. This new approach could in fact become a standard facility in control systems in cases when on-board cameras are used for spacecraft health monitoring.

MCS development

Key events of the MCS development are shown in Table 1, highlighting the short lead times for the successive deliveries of the control system. For example, a usable basic version of the control system was available only six weeks after the start of the implementation.

Preparation was completed on 25 September, five days before the expected launch date. At this point, a significant launch delay was announced. To avoid the substantial costs of keeping the operations team in Kourou, it was decided to relocate the MCS at ESOC. This posed the risk that the system could not be re-integrated in time. Added to this was the need to reconfigure and revalidate the communications system which was, in the event, done within a remarkably short time of only eight days, taking advantage of the expertise and infrastructure available at ESOC. This resulted in the final operational configuration shown in Figure 4. By the end of the first week of October 1997, the sequence of testing, simulations and dress rehearsal could be repeated with the new set-up. The whole ground system and operations team was then fully prepared for the launch on 30 October and the subsequent five-day mission.

Table 1

Event	Date (in 1997)
Analysis of requirements	End February
Kick-off of implementation work	Mid March
First version of basic control system	End April
Initial installation in Kourou (4 workstations)	Mid July
Completion of final installation in Kourou	Mid September
Announcement of launch delay	25 September
Reintegration of Control Centre at ESOC, in Darmstadt, completed	10 October
Launch	30 October
End of mission	4 November

Cost Aspects

Both EGSE and MCS were developed at low cost. In the case of the MCS, just one-and-a-half man-years, including software support to operations, was expended. The equipment was drawn from a pool of existing workstations in ESOC.

Why was the low cost so low? The reasons include the following:

- The necessary control system infrastructure (SCOS-II and NCTRS) was available to satisfy the larger part of the requirements (some 95%). Furthermore, since little new development was required, little documentation was necessary. A key point was that the SCOS-II/NCTRS technology allowed rapid customisation, largely without programming effort.
- The use of a small, highly-motivated team with skills in the SCOS-II and NCTRS packages, working against a very demanding schedule.

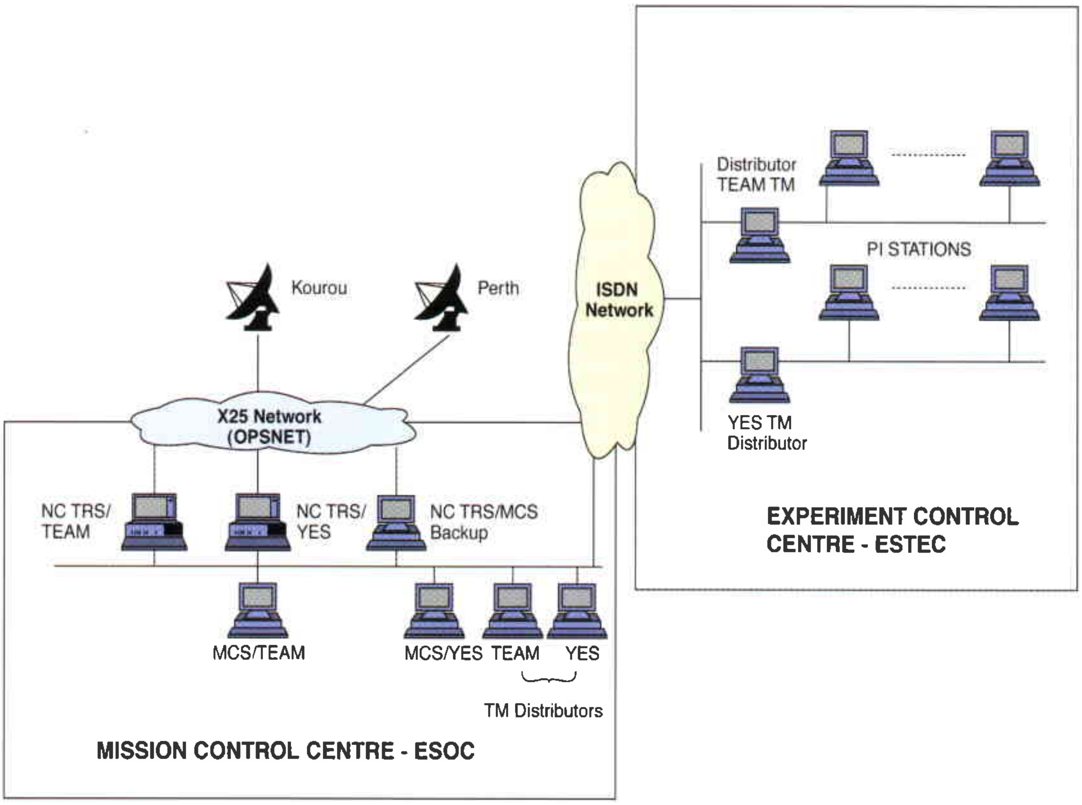

Figure 4. Final ground segment configuration

- Co-location of the team (both ESA and contract staff) at ESOC. This permitted daily and direct exchanges of information and rapid reaction to changes and problems. Moreover, mission and network operations staff, and also the other ground segment engineering disciplines (flight dynamics, ground-station and communications engineering) were also at ESOC, greatly facilitating integration work.

In the case of the EGSE, the explanation is similar. Use of existing products, some at no cost, contributed significantly to the low cost. Using experienced staff to guide students and young engineers had both cost-saving and educational benefits. It should also be remembered that testing was limited in duration, due to the lack of available time, and was manual in nature. As a consequence, no test software had to be developed. Testing relied upon written procedures and manual checks from data displayed on PC screens.

Conclusions

TEAMSAT was a practical and successful example of low-cost ground systems implementation and operation. The analysis shows that the low costs depended chiefly on the availability of facilities (hardware and software) which could do the job and the necessary human resources with the right expertise, organised in small, highly motivated teams. It is also important to note that without these resources, it would not have been possible to provide ground systems in the short time available. The availability of COTS hardware and software products was an essential contributor to the project's success.

The indications are that significant cost reductions in the provision of ground control systems should be feasible by taking advantage of COTS products and reusable facilities like SCOS-II. This is expected to bring more choice and competitiveness to the supply of ground systems for space projects. The original baseline of a common EGSE/MCS turned out to be impractical because of schedule and technical constraints. However, the EGSE and MCS development teams still worked closely together, giving a greater understanding of commonality aspects. This will contribute to future work for providing single products to cover both areas.

Acknowledgements

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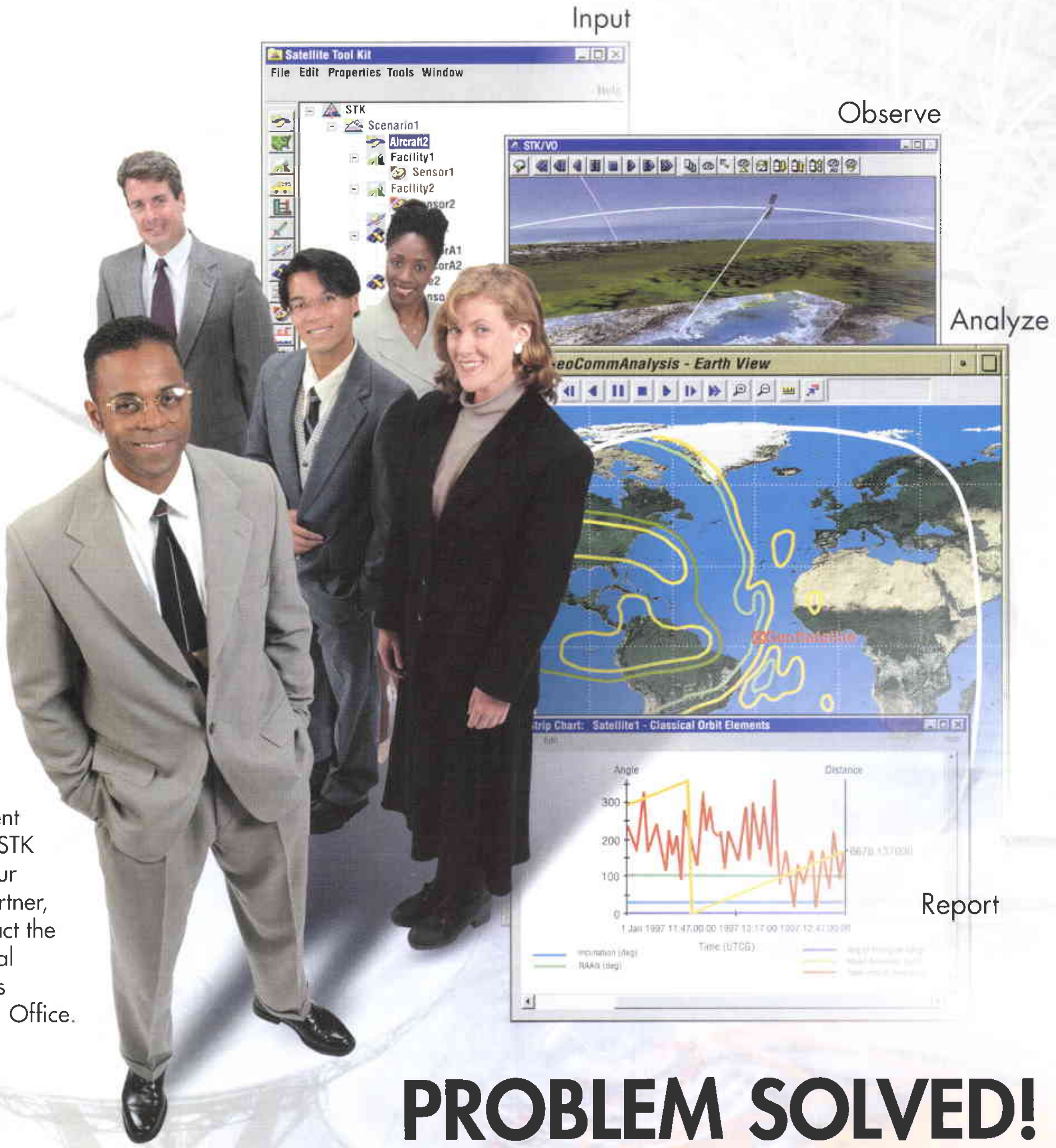

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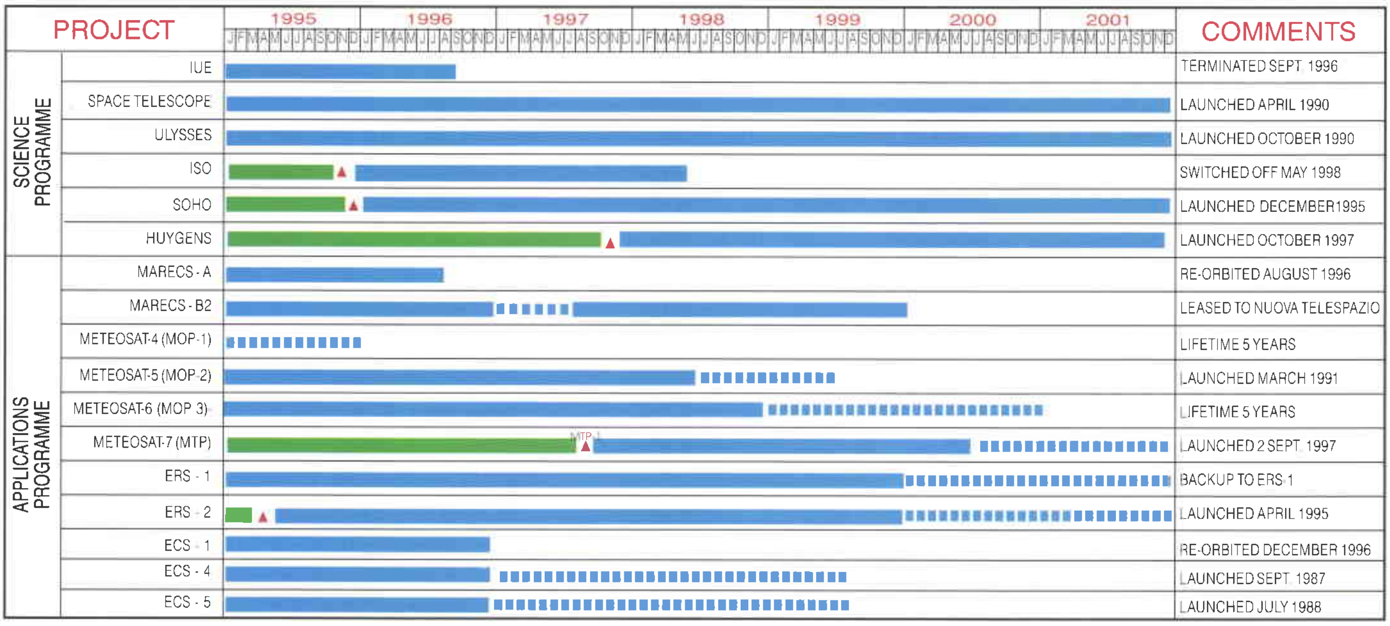

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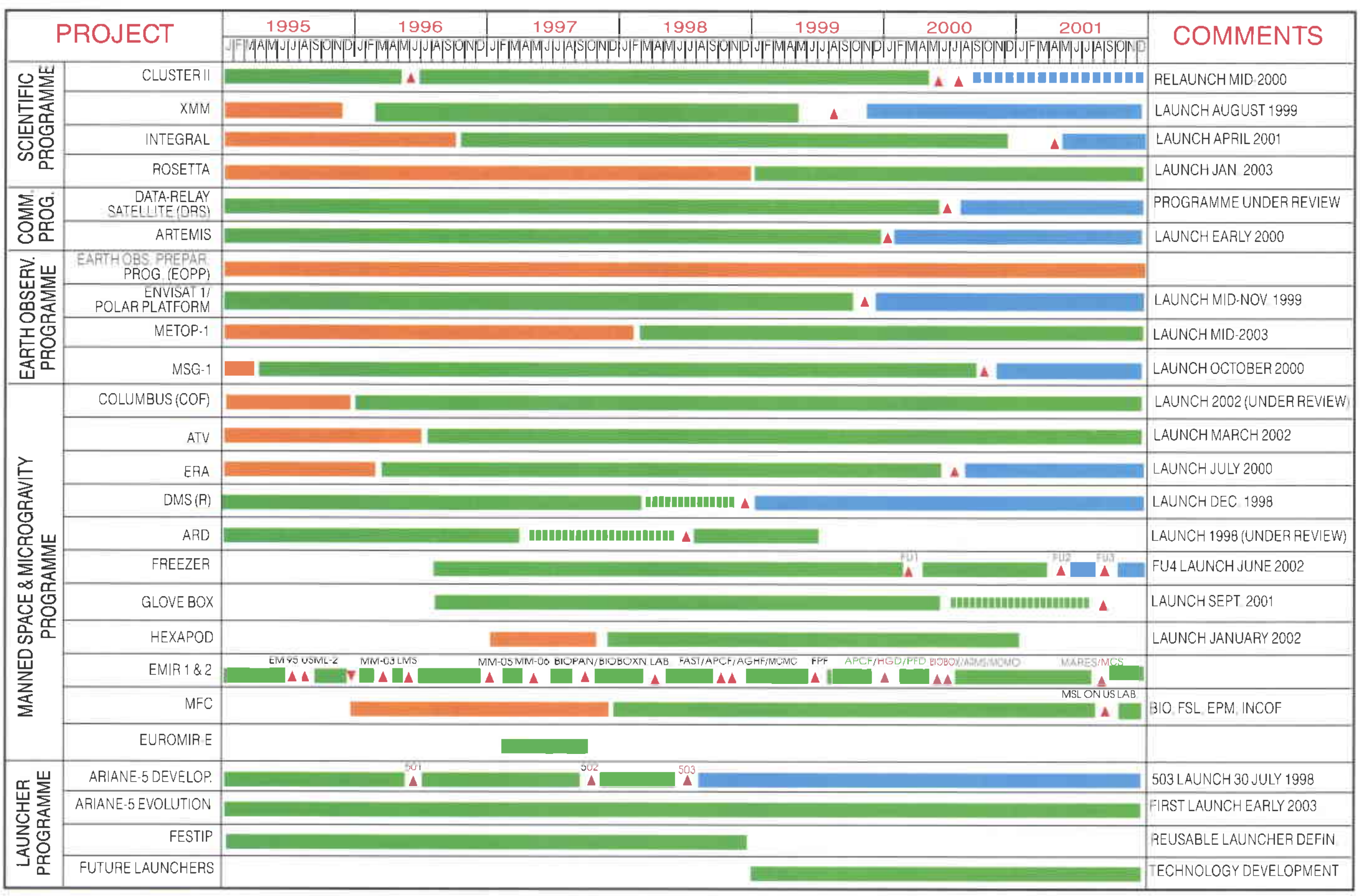


DEFINITION PHASE — MAIN DEVELOPMENT PHASE — LAUNCH/READY FOR LAUNCH

OPERATIONS — ADDITIONAL LIFE POSSIBLE — RETRIEVAL — STORAGE

Télescope spatial Hubble (HST)

L'observatoire HST vient d'entamer sa neuvième année en orbite. Son exploitation se poursuit de manière très efficace, sans problème majeur. La campagne d'observation à l'aide de l'instrument NICMOS (caméra dans le proche infrarouge et spectromètre à objets multiples), au cours de laquelle on a utilisé le miroir secondaire du télescope pour obtenir une mise au point optimale de la caméra n° 3, a été conduite avec succès en janvier. Une deuxième campagne sera bientôt programmée. La NASA envisage d'installer un cryorefroidisseur mécanique au cours de la prochaine mission de maintenance et de réparation (M&R), qui devrait permettre d'augmenter la durée de vie de l'instrument NICMOS avec toutefois des capacités réduites.

Les préparatifs de la prochaine mission M&R se poursuivent, malgré le report de la date de lancement de décembre 1999 à mars-mai 2000 en raison de problèmes liés au calendrier de la Navette. L'événement marquant de cette mission sera le remplacement de la caméra pour objets faiblement lumineux (FOC) de l'ESA par la caméra de technologie avancée pour observations astronomiques (ACS). Le Centre européen de coordination du télescope spatial (ECF) a été invité à participer à la mise au point du logiciel d'étalonnage pour les modes prisme à réseaux et polarimétrie de l'ACS.

Les négociations progressent en ce qui concerne la prolongation du mémorandum d'accord (MOU) ESA/NASA relatif au HST. La dernière réunion, qui a eu lieu les 21 et 22 avril, a débouché sur l'élaboration d'un projet d'accord, qui est actuellement examiné par les Directions de l'ESA et de la NASA.

Résultats scientifiques marquants

Parmi les nombreux résultats scientifiques marquants obtenus récemment, Hubble a fourni de nouvelles images de l'éjection de matière résultant de l'explosion de la supernova 1987A. L'autodestruction de cette étoile massive a été observée pour la première fois il y a environ 11 ans par des astronomes utilisant des télescopes basés à terre. La caméra planétaire à grand champ n° 2 (WFPC 2) et le spectrographe imageur du télescope spatial Hubble (STIS) ont montré que les débris issus de l'explosion de la supernova entrent en collision avec un anneau de matières présent autour de l'étoile en fin de vie. Cette collision provoque l'illumination de la partie de l'anneau qui s'était constitué avant l'explosion de l'étoile. Ce phénomène a permis aux chercheurs d'étudier la structure qui entoure la supernova et d'élucider certains aspects relatifs aux dernières années d'existence de l'étoile.

Ulysse

Le 17 avril, au terme d'un voyage de plus sept ans représentant 3,8 milliards de kilomètres, Ulysse a décrit sa première orbite autour du Soleil. L'ensemble des sous-systèmes et expériences placés à bord du satellite continue de fonctionner de manière extrêmement satisfaisante et la récente campagne MIDAS (étude multi-projets avec alignement de satellites), à laquelle ont participé Ulysse, SOHO, ACE et Wind, a été un grand succès et a permis d'obtenir une couverture quasi continue à haut débit sur une période de plusieurs semaines. Progressant lentement vers le sud sur sa trajectoire post-aphélie, Ulysse traversera le plan de l'ecliptique à la mi-mai, à une distance de 5,4 unités astronomiques du Soleil.

Résultats scientifiques marquants

Après une période de calme prolongée, deux importantes éruptions solaires ont eu lieu à intervalles rapprochés début novembre. Ces phénomènes, qui ont produit des perturbations interplanétaires significatives, ont fait l'objet d'un certain nombre d'études comparatives auxquelles ont participé Ulysse et la flotte des satellites évoluant à 1 UA, y compris SOHO. Alors que la réponse à l'activité solaire observée sur Terre se déroulait selon un schéma relativement bien établi, tant en ce qui concerne les particules à haute énergie émises par le Soleil à grande vitesse que les perturbations magnétiques, dont la vitesse de propagation est plus lente, les signatures enregistrées par Ulysse, qui ont été classées en fonction de leur distance radiale et de leur longitude par rapport à la Terre, étaient plus complexes. En étudiant ces phénomènes en détail, on espère mieux comprendre la structure globale des perturbations et leur influence sur le transport des particules. Les études de ce type, conduites avec plusieurs satellites, joueront un rôle de plus en plus important dans l'analyse des données d'Ulysse pendant le déroulement du cycle solaire.

Les chercheurs qui travaillent avec Ulysse se sont également penchés sur la question beaucoup plus vaste du confinement du rayonnement cosmique. En mesurant avec une haute précision la composition isotopique de l'aluminium et du chlore présents dans le rayonnement cosmique, le Professeur John Simpson et son équipe travaillant sur l'expérience COSPIN ont calculé que l'âge' du rayonnement cosmique était de 20 millions d'années, ce qui implique que les particules du rayonnement cosmique ont passé une part significative de leur durée de vie dans le halo galactique à faible densité.

Telles sont quelques-unes des nombreuses découvertes qui ont été évoquées à l'occasion des dernières réunions de l'équipe scientifique d'Ulysse et de la Société européenne de géophysique.

Huygens

Cassini/Huygens a connu sa première phase d'assistance gravitationnelle planétaire le 26 avril. Le véhicule spatial est passé à l'altitude prévue de 284 km au-dessus de la surface de Vénus à 15 h 52 mn 14 s TU. Deux instruments scientifiques ont été mis sous tension lors du survol de Vénus : le radar pour un essai de réflexion de signaux de bout en bout à la surface de Vénus et le sous-système de détection d'ondes radio et d'ondes de plasma afin de rechercher la présence d'éclairs dans l'atmosphère vénusienne. Les données enregistrées lors du survol ont été retransmises vers la Terre une semaine plus tard et sont en cours d'analyse.

Le deuxième contrôle en orbite de la sonde Huygens a été exécuté le 27 mars et les résultats de l'analyse préliminaire ont été passés en revue à l'ESOC le 17 avril. L'ensemble des sous-systèmes et instruments de la sonde ont fonctionné correctement. On a constaté certaines interférences sur les deux récepteurs

Hubble Space Telescope (HST)

The HST Observatory has recently completed its eighth year in orbit. Operations continue in a very efficient manner, with no major problems. The Near-Infrared Camera and Multi-Object Spectrometer (NICMOS) observing campaign, during which the telescope's secondary mirror was used to bring Camera 3 into best focus, was carried out successfully in January. A second campaign will be scheduled soon. NASA is considering installing a mechanical cryocooler during the next Maintenance and Repair (M&R) mission, which could extend the lifetime of the NICMOS instrument, albeit with reduced capabilities.

Preparations for the next M&R mission are proceeding, although the launch date has been moved back from December 1999 to March-May 2000 due to Shuttle scheduling problems. The main mission event will be the replacement of the ESA Faint Object Camera (FOC) by the Advanced Camera for Surveys (ACS). The ST European Coordination Facility (ECF) has been asked to participate in the development of the calibration software for the grism (i.e. grating-prism) and polarimetry modes of the ACS.

The negotiations for the extension of the HST ESA/NASA Memorandum of Understanding (MOU) are progressing. At the last meeting on 21-22 April, a draft agreement was prepared which is now under discussion within the ESA and NASA Executives.

Science highlights

Among the many recent scientific highlights, Hubble contributed new views of the expanding wave of material from the explosion of Supernova 1987A. The massive star's self-destruction was first seen nearly 11 years ago by astronomers using ground-based telescopes. Hubble's Wide Field and Planetary Camera 2 (WFPC 2) and the Space Telescope Imaging Spectrograph (STIS) have shown that debris from the supernova blast is slamming into a ring of material around the dying star. The collision has illuminated part of the ring, which had been formed before the star exploded. The crash has allowed scientists to probe the structure around the supernova and to uncover new clues about the final years of the progenitor star.

Ulysses

On 17 April, after travelling for more than seven years and covering 3.8 billion kilometres, Ulysses completed its first orbit of the Sun. All spacecraft subsystems and experiments continue to perform extremely well, and the recent MIDAS (Multi-project Investigation During Alignment of Spacecraft) campaign involving Ulysses, SOHO, ACE and Wind was very successful in obtaining near-continuous coverage at high bit rate over a period of several weeks. Moving slowly southward on its post-aphelion trajectory, Ulysses will cross the ecliptic in mid-May at a distance of 5.4 astronomical units from the Sun.

Science highlights

After an extended period of quiet solar conditions, two major solar flares occurred in quick succession at the beginning of November. These events, which produced significant interplanetary disturbances, have been the subject of a number of comparative studies involving Ulysses and the fleet of spacecraft at 1 AU, including SOHO. Although the response to the solar activity, both in the form of energetic particles arriving promptly from the Sun, and the more slowly propagating magnetic disturbances, followed relatively well-established patterns at the Earth, the signatures at Ulysses, which was separated in both radial distance and longitude from Earth, were more complex. By studying these effects in detail, it is hoped to gain a better understanding of the global structure of the disturbances and their influence on particle transport. Such multi-spacecraft studies will play an increasingly important role in the analysis of Ulysses data as the solar cycle develops.

Another topic addressed by Ulysses relates to the much larger scale issue of cosmic-ray confinement. By measuring the isotopic composition of cosmic-ray aluminium and chlorine with high precision, Prof. John Simpson and his co-workers on the COSPIN experiment have derived a cosmic ray "age" of 20 My, requiring that the cosmic-ray particles spend a significant fraction of their lifetime in the low-density galactic halo.

These and many other findings were reported at the recently held Ulysses Science Working Team and European Geophysical Society meetings.

Huygens

The first Cassini/Huygens planetary gravity-assist occurred on 26 April. The spacecraft flew at the planned altitude of 284 km over the Venusian surface at 15:52:14 UT. Two science instruments were switched on during the Venus flyby: the radar, for an end-to-end signal bounce test on the surface of Venus, and the Radio and Plasma Wave Subsystem, to search for lightning in the Venusian atmosphere. The flyby data were played back to Earth a week later and are currently being analysed.

The second Huygens Probe in-orbit checkout was conducted on 27 March and the results of the preliminary data analysis were reviewed at ESOC on 17 April. All of the Probe subsystems and instruments performed well. There was some noise interference on the two Huygens radio receivers, which is thought to relate to the need to point Cassini's High-Gain Antenna (HGA) towards the Sun to shade the spacecraft. Whilst it is acting as a sunshade during the voyage, the HGA also picks up the solar radio noise and feeds it to the Huygens receivers in parallel with the RF signal fed through the umbilical connection. Such a configuration will not apply during the Huygens mission phase at Saturn, as the HGA will then be pointed at Titan.

The Probe Engineering Model (EM) has been retrofitted by Industry and was delivered to the Huygens Probe Operations Centre (HPOC) at ESOC in Darmstadt (D) in February. The EM Probe Command and Data Management System (CDMS) is a replica, in both hardware and software terms, of the Flight Model configuration. It will serve as a test-bed during the 7-year cruise phase for validating any modifications to the in-orbit checkout sequences that may be required, and to validate possible on-board-software modifications. The EM Probe has been set up next to the Huygens Dedicated Control Room in ESOC and has already been used successfully in helping to debug the solar-noise interference by replicating the in-flight behaviour of the receivers.

radio de Huygens, qui sont probablement liées à la nécessité de pointer l'antenne à haut gain (HGA) de Cassini vers le Soleil afin de maintenir le véhicule spatial à l'ombre. Tout en agissant comme pare-soleil au cours du voyage, la HGA capte également le bruit radio du Soleil et l'envoie dans les récepteurs de Huygens parallèlement aux signal RF transmis par la connexion ombilicale. Cette configuration ne sera pas utilisée lors de la phase de la mission de Huygens à proximité de Saturne puisque la HGA sera alors pointée sur Titan.

Le modèle d'identification (EM) de la sonde a été mis à niveau par l'industrie et livré en février au Centre des opérations de la sonde Huygens (HPOC) à l'ESOC, Darmstadt (D). Le système de télécommande et de gestion des données (CDMS) du modèle d'identification de la sonde est une réplique de la configuration de vol, tant en ce qui concerne le matériel que le logiciel. Il servira de banc d'essai au cours de la phase de croisière de sept ans afin de valider toute modification qu'il conviendrait d'apporter aux séquences de vérification en orbite, ainsi qu'au logiciel embarqué. Le modèle d'identification a été installé à proximité de la salle de contrôle de l'ESOC destinée à Huygens et a déjà été utilisé avec succès pour résoudre le problème des interférences dues au bruit solaire en reproduisant le comportement en vol des récepteurs.

ISO

Les activités se concentrent actuellement sur le soutien de l'exploitation des données ISO par la communauté des astronomes et sur les préparatifs en vue du retraitement, de l'analyse et de l'interprétation des données, qui dureront 3 ans et demi et doivent aboutir à des archives définitives en 2001, dont les astronomes pourront faire usage pendant plusieurs décennies. Ces activités, auxquelles coopèrent cinq centres européens associés aux équipes qui ont réalisé les instruments embarqués, ainsi qu'un centre américain, sont coordonnées par le Centre des données ISO à Villafranca, (E). Le retraitement de l'intégralité des données scientifiques est sur le point de démarrer et la version initiale des archives devrait être accessible à l'automne. En outre, tout est mis en œuvre pour tirer profit des connaissances acquises par les personnes qui quittent le projet.

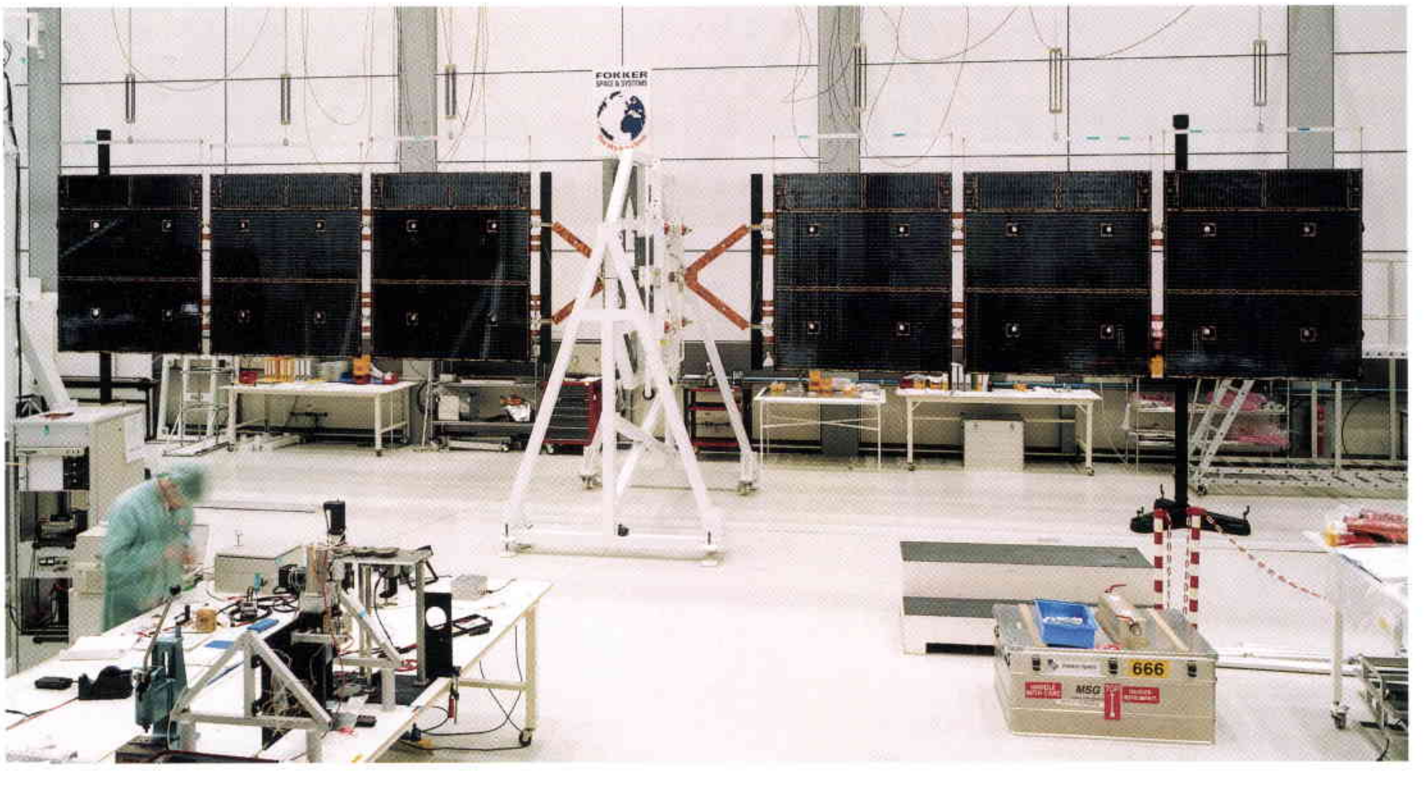
L'épuisement des réserves d'hélium liquide du véhicule spatial, qui assurait le refroidissement du télescope et des instruments scientifiques à une température proche du zéro absolu, a eu lieu le 8 avril. Cette date est postérieure de presque un an à celle qui avait prévue à l'origine et marque la fin de l'exploitation courante d'ISO, qui se solde par un grand succès.

Un programme d'essais technologiques a ensuite été conduit avec le satellite pendant environ un mois. Les résultats de ces essais bénéficieront aux futurs satellites de l'ESA comme XMM et Integral, qui reprendront certains de ses composants. Les activités conduites à cette occasion ont consisté notamment à tester le fonctionnement des suiveurs stellaires à basse altitude, c'est-à-dire dans les ceintures de radiations, à utiliser les unités redondantes de bord qui n'étaient pas nécessaires lors des opération de routine compte tenu des performances exceptionnelles du satellite et à évaluer le logiciel conçu pour remédier à différentes pannes de gyroscope.

Au cours des temps morts du programme, on a utilisé les détecteurs d'ondes les plus courtes de l'un des spectromètres, qui peuvent fonctionner à des températures allant jusqu'à 60 K, pour observer les spectres de 2,38 à 4,08 microns d'environ 300 étoiles afin d'établir un atlas de classification spectrale.

XMM's solar arrays in deployed configuration at Fokker Space & Systems (NL)

Générateur solaire de XMM en déploiement chez Fokker Space & Systems



ISO

Activities are now focussed on supporting exploitation of the ISO data by the astronomical community and on preparing for a 3.5-year long period of data re-processing, analysis and interpretation, with the aim of providing a final archive of data in 2001 that will be useful to astronomers for decades to come. This work is a collaborative effort, coordinated by the ISO Data Centre in Villafranca, Spain, and involving five European centres associated with the groups that built the on-board instruments, plus one in the USA. Full-scale reprocessing of all of the scientific data is about to start and the initial version of the archive is scheduled to open in the autumn. A major effort is also being made to capture the knowledge of the people leaving the project.

Depletion of the spacecraft's liquid-helium supply, responsible for cooling the telescope and scientific instruments to a temperature close to absolute zero, occurred on 8 April. This date was almost 1 year later than originally foreseen and brought to an end the highly successful ISO routine-phase operations.

For approximately the next month, a technology test programme was carried out with the spacecraft. Results from these tests will benefit future ESA spacecraft such as XMM and Integral, which use some of the same components. Activities included testing the operation of the star trackers at low altitudes, i.e. in the radiation belts, use of the on-board redundant units that were not needed during the routine operations due to the superb performance of the satellite, and evaluation of the software intended to overcome multiple gyro failures.

During any gaps in the test programme, the shortest wavelength detectors — which can operate at temperatures up to 60 K — of one of the spectrometers were used to observe the 2.38 – 4.08 micron spectra of nearly 300 stars in order to generate an atlas of classification spectra.

Two de-orbiting manoeuvres were carried out on 11 and 14 May, respectively, to lower the perigee from 1380 km to 715 km. At 11.00 UT on 16 May, a time-tagged command was used to isolate the batteries and at 12.00 UT another time-tagged command switched off the transmitter, thus ending the operational life of ISO.

Cluster-II

The manufacture of all subsystems is on schedule and they will be ready for the system integration of the first new Cluster-II spacecraft in the third quarter of 1998. The first structure has left Contraves (CH) and is currently at Matra Marconi Space in Bristol (UK) being integrated with the reaction-control subsystem. As regards the new equipment, a Critical Design Review has been held for the solid-state recorder and a Hardware Design Review for the high-power amplifier. Delivery of much flight equipment, such as antennas, valves, etc., has already taken place.

The payload rebuild is also progressing satisfactorily. Functional testing of the experiments comprising the Wave Experiment Consortium (WEC) has been successfully completed, demonstrating the validity of all software updates and the new elements needed due to the unavailability of the original processors and parts.

The technical contract with Starsem for assessing all mission-analysis aspects of the Soyuz launch has also been successfully completed and no show-stoppers were identified. A detailed review of the launch facilities at Baikonur has also confirmed that all of the Cluster-II launch operations constraints can be met.

As far as the ground segment and Cluster Science Data System (CSDS) are concerned, the maintenance/upgrade activities are going according to plan. It has been now decided that the Odenwald (D) ground station will be moved to Villafranca (E), where it will serve as the primary ground station for Cluster-II operations.

XMM

The test campaigns on the structural and thermal model and the engineering model have been completed. The service modules of both models have been delivered to Alenia (I) for use within the Integral project.

Integration of the flight satellite is in progress at Dornier (D), which has the task of finalising this step and delivering the flight satellite for testing by October of this year. In the meantime, the tests on the attitude and orbit control system are approaching completion at Matra Marconi Space in Bristol (UK). The elements of this subsystem are now being delivered to Dornier for final integration into the flight satellite.

Tests at Centre Spatial de Liège (CSL) continued with the acceptance-test sequence for the fourth mirror module, which showed excellent performance parameters. Activities are now concentrating on the combined testing of the mirror modules with their associated X-ray baffles and reflection gratings. At the Max Planck X-ray facility (PANTER) in Munich (D), calibration tests on the flight optics will continue until early July. To complete the validation of the stray-light behaviour of the complete optical chain, wide-angle stray-light tests were commenced in late June at MBB in Munich.

Efforts on the experiment side are concentrated on delivering the flight equipment as close as possible to the newly agreed dates. By the end of June, five of the seven instruments will be at Dornier. Pre-delivery instrument calibration is being done in Orsay (F) for the three EPIC cameras, and at the PANTER facilities in Munich for the RGS.

Delivery of the first version of the control software for the ground segment has taken place as foreseen. The ground-segment implementation is currently under review in order to accommodate the changes required.

Integral

At the end of May, a large shipment of flight-representative hardware arrived at ESTEC (NL), from Alenia's plant in Turin (I), for thermal testing in the Large Space Simulator (LSS). The shipment included Structural and Thermal Models (STMs) of the four instruments, of the payload module (developed specifically for Integral) and of the service module (re-used from the XMM programme). It also included ground-handling devices for the nearly 4 ton spacecraft. The industrial

Deux manœuvres de dégagement d'orbite ont été exécutées les 11 et 14 mai afin d'abaisser le périgée de 1380 km à 715 km. Le 16 mai à 11 h TU, une première télécommande programmée dans le temps a été utilisée pour isoler les batteries, puis une deuxième à 12 h TU pour mettre l'émetteur hors service, mettant ainsi fin à la vie opérationnelle d'ISO.

Cluster-II

Tous les sous-systèmes sont en cours de fabrication selon le calendrier prévu et seront prêts pour l'intégration système du premier des nouveaux satellites Cluster-II au troisième trimestre 1998. La première structure a quitté Contraves (CH) et est en cours d'intégration chez Matra Marconi Space à Bristol (R-U) avec le sous-système de commande par réaction. En ce qui concerne les nouveaux équipements, une revue critique de conception a été organisée pour l'enregistreur à semi-conducteurs, ainsi qu'une revue de conception du matériel pour l'amplificateur haute puissance. De nombreux équipements de vol, comme les antennes, les vannes, etc, ont déjà été livrés.

La reconstruction de la charge utile progresse également de manière satisfaisante. Les essais fonctionnels des expériences composant le groupe d'expériences sur les ondes (WEC) ont été concluants, ce qui prouve la validité de toutes les mises à jour de logiciels et des nouveaux éléments nécessaires pour remplacer les processeurs et composants d'origine non disponibles.

Le contrat technique conclu avec Starsem pour évaluer les aspects analyse de la mission du lancement Soyouz a également mené à bien et aucun écueil majeur n'a été relevé. En outre, une revue détaillée des installations de lancement de Baïkonour a confirmé que toutes les contraintes opérationnelles liées au lancement de Cluster-II pourvaient être respectées.

En ce qui concerne le secteur sol et le système d'accès aux données scientifiques de Cluster (CSDS), les activités de maintenance et de mise à niveau se déroulent comme prévu. Il a maintenant été décidé de transférer la station sol d'Odenwald (D) à Villafranca (E), où elle servira de station sol principale pour l'exploitation de Cluster-II.

XMM

Les campagnes d'essais conduites sur le modèle structurel et thermique et sur le modèle d'identification ont été menées à bien. Les modules de servitude de ces deux modèles ont été livrés à Alenia (I) pour être utilisés dans le cadre du projet Integral.

L'intégration du modèle de vol est en cours chez Dornier (D), qui est chargé de finaliser cette étape et de livrer le modèle de vol du satellite pour une série d'essais d'ici octobre prochain. Parallèlement, les essais du système de contrôle d'attitude et de correction d'orbite sont en voie d'achèvement chez Matra Marconi Space à Bristol (R-U). Les éléments de ce sous-système sont en cours de livraison chez Dornier pour intégration finale sur le modèle de vol du satellite.

Les essais conduits au Centre spatial de Liège (CSL) se poursuivent avec la série d'essais de recette du quatrième module miroir, qui ont révélé un excellent comportement. Les activités se concentrent maintenant sur l'essai combiné des modules miroirs et des écrans de protection contre les rayons X et des réseaux de diffraction qui leur sont associés. Des essais d'étalonnage de l'optique de vol se poursuivront jusque début juillet dans l'installation rayons X de l'Institut Max Planck (PANTER) à Munich (D). Afin d'achever la validation du comportement en lumière diffuse de l'ensemble de la chaîne optique, des essais en lumière parasite ont débuté fin juin à MBB, Munich.

En ce qui concerne les expériences, les efforts portent en priorité sur la fourniture des équipements de vol à des dates aussi proches que possible des nouveaux délais fixés. Fin juin, cinq des sept instruments auront été livrés chez Dornier. L'étalonnage des instruments avant la livraison est réalisé à Orsay (F) pour les trois caméras EPIC et dans les installations PANTER à Munich pour le RGS.

La première version du logiciel de contrôle du secteur sol a été livré dans les délais prévus. La mise en œuvre du secteur sol est en cours de réexamen afin de tenir compte des modifications nécessaires.

Intégral

Fin mai, un important lot de matériels représentatifs de la configuration de vol est arrivé à l'ESTEC (NL) en provenance de l'usine d'Alenia à Turin (I) pour subir des essais thermiques dans le grand simulateur spatial (LSS). Ce lot comprenait des modèles structurels et thermiques (STM) des quatre instruments, du module charge utile (réalisé spécialement pour Intégral) et du module de servitude (repris du programme XMM), ainsi que des équipements de manutention pour le satellite, dont le poids approche 4 tonnes. L'équipe industrielle a procédé rapidement à l'intégration du satellite pour qu'il puisse être placé dans les délais prévus à l'intérieur de la chambre du LSS, qui a été spécialement modifiée pour répondre aux exigences d'Intégral.

Il s'agit là d'une étape importante du programme après plusieurs années d'un travail minutieux sur les plans scientifique, technique et logistique. Elle l'est notamment pour les équipes chargées des instruments, qui ont eu à résoudre de délicats problèmes de développement, et pour le consortium industriel, qui a mené à bien la réutilisation du concept du SVM et du matériel du STM tous deux empruntés au programme XMM selon une méthode inédite de réduction des coûts.

Des travaux ont été conduits en parallèle sur d'autres aspects de la mission, l'événement le plus notable ayant été le choix d'une nouvelle orbite en cas de lancements sur Proton. Compte tenu des dernières découvertes sur la ceinture de rayonnements; on a calculé une nouvelle orbite permettant d'augmenter au maximum la durée de séjour du satellite à plus de 60 000 km au-dessus de la Terre. Cette nouvelle orbite conduit à une simplification des premières phases de vol au cours du lancement et à une réduction du nombre de stations sol nécessaire à la couverture de la mission. Le prochain cap sera l'intégration et la campagne d'essais du modèle d'identification/maquette électrique, dont les préparatifs sont en cours.

team rapidly integrated the spacecraft for its timely entry into the LSS chamber, which had been specially modified to meet Integral's requirements.

This milestone is a significant achievement for the programme after years of careful scientific, engineering and logistic effort. In particular, it is an accomplishment for the instrument teams facing difficult development issues and for the industrial consortium, which has successfully re-used the XMM SVM design and XMM STM hardware in an unprecedented cost-saving exercise.

Other aspects of the mission have been worked on in parallel, the most noteworthy event being the selection of a new orbit in the case of the Proton launch. Because of the latest findings on radiation background, a new orbit has been computed which maximises the time that the spacecraft spends more than 60 000 km above the Earth. This new orbit tends to simplify the first flight phases during launch and the number of ground stations required for coverage of the mission. The next challenge will be the engineering/elelectrical model integration and test campaign, for which preparations are in progress.

Rosetta

A major part of the project activities are still focussed on the selection of the equipment suppliers, which is making good progress. The Rosetta industrial consortium is expected to be fully consolidated before the summer break.

A continuous scrutiny of the spacecraft mass and power budgets has been implemented to ensure that the very tight constraints on launch mass and available power are met. Other critical technical issues requiring close attention are the sizing of the solar arrays and the spacecraft thermal-control design.

The Science Working Team discussed the Rosetta mission extensively in early May. A further optimisation of the comet dust and environment model has been presented and a new value of the comet nucleus' radius, based on recent astronomical observations, has been agreed. The scientific community also recommended selecting Otawara and Siwa as asteroid flyby targets instead of Mimistrobel and Rodari. This change is motivated by the high scientific interest in the Siwa asteroid, which is one of the largest and most primordial of such bodies.

The definition of the ground segment and procurement of the new 34 m antenna for installation at Perth, in W. Australia, is progressing as planned.

Artemis

Since its launch in March, the Silex optical terminal onboard Spot-4 has been thoroughly and successfully checked-out. This has included verifying correct operation of the terminal, ensuring its compatibility with the other Spot-4 instruments, and exercising its tracking performance using a series of stars. Silex will now remain dormant, except for periodic health checks, until the launch of Artemis.

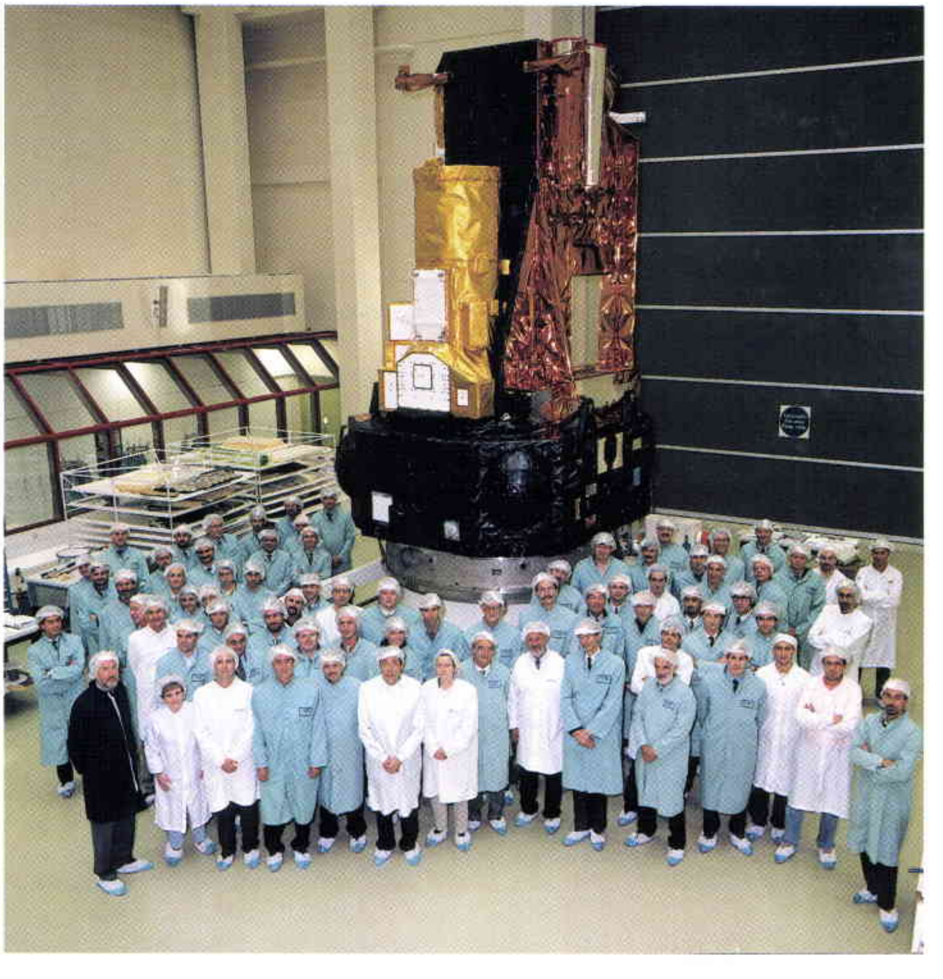
The Artemis satellite integration and initial electrical checkout has now been completed and the satellite will be shipped to ESTEC (NL) in mid-June 1998 for environmental testing.

Envisat/Polar Platform

Envisat-1 system

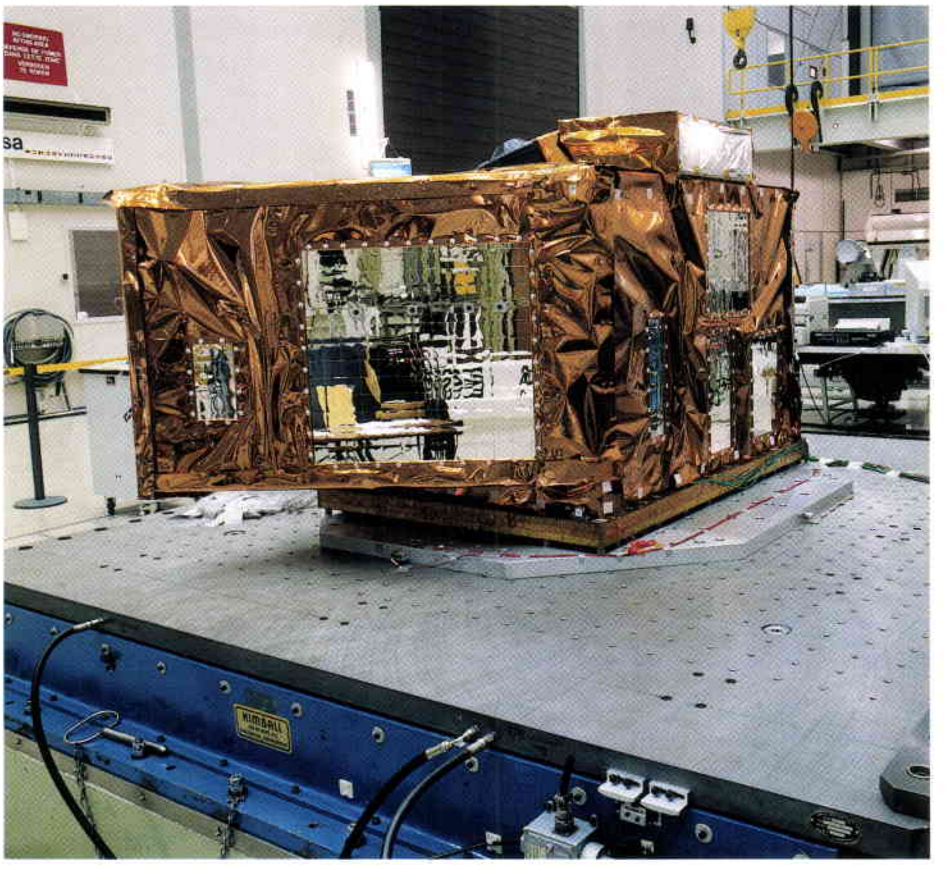
The Announcement of Opportunity (AO) for Scientific Data Exploitation and Pilot Projects has attracted very high interest in the Earth Observation user community, with more than 700 proposals having been submitted. The results of the selection process will be published before the end of the year.

System activities are now focusing on the preparations for system verification, in particular the ground-segment overall verification, and the preparations for the



Representatives of the Instrument, Industry and Project teams in front of the Integral Structural and Thermal Model at ESTEC (NL)

Le modèle structurel et thermique d'Intégral à l'ESTEC (NL) en présence de représentants de la communauté scientifique, de l'industrie et de l'équipe de projet



Flight model of Envisat's MERIS instrument undergoing vibration testing at ESTEC (NL)

Modèle de vol de l'instrument MERIS d'Envisat aux essais de vibrations à l'ESTEC

Rosetta

Une bonne part des activités de l'équipe de projet porte toujours sur la sélection des équipementiers, qui est en bonne voie. Le consortium industriel de Rosetta devrait être entièrement constitué avant les vacances d'été.

Un suivi continu des bilans de masse et de puissance du satellite a été mis en place pour garantir le respect des contraintes très strictes concernant la masse au lancement et la puissance disponible. Le dimensionnement des réseaux solaires et le concept de régulation thermique du satellite constituent d'autres points critiques sur le plan technique, qui exigent une attention particulière.

Le groupe de travail scientifique a procédé à un examen approfondi de la mission Rosetta début mai. Une nouvelle modélisation optimisée des jets de poussières et de l'environnement de la comète a été présentée et une nouvelle valeur a été adoptée pour le rayon du noyau de la comète sur la base des dernières observations astronomiques. Les chercheurs ont également recommandé de retenir Otawara et Siwa comme objectifs de survol d'astéroïdes au lieu de Ministrobel et Rodari. Cette modification est motivée par le grand intérêt scientifique que présente l'astéroïde Siwa, qui est l'un des plus gros et des plus primitifs parmi les corps célestes de ce type.

Le définition du secteur sol et l'approvisionnement de la nouvelle antenne de 34 m qui doit être installée à Perth (Australie occidentale), se déroulent comme prévu.

Artémis

Depuis son lancement en mars sur Spot-4, le terminal optique Silex a subi avec succès des essais complets : vérification du bon fonctionnement du terminal, de sa compatibilité avec les autres instruments du satellite, de sa fonction de suivi au moyen d'une série d'étoiles. Silex restera en mode 'veille', à l'exception de contrôles périodiques, jusqu'au lancement d'Artémis.

L'intégration du satellite et les premiers contrôles électriques sont achevés et Artémis a été expédié à l'ESTEC à la mi-juin 1998 pour y subir des essais d'ambiance.

Envisat/Plate-forme polaire

Système Envisat-1

L'Appel à propositions (AO) de projets pilotes et d'exploitation des données a suscité un grand intérêt parmi les utilisateurs de l'observation de la Terre qui ont envoyé plus de 700 propositions. Les résultats de la procédure de sélection seront publiés avant la fin de l'année.

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

Activités relatives au satellite

Le programme d'assemblage, d'intégration et d'essais (AIT) du modèle d'identification du satellite Envisat se poursuit, avec la réalisation de plusieurs essais fonctionnels du module de charge utile intégré selon des scénarios d'exploitation réalistes. Un test de pointage d'antenne en bande Ka a également été exécuté.

Les activités AIT sur le modèle de vol ont démarré après la livraison par DASA/DSS du modèle de vol du compartiment des équipements de charge utile (PEB) à Matra Marconi Space, (Bristol, R-U). L'intégration de la PEB sur la plate-forme a déjà commencé.

La question de la compatibilité avec Ariane-5 en ce qui concerne la résistance aux chocs reste préoccupante et plusieurs options sont actuellement à l'étude en vue de résoudre ce problème.

Charge utile Envisat-1

Le dernier modèle d'identification de l'antenne ASAR, un sous-système majeur, est en cours de livraison et doit être intégré au modèle d'identification du satellite. La plupart des modèles de vol 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 completion of several functional tests exercising the complete payload with realistic operating scenarios. A Ka-band antenna-pointing test has also been performed.

The flight-model AIT activities have started, following the delivery of the flight-model Payload Equipment Bay (PEB) by DASA/DSS to Matra Marconi Space in Bristol (UK). Integration of the PEB onto the payload carrier has already started.

The issue of shock compatibility with Ariane-5 remains a concern and several possible options are under investigation to resolve the problem.

Envisat-1 payload
The last major engineering-model instrument subsystem, the ASAR antenna, is being delivered for integration into the satellite engineering model. Most flight-model instruments are in the final instrument integration and testing phase. The assembly and testing of the ASAR antenna flight-model tiles is progressing well, and the antenna's flight-model structure is undergoing final testing and will soon be ready to be equipped with the flight-model radiating tiles.

The DORIS/MWR flight-model composite has been delivered, after a successful hardware status review. A mechanical vibration problem has been identified in the focal-plane assembly of the AATSR flight model and detailed investigations are in progress.

Envisat-1 ground segment
Integration of the Payload Data Segment (PDS) facilities is continuing on the reference platform at Datamat in Rome (I). The PDS Test Readiness Review is planned for end-June 1998.

The 13-m antenna of the User Earth Terminal for the reception of payload data via the Artemis data-relay satellite has been installed at ESRIN in Frascati (I). The Flight Operation Segment (FOS) development and integration effort is progressing according to plan, the next major milestone being the Satellite Verification Test 1 planned for the end of 1998.

Meteosat

Meteosat operations
The operational service was transferred to Meteosat-7 (launched in September 1997) on 3 June and, all being well, it should continue to function in that role until the launch of the Meteosat Second Generation spacecraft early in the next decade.

Meteosat Second Generation
The satellite structural and thermal model has successfully passed its thermal testing in the Large Space Simulator (LSS) chamber at ESTEC (NL). The accompanying photograph shows the model whilst still at Aerospatiale in Cannes (F) during the last assembly and integration activities. The black, white and grey 'dots' on the spacecraft's skin are structurally and thermally representative dummy solar cells, needed to simulate its thermal behaviour.

Critical Design Reviews (CDRs) at equipment and subsystem level are continuing, releasing more flight hardware for manufacture. A CDR at system level is planned for October 1998.

The development of the MSG-1 spacecraft and the procurement of MSG-2 and -3 are on schedule, with engineering-model and some flight-model production in progress at equipment and subsystem level. The SEVIRI instrument for the first flight model remains on a critical path.

The launch of MSG-1 remains on schedule for October 2000, with MSG-2 to be launched in 2002 and MSG-3 to go into storage in 2003.

Metop

Following the kick-off of the main development-phase (Phase-C/D) activities in February, an orderly startup of the Metop industrial consortium, which consists of some 50 companies (45 of which have already started work) covering some 96 distinct contractual elements, has been achieved.

The release of the Invitations to Tender for the remaining elements of the single space segment, namely the GRAS and GOME-2 instruments, is now in progress. A preparatory phase for the latter, a modified and upgraded version of the instrument flown on ERS-2, is also underway.

The main thrust of the activities at satellite system level is focussed on the consolidation of the satellite design and the freezing of its configuration. A major effort is being undertaken to finalise the interface documentation with the customer-furnished instruments. At subsystem and equipment level, the detailed design phase is in full swing. These activities will lead to lower-tier design consolidation reviews, culminating in the Preliminary Design Review scheduled for mid-1999.

MSG-1 structural and thermal model during integration at Aérospatiale in Cannes (F)

Modèle structurel/thermique du MSG-1 en cours d'intégration chez Aérospatiale à Cannes *des instruments ont atteint la phase finale d'intégration et d'essai. L'assemblage et les essais des modèles de vol des tuiles de l'antenne ASAR se poursuivent correctement et le modèle de vol de la structure de l'antenne subit actuellement les derniers essais ; il pourra bientôt être équipé des modèles de vol des tuiles.*

Le modèle de l'ensemble DORIS/MWR a été livré après la revue d'état du matériel. On recherche actuellement les causes des vibrations mécaniques détectées dans l'ensemble au plan focal du modèle de vol de l'AATSR.

Secteur sol Envisat-1

L'intégration des moyens du système de gestion des données de charge utile (PDS) se poursuit sur la plate-forme de référence chez Datamat à Rome. La revue d'aptitude au test du PDS devait avoir lieu fin juin 1998.

L'antenne de 13 m du terminal terrien d'utilisateur utilisé pour la réception des données de charge utile via le satellite de relais de donnés Artemis a été installée à l'ESRIN (Frascati, Italie).

Les travaux de développement et d'intégration du secteur des opérations en vol (FOS) se poursuivent conformément au calendrier ; la grande étape suivante, le test 1 de vérification du satellite, est prévue pour fin 1998.

Météosat

Exploitations de Météosat

Le service opérationnel a été transféré le 3 juin sur Météosat (lancé en septembre 1997) et devrait être assuré, si tout va bien, jusqu'au lancement du premier satellite Météosat de deuxième génération au début de la prochaine décennie.

Météosat de deuxième génération (MSG)

Le modèle structurel et thermique du satellite a subi avec succès ses essais thermiques dans le grand simulateur spatial (LSS) de l'ESTEC. On voit ici le modèle du satellite en cours d'assemblage et d'intégration chez Aérospatiale à Cannes. Les points noirs, blancs et gris à la surface du satellite sont des cellules solaires fictives, représentatives sur le plan structurel et thermique, qui sont nécessaires pour simuler le comportement thermique du satellite.

Les revues critiques de conception (CDR) au niveau des équipements et des sous-systèmes se poursuivent et s'accompagnent de nouvelles autorisations de fabrication du matériel de vol. Une revue CDR au niveau système est prévue en octobre 1998.

Les travaux de développement du satellite MSG-1 et l'approvisionnement des unités MSG-2 et -3 se poursuivent conformément au calendrier ; la production du modèle d'identification et d'une partie du modèle de vol est en cours au niveau des équipements et des sous-systèmes. Le SEVIRI du premier modèle de vol demeure sur le chemin critique.

Le lancement du MSG-1 est toujours prévu pour octobre 2000, et celui de MSG-2 en 2002, MSG-3 étant mis en stockage en 2003.

Métop

Après le démarrage de la principale phase de développement (Phase C/D) en février, le consortium industriel Métop, qui se compose de quelque 50 sociétés (dont 45 ont déjà commencé à travailler) réalisant 96 éléments contractuels distincts, est entré en activité.

Les appels d'offres pour les autres éléments du secteur spatial unique, à savoir les instruments GRAS et GOME-2, sont en cours de diffuson. Ce dernier instrument, qui est une version modifiée et mise à hauteur de l'instrument embarqué sur ERS-2, fait l'objet d'une phase préparatoire.

Au niveau système du satellite, les travaux sont concentrés sur la consolidation de la conception du satellite et sur le choix définitif de sa configuration. Un gros effort est entrepris pour compléter la documentation relative aux interfaces avec les instruments fournis par le client.

La phase de conception détaillée, au niveau des sous-systèmes et des équipements, est en cours d'exécution. Ces activités conduiront aux revues de consolidation de la conception des sous-traitants, pour culminer lors de la revue de conception préliminaire prévue pour la mi-1999.

Pour ce qui est des aspects programmatiques, les activités industrielles se déroulent avec le financement limité autorisé par les délégués en janvier qui a permis le démarrage des travaux mais qui sera épuisé en septembre. La poursuite du programme EPS/Metop dépend donc des résultats de la réunion du Conseil d'Eumetsat de juillet. Les délégués à Eumetsat doivent également approuver l'approvisionnement de l'instrument IASI qui doit être mis au point par le CNES grâce à un cofinancement d'Eumetsat, faute de quoi le calendrier de Metop-1 se trouvera touché.

La souscription de l'Espagne au programme Métop-1 a été confirmée en mai, complétant ainsi la participation anticipée dans le programme de l'ESA, qui n'attend plus maintenant que l'approbation du programme EPS Eumetsat pour être lancé.

ERS

Après plus de trois ans d'exploitation, les performances techniques d'ERS-2 restent très bonnes. La charge utile continue de fournir d'excellentes données tant sur le plan de la qualité que sur celui de la disponibilité. Le 3 juin, la mission a cependant interrompue pendant trois jours suite à une défaillance de gyroscope qui a perturbé le pointage du satellite. Pour des raisons de sécurité, la charge utile a été automatiquement mise hors tension ; après une analyse détaillée de la situation et des mesures de récupération, la mission a repris avec la même qualité de données.

ERS-1 est en hibernation et les vérifications périodiques montrent que les performances de la charge utile sont préservées. Après la défaillance de panneaux solaires précédente, l'énergie disponible pour l'exploitation de la charge utile dépend des saisons, le minimum étant atteint au moment du solstice d'été. On procède actuellement à des essais complexes pour déterminer les capacités de fonctionnement maximales et minimales de chaque instrument. Il est évident que l'altimètre radar, l'AMI et l'ATSR ne peuvent plus fonctionner en parallèle ; en fonction de l'époque de

On the programmatic side, the industrial activities are running under the limited funding authorised by Delegations in January. This funding has permitted the full start-up of the work, but runs out in September. The outcome of the forthcoming Eumetsat Council meeting in July is therefore crucial to the orderly continuation of the EPS/Metop programme. The Eumetsat delegates must also approve procurement of the IASI instrument to be developed by CNES with Eumetsat co-funding, otherwise the Metop-1 schedule will be impacted.

Spain's subscription to Metop-1 was confirmed in May, completing the anticipated participation in the ESA programme, which now only awaits the approval of the Eumetsat EPS programme in order to enter fully into force.

ERS

After more than three years of spacecraft operations, the technical performance of ERS-2 remains very high. The payload continues to provide excellent data in terms of both quality and availability. On 3 June, the mission was however interrupted for 3 days due to a gyro failure that affected spacecraft pointing. The payload was automatically switched-off for safety reasons, but after a careful analysis and subsequent recovery actions, the mission was resumed with the same data quality.

ERS-1 is in hibernation, but the periodic check-outs show that its payload performance is also being maintained. After the earlier solar-array failure, the power available for payload operation is season-dependent, reaching a minimum at summer solstice. Careful tests are being performed to determine the minimum and maximum operating capabilities for each instrument. It is clear that the Radar Altimeter, Active Microwave Instrument and Along-Track Scanning Radiometer can no longer be operated in parallel and, depending on the time of year, operations have to be further de-scoped. SAR imaging is also restricted, but interferometry with the ERS-2 SAR is still possible, and consequently the ERS-1/2 SAR interferometry campaign is continuing with one or two image pairs per day.

International Space Station Programme

ISS overall assembly sequence

Revision-D of the assembly sequence was baselined by the Space Station Control Board (SSCB) at the end of May. This revision introduces slippages of one to six months in key programme elements — e.g. First Element Launch, Russian Service Module, Three Persons Permanent Presence Capability, Last Element Launch — as well as in the dates associated with the launches of various ESA contributions. The changed launch dates for the COF (slippage from October 2002 to February 2003) and for Flight 17A, which were proposed by NASA just prior to the SSCB meeting are still being discussed. For each of the elements under its responsibility, ESA will assess the most cost-effective trade-offs between the various delivery-date options and the slipped launch dates.

Columbus Laboratory (COF)

Another round of interface meetings with NASA has been completed, resulting in the complete definition of Module to Hatch, Common Berthing Mechanism interfaces, and advances in the interface definition with the overall Space Station, the International Standard Payload Racks (ISPRS) and the Space Vision System. Technical discussions in the power/EMC field have led to a better understanding of the Station's overall power stability, and the first joint ESA/NASA test on the power interface has been successfully conducted.

Industry has been authorised to proceed with the implementation of an External Payload Facility. This facility will provide users with four adapters similar to those of the ISS Express Pallet and will be managed by the COF system in a similar manner to the ISPRS. A design and verification solution to the fire-detection problem identified during the System Preliminary Design Review (PDR) has been agreed. The in-orbit dynamic mathematical models were delivered to NASA at the end of March.

The Meteoroid and Debris Protection System panels have been tested up to impact velocities of 7 km/sec. The Laboratory water loop has passed its first closed-loop control test. Primary structure manufacturing is underway, and a number of equipment Critical Design Reviews (CDRs) have been conducted. The system Electrical Ground-Support Equipment (EGSE) has passed its CDR and is currently in qualification testing.

COF launch barter

A second design review has recently been completed, looking at the functional architecture of Nodes 2 and 3. Agreement (between ASI and NASA) on to how to fund these significant changes is close, one result being that the industrial return to Member States will be increased by about 20 MECU due to the replacement of former US equipment purchases. A number of proposed interface changes have arisen, some of which affect the Columbus Laboratory. The Engineering Support personnel have continued their work in Houston in the context of Software Deliveries/DMS-R items/Associated Sustaining Engineering for NASA.

Cupola 1 and 2

Following an 'Agreement in Principle' with NASA, ESA will produce two Cupolas for the ISS in exchange for the up/down transportation of 5 Express Pallet-type external payloads. The technical specifications for the Cupolas have been agreed with NASA and the RFQ has been released to Industry, following approval by ESA's industrial Policy Committee (IPC) of the Procurement Proposal.

Automated Transfer Vehicle (ATV)

A high-level management meeting regarding the Phase-C/D proposal and SRR-2 Recovery Plan took place on 12 March, with Aerospatiale, DASA-RI and ESA participating. Commitments were made by both companies and subsequently confirmed in writing, and fully revalidated proposals based on those commitments were delivered early in May. It is planned to submit the ATV Contract Proposal to the IPC in June. Considering the positive results achieved so far and the criticality of the Phase-C/D planning, the Executive released a Preliminary Authorisation to Proceed (PATP) in early April.

The technical and programmatic contents of an ESA/RSA barter between ATV integration (RSA/RSC-Energia) and DMS-R sustaining-engineering activities (ESA/DASA-RI) have been established. The target is agreement on this barter before the end of June 1998 but, as feared, significant difficulties relating *l'année, les opérations doivent donc être revues à la baisse. La fonction d'imageur du SAR est également limitée mais l'interférométrie avec le SAR d'ERS-2 reste possible. En conséquence, la campagne d'interférométrie SAR d'ERS-1/2 se poursuit avec une ou deux paires d'images par jour.*

Programme de Station spatiale internationale

Séquence d'assemblage de l'ISS

La Révision-D de la séquence d'assemblage a été préparée par la Commission de contrôle de la Station spatiale (SSCB) fin mai. Elle fait apparaître des décalages de un à six mois pour les éléments clé du programme, comme le lancement du premier élément, le module de service russe, la présence permanente de trois membres d'équipage, le lancement du dernier élément, ainsi que dans les dates associées aux lancements des divers contributions de l'ESA. Les dates de lancement modifiées du COF (dérapage d'octobre 2002 à février 2003) et du vol 17A qui ont été proposées par la NASA juste avant la réunion de la SSCB font toujours l'objet d'un examen. Pour chacun des éléments dont elle est responsable, l'ESA évaluera les meilleurs compromis sur le plan de la rentabilité entre les diverses dates de livraison possibles et les dates de lancement modifiées.

Elément orbital Columbus (COF)

La série de réunions sur les interfaces avec la NASA a été menée à bon terme et toutes les interfaces module-écoutille, mécanisme commun d'accostage, ont été définies et on a progressé dans la définition des interfaces avec l'ensemble de la Station spatiale, les ISPR et le système spatial. Les discussions techniques dans le domaine de l'énergie/EMC ont conduit à une meilleure compréhension du problème global de stabilité d'énergie de la Station et le premier essai conjoint ESA/NASA sur l'interface de puissance a été mené à bon terme.

L'industrie a été autorisée à poursuivre ses travaux de mise en œuvre d'une installation de charge utile externe qui mettra à la disposition des utilisateurs quatre adaptateurs similaires à ceux de la palette expresse ISS et qui seront gérés par le système COF selon une méthode similaire à celle des ISPR. Lors de la revue de conception préliminaire du système, les participants se sont mis d'accord sur une solution de conception et vérification du projet de détection d'incendie. Les modèles mathématiques dynamiques en orbite ont été remis à la NASA fin mars.

Les panneaux du système de protection contre les météorites et les débris ont été testé jusqu'à des vitesse d'impact de 7 km/sec. Le circuit d'eau du laboratoire a subi son premier test de contrôle en circuit fermé. La structure principale est en cours de fabrication et on a procédé à un certain nombre de revues de conception critique des équipements (CDR). L'équipement électrique de soutien sol du système (EGSE) a passé avec succès le cap de sa CDR et est en cours de test de qualification.

Compensation du lancement du COF

Une seconde revue de conception a été récemment menée à bon terme ; elle se concentrait sur l'architecture fonctionnelles des éléments de jonction 2 et 3. L'accord (entre l'Asie et la NASA) sur le mode de financement de ces modifications importantes est clos, l'un des résultats étant que le retour industriel aux Etats membres sera augmenté d'environ 20 MECU grâce au remplacement de précédents achats d'équipements américains. Un certain nombre de modifications d'interfaces proposées ont été apportées dont certaines touchent le laboratoire Columbus. Le personnel chargé du soutien technique a poursuivi ses travaux à Houston dans le contexte des fournitures de logiciels/éléments DMS-R/ Ingénierie de soutien associée pour la NASA.

Coupoles 1 et 2

Suite à un 'accord de principe' avec la NASA, l'ESA fabriquera deux coupoles pour l'ISS en échange de l'acheminement, dans les deux sens, de 5 charges utiles externes de type Palette Express. Les spécifications techniques des Coupoles ont fait l'objet d'un accord avec la NASA et la demande de prix a été diffusée à l'industrie après que le Comité de la Politique industrielle de l'ESA (IPC) ait approuvé la proposition d'approvisionnement.

Véhicule de transfert automatique (ATV)

Le 12 mars, Aérospatiale, DASA-RI et l'ESA se sont réunis pour étudier, à un niveau élevé, la proposition de phase C/D et le plan de récupération SRR-2. Les deux sociétés se sont engagées et on ensuite confirmé par écrit et des propositions entièrement revalidées basées sur ces engagements ont diffusé début mai. On envisage de présenter la proposition de contrat de l'ATV à la réunion de l'IPC en juin. Vu les résultats positifs obtenus jusqu'à présent et le caractère critique du planning de la phase C/D, l'Exécutif a diffusé une autorisation préliminaire d'engagement des travaux (PATP) début avril.

Le contenu technique et programmatique d'un accord de compensation ESA/RKA entre l'intégration de l'ATV (RKA/RSC-Energia) et les activités de soutien technique du DMS-R (ESA/DASA-RI) a été défini. Il s'agit d'obtenir un accord sur cette compensation avant la fin juin 1998 mais, comme on le craint, des signes évidents de difficultés se sont manifestés lors de la réunion de niveau 1 ESA/RKA tenue à Moscou le 6 mai, notamment

Coopération relative au véhicule de transfert d'équipage/X-38

Suite à l'autorisation d'engagement du nouveau Programme de technologie de rentrée appliquée (ART), la réorientation proprement dite du contrat existant venant en soutien de la coopération ESA/NASA relative au X-38 se poursuit comme prévu.

Lors d'une réunion avec le responsable du projet X-38 de la NASA et le Bureau des partenaires internationaux de l'ISS au Johnson Space Center en février, la NASA a déclaré qu'elle souhaitait élargir au programme CRV la coopération actuelle relative au programme X-38 comme en témoigne une liste d'activités potentielles relatives que l'industrie européenne pourrait entreprendre dans les domaines du X-38 et du CRV.

Démonstrateur de rentrée atmosphérique (ARD)

La recette définitive du secteur spatial de l'ARD a eu lieu à Bordeaux (F) à la mi-mai; elle a été suivie par une cérémonie de présentation de l'ARD qui devait être expédié à Kourou début juin avec la case à équipements d'Ariane-503.

particularly to the notion of partnership and respective responsibilities were evident in an ESA/RSA Level-1 meeting held in Moscow on 6 May.

Crew Transfer Vehicle / X-38 cooperation
Following authorisation to start the new Applied Reentry Technology (ART) programme, the full reorientation of the existing contract in support of the ESA/NASA cooperation on X-38 is proceeding as planned.

During a meeting with the NASA X-38 Project Manager and the ISS International Partners Office at Johnson Space Center in February, NASA's interest in extending the present cooperation on the X-38 programme to the CRV programme was confirmed and is reflected in an agreed list of potential X-38/CRV activities for European industry.

Atmospheric Reentry Demonstrator (ARD)
The final ARD flight-segment acceptance took place successfully in Bordeaux (F) in mid-May, and was followed by a roll-out ceremony. The ARD will be shipped to Kourou in early June, together with the Ariane-503 Vehicle Equipment Bay.

Ground segment development & operations preparation
As a contribution to the ATV proposal recovery activities, ESA has strongly supported Aerospatiale in the production of the ATV Operations Reference Concept. The ATV Cargo Accommodation Working Group charged with the selection of a secondary structure concept and to the refinement of the related System Requirements Document (SRD) has completed its work.

The Flight Automated Procedures (FLAPS) Software Product Requirements Review for the COF has been conducted and work has started on development of the flight displays. NASA has released a version of the Display and Graphics Commonality Standard (DGCS) for review by the International Partners.

The definition study of the COF/ATV Operations Support Functions and Facilities continues to experience serious delays. Efforts continue to achieve agreement with ASI on a reasonable Implementation Plan.

Utilisation
Promotion
Concerning the later phases of Space Station utilisation, studies are in preparation for space-science and Earth-observation facilities, namely a Large X-ray Facility and a Wind Lidar Facility, respectively. In response to an Invitation to Tender (ITT) issued for a feasibility study of assembling an X-ray facility at the Space Station, three industrial offers were received and evaluated. Likewise, two proposals have been received for the accommodation of the Wind Lidar Facility on Space Station. Contract proposals for both studies were submitted to the May IPC, which approved the Large X-ray Facility.

Within the Microgravity Applications Promotion Programme, the Osteoporosis Project with MEDES entered its second phase. For the Advanced Combustion Research Project, the University of Orleans was joined by ZARM (Bremen, D) and two topical team activities were initiated. The Manned Space Programme Board endorsed the Atomic Clock Ensemble in Space (ACES) project, including the development of a microwave link to support time and frequency transfer.

Preparation
The procurement proposal to initiate the industrial integration contract for the pressurised payloads launched with the COF was approved by the IPC at its meeting on 12/13 May. Work has continued with an industrial consolidation study of the accommodation of payloads for the five Express Pallet Adapters, which have been approved for fight in the framework of the Early Opportunity Agreements with NASA. The five payloads selected are: ACES (Atomic Clock Ensemble in Space, consisting of three Physical Science Instruments), FOCUS (an instrument for forest-fire detection), SOLAR (three solar-science instruments mounted on a Coarse Pointing Device), SPORT (Sky Polarisation Observatory — a space-science instrument), and TEF (Technology Exposure Facility — a modular facility accommodating various technology and environmental-monitoring experiments and instruments).

Discussions continued regarding the provision by ESA to NASA of two Cupola flight models in return for the barter offset of the launch and return costs of the payloads for these external adapters.

The Space Station User Panel (SSUP) met on 25/26 March and reviewed the present situation regarding the promotion of application-oriented utilisation of Space Station. In order to stimulate wider interest in sciences and applications on the Space Station and to allow for cross-disciplinary proposals, the SSUP recommended that there should be a single European Space Station Announcement of Opportunities (AO), rather than facility-specific AOs.

Planning progressed for the second Space Station Utilisation Symposium at ESTEC in November 1998. Planning and definition activities were started for a Space Station Utilisation Information Centre, to be established at ESTEC (NL).

Hardware development
The ongoing Critical Design Reviews (CDR) for the -80 deg C Freezer (MELFI) and the Microgravity Science Glovebox (MSG) will be completed in June/July. The International Standard Payload Rack (ISPR) procurement effort is on schedule. The first 5 flight models of the 12 ISPRs which had been bartered with Japan were accepted and delivered to Europe in February. The remaining 7 will arrive in 1999.

Following approval of the contract proposal by the IPC in May, the contract for the development of the European Drawer Rack (EDR) has been awarded to a consortium led by Alenia (I).

The Preliminary Design Review for the Hexapod pointing system is planned for October 1998. Delivery of the flight unit to NASA is scheduled for January 2001, for launch on UF-4 in January 2002. Prior to the start of Phase-C/D, a short consolidation phase for the Coarse Pointing Device was initiated to take into account the Pallet Adapter configurations selected.

The developments of the Standard Payload Outfitting Equipment SPLC, RPDA and AAA are proceeding as planned, and engineering models will be delivered in the first half of 1998.

Astronaut activities
In March, the ESA Council approved a Resolution (see ESA Bulletin No. 94, page

Développement du secteur sol et préparation des opérations

L'ESA, dans le cadre de sa contribution aux activités de reprise de la proposition relative à l'ATV, a apporté un vif soutien à Aerospatiale qui travaille sur le concept de référence des opérations de l'ATV. Le Groupe de travail sur l'installation du fret à bord de l'ATV chargé de choisir un concept de structure secondaire et d'affiner le document des impératifs système correspondant a terminé ses travaux.

La revue des impératifs du logiciel des procédures automatiques de vol (FLAPS) du COF a été menée à bien et les travaux de développement des affichages de vol a commencé. La NASA a publié une version de la norme sur les communités entre les affichages et les graphiques (DGCS) que doivent examiner les partenaires internationaux.

L'étude de définition des installations et des fonctions de soutien des opérations du COF/ATV continue à subir de graves retards. Les efforts se poursuivent en vue de parvenir à un accord avec l'ASI sur un plan de mise en œuvre raisonnable.

Utilisation

Promotion de l'utilisation

En ce qui concerne l'utilisation ultérieure de la Station spatiale, des études sur des installations de science spatiale et d'observation de la Terre, respectivement une grande installation d'observation dans le rayonnement X et un Lidar vents sont en cours d'exécution. En réponse à un appel d'offres lancé pour une étude de faisabilité relative à l'assemblage d'une installation d'observation dans le rayonnement X sur la Station spatiale, l'Exécutif a reçu et évalué trois offres d'industriels. Il a également reçu deux propositions portant sur l'installation du Lidar vents sur la Station spatiale. Des propositions de contrats pour ces deux études ont été présentées à l'IPC réuni au mois de mai, qui a approuvé l'installation d'observation dans le rayonnement X.

Dans le cadre du Programme de Promotion des applications de la microgravité, le projet Ostéoporose avec MEDES est entré dans sa deuxième phase. Quant au projet de recherche de pointe sur la combustion, l'Université d'Orléans a reçu le concours de ZARM (Brême, D) et deux activités spécialisées ont été engagées. Le Conseil directeur des programmes spatiaux habités a adopté le projet ACES (horloge atomique pour l'espace), y compris le développement d'une liaison hyperfréquences pour le transfert du signal d'horloge et de la fréquence.

Préparation de l'utilisation

Lors de sa réunion des 12 et 13 mai, l'IPC a approuvé la proposition d'approvisionnement portant sur le démarrage du contrat d'intégration par l'industrie des charges utiles pressurisées lancées avec le COF. Les travaux se sont poursuivis avec une étude de consolidation par l'industrie de l'installation des charges utiles pour les cinq adaptateurs de Palletes Express qui ont été approuvés et qui doivent être embarqués dans le cadre des accords d'utilisation initiale avec la NASA. Les cinq charges utiles sélectionnées sont les suivantes : ACES (Horloge atomique pour l'espace, qui se compose de trois instruments de recherche en science physique), FOCUS (instrument pour la détection des incendies de forêt), SOLAR (trois instruments de recherche en science solaire montés sur un dispositif de pointage grossier), SPORT (observatoire de polarisation du Soleil, qui est un instrument de science spatiale) et TEF (installation d'exposition au milieu spatial pour les recherches technologiques, installation modulaire acceptant plusieurs instruments et expériences de surveillance de l'environnement et de la technologie).

Des discussions se sont poursuivies en ce qui concerne la fourniture par l'ESA à la NASA de deux modèles de vol de coupole en compensation du paiement des coûts de lancement et de retour des charges utiles de ces adaptateurs externes.

Le groupe des utilisateurs de la Station spatiale (SSUP) s'est réuni les 25 et 26 mars pour passer en revue la situation actuelle en ce qui concerne la promotion des utilisations de la Station spatiale axées sur les applications. Pour développer l'intérêt envers les sciences et les applications à bord de la Station spatiale et pour que des propositions pluridisciplinaires puissent être présentées, le SSUP a recommandé la préparation d'un avis unique d'offre de participation européen à la Station spatiale (AO) plutôt que des avis d'offre de participation propres à des installations.

L'établissement du planning du deuxième symposium consacré à l'utilisation de la Station spatiale prévu à l'ESTEC en novembre 1998 a progressé. Les activités de planning et de définition d'un centre d'information sur l'utilisation de la Station spatiale, qui sera établi à l'ESTEC (NL), ont commencé.

Réalisation des matériels

Les revues critiques de conception (CDR) en cours pour le congélateur -80 degrés C (MELFI) et pour la boîte à gants seront achevées en juin/juillet. L'approvisionnement des bâtis internationaux de charge utile normalisées (ISPR) est conforme au calendrier. Les cinq premiers modèles de vol des douze ISPR qui font l'objet d'un accord de compensation avec le Japon ont été acceptés et livrés en Europe en février. Les sept bâtis restants arriveront en 1999.

Après approbation de la proposition de contrat par l'IPC réuni en mai, le contrat de développement du bâti à tiroirs européen (EDR) a été attribué à un consortium piloté par Alenia (I).

La revue de conception préliminaire du système de pointage Hexapod est prévue pour octobre 1998. L'unité de vol devrait être livrée à la NASA en janvier 2001 pour être lancée lors du vol UF-4 en janvier 2002. Avant le démarrage de la phase C/D, il est prévu une petite phase de consolidation du dispositif de pointage grossier afin de tenir compte des configurations retenues pour les adaptateurs de palettes.

Les travaux de développement du SPLC des équipements de charges utiles standard, du RPDA et de l'AAA se poursuivent comme prévu et les modèles d'identification seront fournis dans le courant du premiers semestre 1998.

Activités des astronautes

En mars, le Conseil de l'ESA a approuvé une résolution (voir Bulletin ESA n° 94, page 120) relative à la création d'un corps européen unique d'astronautes composé de 16 membres ; ce corps est le résultat de la fusion de programmes nationaux existants avec le programme de l'ESA. Il devrait être totalement constitué pour la mi-2000, après quoi les activités nationales relatives aux astronautes cesseront.

P. Duque a commencé son entraînement

120) on the establishment of a single European Astronaut Corps, composed of 16 astronauts, by merging existing national programmes with the ESA programme. The Corps should be fully established by mid-2000, after which national astronaut activities will cease.

P. Duque has begun his formal training for the STS-95 (Spacehab) mission, which involves an important ESA payload. At a ceremony on 24 April 1998 in Houston, NASA formally confirmed C. Fuglesang and P. Duque as Mission Specialists, both of them also having received EVA training. C. Nicollier and J.F. Clervoy are performing collateral duties in NASA, pending their nomination for a next flight assignment.

Early deliveries

Data Management System for the Russian Service Module (DMS-R)

Following the successful DMS-R Qualification Review, the Russian Service Module contractor RSC-Energia introduced additional technical requirements, which are currently being implemented. During the required hardware modification of the Fault Tolerant Computer (FTC), minor mechanical deviations were observed in one flight model. The analyses of these deviations have been successfully concluded and shipment of this flight model was completed by the end of May. The necessary software modifications both for the FTC and for the Control Post Computer (CPC) are also being finalised and shipment of the CPCs and the FTC spare was completed in early May.

The technical definition of the DMS-R Long-Term Engineering Support for the Service Module DMS-R has been agreed.

MPLM ECLSS Environmental Control and Life-Support Subsystem

After the solution of several problems, the full set of Flight Unit 1 and Flight Spares hardware has been delivered to ASI/Alenia (I) for incorporation into the first MPLM flight model, to complement the already delivered EQM hardware and the full sets of Ground Support Equipment. Continuing cooperative discussions with the MPLM project management has ensured that the delays have not impacted upon the delivery date to NASA of the system, and the system qualification tests have shown that the ECLS has performed in accordance with specifications.

Most of the Equipment Qualification Reviews have been conducted, and will be completed in June. The Subsystem Qualification Review is in currently in progress, thereby ensuring its completion before acceptance of the overall MPLM flight model by NASA, currently scheduled for late-July. ECLS Flight Unit 2 equipment has started to be delivered, and Flight Unit 3 is in production. It is still anticipated that the contract deliveries will be completed in the third quarter of this year.

European Robotic Arm (ERA)

Following the shipment of the ERA Electrical Interface Model at the end of 1997, a full-size ERA Geometric Model was shipped in February. This will be used for mass and geometric measurements. In addition, the first ERA flight-equipment delivery has been completed with the delivery of the First End-Effector Basepoints.

Further items delivered in April and May include a ground prototype version of the lap-top-based "Refresher Trainer", the flight version of which will be used in orbit to enable Cosmonauts to rehearse techniques prior to ERA operations, and the major element of the Weightless Environment Test Model (the re-locatable arm). The latter model has been designed for use in neutral-buoyancy testing at the Gagarin Cosmonaut Training Centre.

The ERA schedule indicates a potential slippage of about 2 months from the baseline. Efforts are being made to contain these slippages, but the overall schedule is now considered critical since these 2 months are consuming the project's schedule reserve and could ultimately endanger the currently agreed delivery date of July 1999 for the ERA flight model.

Microgravity

EMIR-1 and EMIR-2

The ESA hardware for the sixteen-day flight of the ESA Developed Elements for Neurolab (EDEN) was installed in the Neurolab Spacelab at Kennedy Space Center. STS-90 was launched on 17 April, after a one-day delay due to a Shuttle computer data-management problem, and landed on 3 May. The mission was dedicated to research into the human neurological and neuro-vestibular systems under microgravity conditions. The ESA-provided Vestibular and Visual Investigation System (VVIS) — an off-axis rotating chair to investigate the human balance system — worked well and the mission can be considered very successful for the European scientists involved and for ESA.

The flight opportunity aboard the Foton-12 mission for the ESA-developed Fluidpac for experiments in fluid sciences has been confirmed for June 1999. The launch dates for the STS-95 mission carrying the ESA-developed Facility for Adsorption and Surface Tension (FAST) studies and a reflight of the Advanced Protein Crystallisation Facility (APCF) have been confirmed for October 1998. This Spacehab mission will also include the flight of the Advanced Gradient Heating Facility (AGHF reflight), Biobox-3 and MOMO-2 (Morphological Studies on Model Systems).

Microgravity Facilities for Columbus (MFC)

The Biolab development effort is progressing as scheduled and the first meeting of the Biolab Science Team took place as planned in April 1998.

The final Phase-B presentation for the Material Science Laboratory (MSL) was held in March. A successful preliminary negotiation took place with the Prime Contractor for the MSL in the US module contract. The main contract will include the Low-Gradient Furnace (LGF) module. Preliminary Authorisation to Proceed (PATP) for Phase-C/D was given to the contractor in April. The option to develop the Solidification and Quenching Furnace (SQF) module will be placed at a later date. MSL is scheduled for a launch on UF-3 in February 2002. The industrial proposal for the development of the Fluid Science Lab (FSL) was received and evaluated, and the contract was awarded in early April.

Activities in the framework of the two parallel Phase-A contracts concerning the European Physiology Modules (EPMs) are in progress at the prime contractors, Aerospatiale (F) and DASA/Dornier (D). The mid-term reviews took place in March, and the final presentations are scheduled for end-September 1998.

pour la mission STS-95 (Spacehab) qui aura a son bord une importante charge utile de l'ESA. Lors d'une cérémonie qui s'est tenue le 24 avril 1998 à Houston, la NASA a officiellement confirmé comme spécialistes mission C. Fuglesand et P. Duque, tous deux ayant reçu également une formation aux EVA. C. Nicollier et J.F. Clervoy se sont vus confier des tâches annexes à la NASA en attendant leur nomination pour un prochain vol.

Livraisons à cours terme

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

La revue de qualification du DMS-R ayant été menée à bon terme, le contractant chargé de la réalisation du module de service russe (RSC-Energia) a introduit quelques impératifs techniques supplémentaires qui sont en cours de mise en œuvre. Pendant les modifications à apporter au matériel de l'ordinateur à tolérance de pannes (FTC), on a constaté de légères différences sur le plan mécanique sur l'un des modèles de vol. Ces différences ayant été élucidées, le modèle de vol a été expédié fin mai. Les modifications nécessaires du logiciel, pour le FTC et pour l'ordinateur du poste central (CPC), sont également en cours de mise au point définitive ; le CPC et le FTC de secours ont été expédiés début mai.

La définition technique du soutien Ingénierie à long terme du DMS-R du module de service russe a été adoptée.

Sous-système de contrôle de l'environnement et de soutien-vie (ECLSS) du MPLM

Plusieurs problèmes ayant été résolus, l'ensemble du matériel de l'unité de vol 1 et des rechanges de vol a été livré à ASI/Alenia (I) pour être intégré au premier modèle de vol du MPLM, ce qui complète le matériel EQM déjà livré ainsi que les ensembles complets d'équipement de soutien sol. Les discussions avec la direction du projet MPLM se sont poursuivies et il en ressort que les retards n'ont pas d'incidence sur la date de livraison du système à la NASA. Les essais de qualification du système ont montré que l'ECLS s'est comporté conformément aux spécifications.

La plupart des revues de qualification des équipements ont été achevées en juin. La revue de qualification des sous-systèmes est en cours et devrait se terminer avant la recette par la NASA du modèle de vol du MPLM prévue pour la fin juillet. La livraison des équipement de l'unité de vol n°2 de l'ECLS a commencé et l'unité de vol n°3 est en fabrication. Les livraisons prévues au contrat devraient se faire au cours du troisième trimestre.

Bras télémanipulateur européen (ERA)

L'expédition du modèle d'interface électrique de l'ERA fin 1997 a été suivie par celle du modèle géométrique grandeur nature de l'ERA en février. Ce modèle sera utilisé pour les mesures de masse et de la géométrie. En outre, les livraisons des premiers équipements de vol de l'ERA ont été effectuées et se sont terminées par celle des points d'attache de l'organe terminal.

D'autres équipements ont été livrés en avril et mai, notamment une version prototype 'sol' du simulateur portable 'Refresher Trainer' dont la version spatiale sera utilisée en orbite par les cosmonautes pour revoir certaines techniques avant d'utiliser l'ERA ainsi que l'élément principal du modèle de WET (bras translatable). Ce dernier modèle a été conçu pour être utilisé lors des essais en caisson à immersion au Centre de formation des cosmonautes Gagarin.

Le calendrier de l'ERA fait apparaître une possibilité de glissement d'environ deux mois par rapport à la référence. On s'efforce de limiter ce glissement mais le calendrier d'ensemble est désormais considéré comme critique puisque ces deux mois sont pris sur la réserve du projet et pourraient finalement mettre en péril la date de livraison acceptée de juillet 1999 pour le premier de vol de l'ERA.

Microgravité

EMIR-1 et EMIR-2

Les éléments du Neurolab mis au point par l'ESA (EDEN) ont été embarqués dans le Spacelab Neurolab au Centre spatial Kenedy pour une mission de 16 jours. Le vol STS-90 a décollé le 17 avril, après une journée de retard due à un problème de gestion de données des ordinateurs de la Navette et a atterri le 3 mai. Cette mission était consacrée à des recherches sur les systèmes neurologiques et neurovestibulaires de l'homme en microgravité. le Système d'investigations visuelles et vestibulaires (VVIS) fourni par l'ESA (siège tournant décentré pour étudier le système d'équilibre de l'homme) a bien fonctionné et la mission peut être considérée comme un grand succès pour les chercheurs européens qui y ont participé et pour l'ESA

Il a été confirmé que le Fluidpac mis au point par l'ESA pour des expériences en science des fluides participerait à la mission Foton-12 en juin 1999. La date de lancement de la mission STS-95, avec à son bord l'Installation d'études de l'adsorption et de la tension de surface et, de nouveau l'Installation de cristallisation des protéines de pointe (APCF) a été confirmée pour octobre 1998. Le four à gradient de haute technologie (AGHF), le Biobox-3 et l'Installation pour études de transition morphologique sur des substances modèle (MOMO-2) seront également intégrés au Spacelab pour cette mission.

MFC

Les travaux de développement du Biolab se poursuivent selon le calendrier et l'équipe scientifique Biolab s'est réunie pour la première fois comme prévu en avril 1998.

La présentation définitive de la Phase B du Laboratoire de science des matériaux (MSL) a eu lieu en mars. Les négociations préliminaires ont été menées à bon terme avec le maître d'œuvre du MSL en vue du contrat relatif au module américain. Le contrat principal portera sur le module LGF (four à faible gradient). L'autorisation préliminaire d'engagement des travaux (PATP) de la Phase C/D a été donnée au contractant en avril. La possibilité de développer le module SQF (four de solidification avec trempe) sera proposée à une date ultérieure. Le MSL devrait être lancé sur le vol UF-3 en février 2002.
La proposition industrielle relative au développement du FSL (Laboratoire de science des fluides) a été reçue et évaluée et le contrat a été attribué début avril.

Les activités conduites dans le cadre des deux contrats parallèle de Phase A portant sur les modules de physiologie européens (EPM) se poursuivent chez les maîtres d'œuvre, Aerospatiale (F) et DASA/Dornier (D). La revue à mi parcours a eu lieu en mars et les présentations définitives sont prévues pour fin septembre 1998.

In Brief

Cluster-II Launch Contract Signed

The contract between ESA and Starsem for the re-launch of the four Cluster-II satellites was signed on 24 July at ESA Headquarters in Paris.

The shareholders in Starsem, a company founded in Suresnes, France, in August 1996 to exploit the Soyuz launch vehicle family commercially, are: the Russian Space Agency (RKA), the Samara Space Centre, which manufactures the Soyuz rockets, Aérospatiale, and Arianespace.

The four Cluster satellites will be launched in pairs from Baikonur on two Soyuz launchers with Fregat upper stages, between May and August 2000. The nominal launch dates, which should not be more than 42 days apart for orbit-injection-related reasons, are 15 June and 13 July.

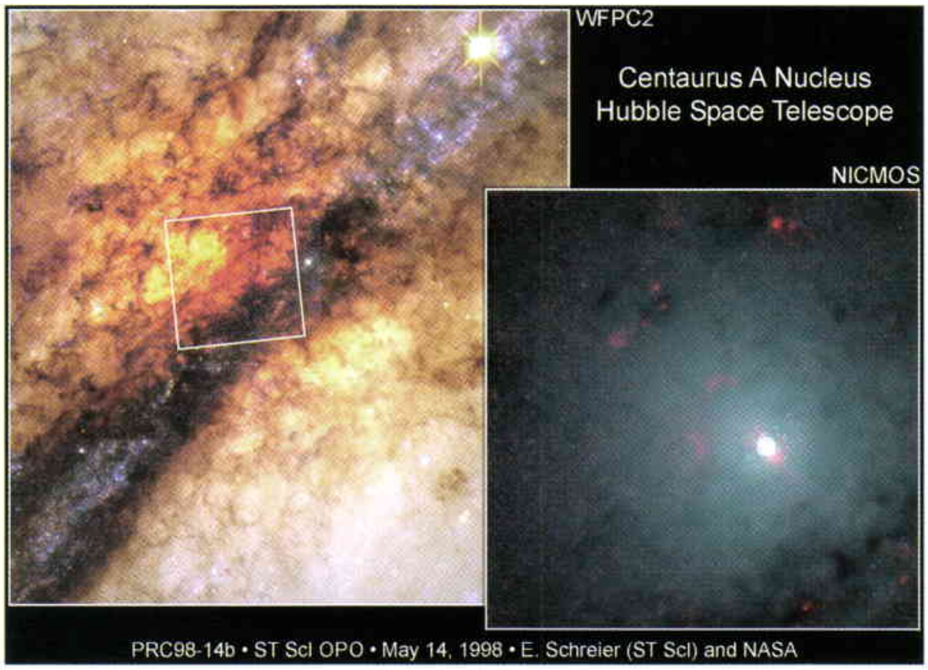
The photograph below shows the launch-contract signing ceremony at ESA Headquarters with, seated from left to right: Roger M. Bonnet, ESA's Director for Science, Jean-Yves Le Gall, Chairman of Starsem, and Jean-Marie Luton, Chairman and CEO of Arianespace. Standing behind, from left to right are: Helge Weber of ESA's Contracts Department, Karl-Egon Reuter, ESA's Head of Cabinet, Jean-Charles Vincent of Starsem, and Daniel Sacotte, ESA's Director of Administration.

ESA at ILA in Berlin

The International Aerospace Exhibition ILA'98 was held in Berlin at Schönefeld Airport during 18-24 May 1998. More than 600 exhibitors from all over the world attended this international trade fair, including leading US aerospace companies and numerous representatives of the aerospace industry from Russia and Eastern Europe, as well as from many Asian countries.

ESA, together with the German Aerospace Centre (DLR), and the German Aerospace Industries Association (BDLI), jointly organised the 'Raumfahrthalle' for the fourth time, the 2000 m^2 Space Activities Hall where current and future European space activities, as well as Germany's national space programmes, were presented to the public. The pavilion featured exclusive spacecraft models and scenery of the Earth and of Saturn's moon Titan. The International Space Station, a special attraction this year, was represented by a detailed full-size mock-up of the European, the US and the Japanese modules. A 1:10 model of the complete Station was suspended overhead, while a 'control centre' fitted with consoles and computers allowed visitors to follow a simulated mission from the ground.

Feeding a Black Hole



Hubble's infrared NICMOS instrument has penetrated the girdle of dust around Centaurus-A for the first time, revealing a disc of superhot gas being swept up by a suspected black hole

Astronomers have obtained an unprecedented look at the nearest example of galactic cannibalism: a massive black hole hidden at the centre of a nearby giant galaxy that is feeding on a smaller galaxy in a spectacular collision. Such fireworks were common in the early Universe, as galaxies formed and evolved, but are rare today.

Although the cause-and-effect relationships are not yet clear, the views provided by complementary images from two instruments aboard the Hubble Space Telescope (HST) are giving astronomers new insights into the powerful forces being exerted in this complex maelstrom. Researchers believe these forces may even have shifted the axis of the massive black hole from its expected orientation.

The Hubble wide-field camera visible image of the merged Centaurus-A galaxy shows a dramatic dark lane of dust girdling the galaxy. Blue clusters of newborn stars are clearly resolved, and silhouettes of dust filaments are interspersed with blazing orange-glowing gas. Located only 10 million light-years away, this peculiar-looking galaxy contains the closest active galactic nucleus to Earth and has long been considered an example of an elliptical galaxy disrupted by a recent collision with a smaller companion spiral galaxy.

Using Hubble's infrared vision, astronomers have penetrated this wall of dust for the first time to see a twisted disc of hot gas swept up in the black hole's gravitational whirlpool. The suspected black hole is so dense that it contains the mass of perhaps a thousand million stars, compacted into a small region of space not much larger than our Solar System.

Resolving features as small as 7 light-years across, Hubble has shown astronomers that the hot gas disc is tilted in a different direction from the black hole's axis. The axis is identified by the orientation of a high-speed jet of material, glowing in X-rays and radio frequencies, blasted from the black hole at 1/100th the speed of light. This gas disc presumably fuelling the black hole may have formed so recently that it is not yet aligned to the black hole's spin axis, or it may simply be influenced more by the galaxy's gravitational tug than by the black hole's.

"This black hole is doing its own thing. Aside from receiving fresh fuel from a devoured galaxy, it may be oblivious to the rest of the galaxy and the collision," said Ethan Schreier of the Space Telescope Science Institute, Baltimore, MD. Schreier and an international team of co-investigators used Hubble's Near Infrared Camera and Multi-Object Spectrometer (NICMOS) to probe deeper into the galaxy's mysterious heart than anyone has before.

The hot gas disc viewed by Hubble investigators is perpendicular to the galaxy's outer dust belt, while the black hole's own internal accretion disc of superhot gas falling into it is tilted approximately diagonally to these axes. *"We have found a complicated situation of a disc within a disc within a disc, all pointing in different directions,"* Schreier said.

It is not clear if the black hole was always present in the host galaxy or belonged to the spiral galaxy that fell into the core, or if it is the product of the merger of a pair of smaller black holes that lived in the two once-separate galaxies.

Having an active galaxy just 10 million light-years away from Earth rather than hundreds of millions of light-years distant offers astronomers a unique laboratory for understanding the elusive details of the behaviour of supermassive black holes as fuelled by galaxy collisions.

"Though Hubble has seen hot gas discs around black holes in other galaxies, the infrared camera has for the first time allowed us to peer at this relatively nearby, very active, but obscured black hole region," Schreier added.

The team of astronomers is awaiting further Hubble data to continue its study of the disc, as well as ground-based spectroscopic observations to measure the velocity of entrapped material around the black hole. This will allow the astronomers to better calculate the black hole's mass.

The Hubble Space Telescope is an ESA/NASA international cooperation project.

ESA and CERN Strengthen their Relationship

ESA's DG, Mr Antonio Rodotà, visited CERN, the European Laboratory for Particle Physics on 7 May 1998. He was welcomed by Prof. Chris Llewellyn Smith, the Director General of CERN, together with his designated successor, Prof. Luciano Maiani. After fruitful and positive discussions, the Directors General agreed on the creation of working groups to study and propose systematic joint activities to be conducted on a regular basis between the two organisations.

The working groups will reinforce the existing cooperation between the organisations in scientific and technical fields; for example, in data acquisition, handling and networking. The importance of communicating the scientific aims and achievements of both organisations to the general public was underlined by setting up new initiatives to take advantage of joint experience in educational projects and outreach activities. Finally, they agreed to reinforce the exchange of information on administrative issues. The working groups will present proposals to the management of the respective Agencies in September 1998. esa

Mr Antonio Rodotà (right) with CERN's Prof Chris Llewellyn Smith

European Global Navigation Satellite System Receives Go-ahead

ESA, the European Community (EC) and the European Organisation for the Safety of Air Navigation (Eurocontrol) have taken an important step towards the development of GNSS, the Global Navigation Satellite System for Europe.

Meeting at the offices of the Council of the European Union in Luxembourg on 18 June, ESA's Director General, Antonio Rodotà; the President-in-office of the Council of the European Union (Minister of Transport of the United Kingdom of Great Britain and Northern Ireland) Gavin Strang; Member of the European Commission, Neil Kinnock; and the Director General of Eurocontrol, Yves Lambert, signed an agreement formalising cooperation between the three organisations in the field of satellite navigation systems and services, with the aim of establishing a satellite navigation and positioning service for Europe as a contribution to a global effort.

The development of GNSS will be carried out in two main stages. GNSS-1 will be the first-generation system, based on signals received from the existing American GPS and Russian GLONASS constellations, and civil augmentation systems using space-based, ground-based and mobile autonomous-based techniques. The European space-based augmentation system, EGNOS (European Geostationary Navigation Overlay Service), consists of a set of navigation payloads on board geostationary satellites which are continuously monitored by ground stations both within and outside Europe. The system, to be completed by 2002, will be developed by ESA. GNSS-2, the second-generation system, will provide services to civil users, and will be under civil operation and control by 2010. A decision on how to proceed with GNSS-2 will be taken by mid-1999.

Aircraft operators represent one of the main markets for satellite navigation systems, which have the potential to transform air traffic management in many areas. With the services provided by satellites, it will be possible not only to improve navigational accuracy, but also to enhance communication and surveillance capabilities, thus increasing safety, gaining time, and reducing fuel consumption and costs.

Airlines will not be the only beneficiaries. Companies operating transport services by road, sea or rail need to know where their vehicles are at all times. So do police, ambulance and taxi services. Some European car manufacturers are already featuring satellite navigation systems in their top-of-the-range vehicles and inexpensive hand-held receivers are becoming widely used by recreational sailors, climbers and hikers.

As well as improving safety, a European contribution to a global navigation satellite system will contribute greatly to improving economic prosperity, industrial returns, employment and the quality of life in Europe. esa

International Space Station Revisions

Representatives of all nations involved in the International Space Station (ISS) have agreed to move the official target date for the launch of the first ISS component from June to November 1998, and to revise subsequent launch target dates for the remainder of the 43-flight Station Assembly Plan.

In meetings of the Space Station Control Board and the Heads-of-Agency on 30-31 May 1998 at the Kennedy Space Center, all station partners agreed to target launch dates of 20 November for the Control Module (FGB) – now called 'Zarya' (Russian for 'daybreak') – and 3 December for Shuttle mission STS-88 with Unity (Node-1). Changes in the construction schedule for the third station component, the Russian-provided Service Module, led the partners to reschedule these first assembly launches.

The rescheduling of the first launch will have only a minor effect on the target dates agreed upon for many major ISS milestones during the latter portions of the 5-year assembly plan. In addition, several enhancements to the Station's assembly have been made, including an exterior 'warehouse' for spare parts and a Brazilian-provided carrier for exterior Station components that are launched aboard the Shuttle.

The ISS partners set an April 1999 target launch date for the Russian Service Module. This module will house the first Station crews and the ESA-provided Data Management System (DMS-R). The first station crew – Commander Bill Shepherd, Soyuz Commander Yuri Gidzenko and Flight Engineer Sergei Krikalev – will take off aboard a Russian Soyuz spacecraft in summer 1999 to begin a 5-month inaugural stay. Launch of the US Laboratory Module is set for October 1999. Launches of other laboratory modules, provided by Europe, Japan and Russia, will take place later in the assembly sequence. The Canadian-provided Space Station Remote Manipulator System will be launched in December 1999. Scientific research will begin aboard the ISS early in 2000.

The expansion from a 3-person crew to a 6-person capability is planned for November 2002 and the final launch in the assembly sequence is set for January 2004, only one month later than in the previous assembly plan. Some issues in the assembly sequence remain under review and will be resolved at a Space Station Control Board meeting in September 1998. For example, ESA's Columbus laboratory is now targeted for February 2003, but the Agency would prefer to return to the previously-scheduled October 2002. Therefore, the final date is subject to further revision.

NASA continues the development of an Interim Control Module (ICM) as a contingency against further delays in the Service Module and to provide a potential additional propellant capability for a more robust Space Station. A decision concerning the configuration of the ICM will be made later this year.

During the Heads-of-Agency meeting, the Russian Space Agency (RSA) stated that the Russian government has made the ISS its number one civil space priority. RSA noted that progress on the Service Module continues to meet the launch target of April 1999. RSA is also working to deorbit Mir as early as safely possible, aiming to have the capability by July 1999. The International Partners expressed their concern with delays to the ISS programme to date and brought to the attention of RSA that it is critical to all participating nations that the programme schedule is met. The agencies' leaders also acknowledged the atmosphere of cooperation, the accomplishments and the successful achievements of the Shuttle-Mir Program (Phase 1) and look forward to the smooth transition to Phases 2 and 3 of the International Space Station. In addition, they highlighted the ongoing ISS training under way for the first four station crews. esa

ISO 9001 Certification Process at ESOC

The Director of Technical and Operational Support (D/TOS) has taken the initiative of implementing a Quality System certified to the ISO 9001 standard at the European Space Operations Centre of ESA to substantiate the quality and value of its products and services in the international space operations market.

The ISO 9001 standard is an internationally recognised benchmark for the management and performance of all activities necessary to ensure that the needs of a customer are satisfied. To prepare for certification, the first phase of activities are focused on the preparation of a Quality Manual and internal procedures to document the work practices within ESOC.

Since November 1997, the ISO 9001 Working Group has been analysing the internal functioning of ESOC and preparing the necessary documents. The Working Group consists of 16 staff members from ESOC and ESTEC Quality Assurance Division, and reports to a Steering Group composed of 7 members chaired by Mr David Dale (D/TOS).

In a second phase, the group will work with all staff to implement the ESOC Quality System. This will include the deployment of tools and the provision of training to support the implementation of the procedures in ESOC. Internal audits will be performed to verify and document that all ESOC staff are working together to provide outstanding mission operations services and space data products.

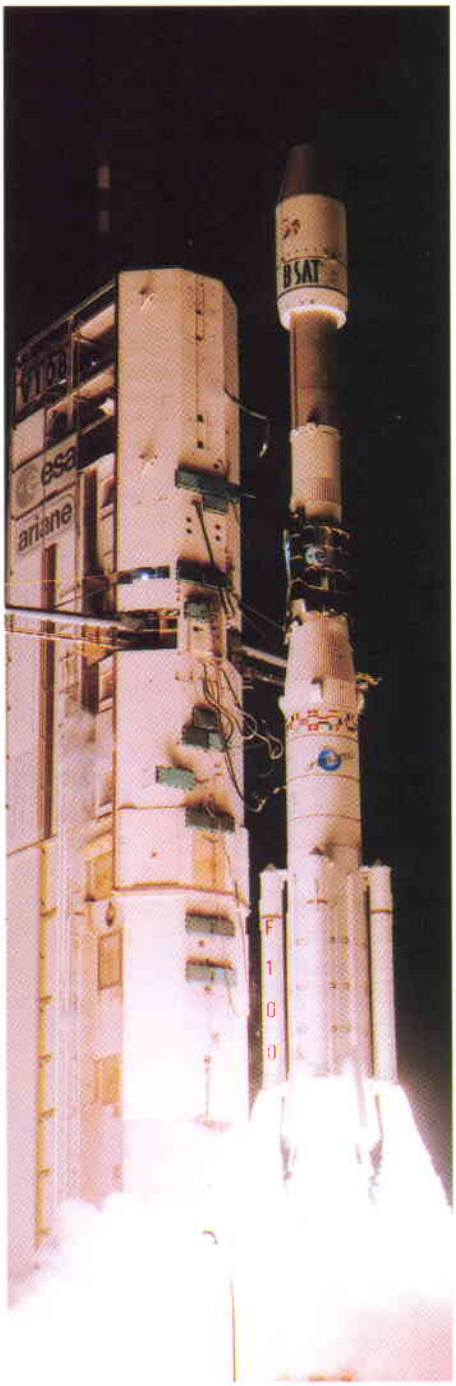
The third and last phase will be an independent audit of ESOC by an internationally accredited registrar to verify compliance with the ISO 9001 requirements. A successful audit will result in a certificate with a validity of 3 years. It is intended to achieve this official certification by the end of 1999.

There are three expected benefits:

- to clarify for all existing and future ESOC staff members the activities to be performed and their relationships to successfully deliver ESOC's products and services
- to provide a documented baseline for future analysis and improvement of methods and procedures used at ESOC
- to independently attest to the excellence of the work processes and staff at ESOC. esa

Ariane 108 Launches Nilesat and BSat

The 108th Ariane launch (V108) was completed successfully at 22:53 UT on 29 April 1998 from the Guiana Space Centre in Kourou, French Guiana. The Ariane-44P vehicle (the '44P' indicating that it was equipped with four solid-propellant strap-on boosters) delivered the Egyptian Nilesat 101 and Japanese BSat-1b telecommunications satellites into the required geostationary transfer orbit.



The LLMS user terminal

First European Payload for Worldwide E-mail Service Launched

ESA's LLMS (Little LEO Messaging System) payload was launched with the Russian Earth observation satellite 'Resours-N4' on 10 July at 08:30 hrs CEST, from the Baikonur launch site in Kazakhstan on board a Zenit launcher. This new telecommunications payload will provide a low-cost, worldwide electronic mail (e-mail) commercial service dubbed IRIS (Intercontinental Retrieval of Information via Satellite).

The host satellite, on an inclined polar orbit at an altitude of 850 km, will 'view' any point on the Earth's surface at least twice a day and will collect and distribute e-mail. Subscribers will need a relatively inexpensive dedicated small satellite modem (half the size of a portable PC). Automatic data collection will also be possible. The hub station, located in Spitsbergen (N), will load and retrieve messages from the satellite once per orbit and interface with public data networks to connect users via a service centre in Brussels (B).

The target customers for the service are travellers in remote areas or at sea and do not have access to terrestrial communications. Large organisations with staff in remote areas of the world are a typical example.

For ESA, this is a new type of small project for which special efforts have been made to reduce development duration and costs, and to capitalise on several years of spread-spectrum technology development. The contractual aspects are also innovative, with a commitment by the prime contractor to offer a commercial service.

Under an ESA ceiling-price, turnkey contract, the prime contractor SAIT Systems of Brussels (B), undertook not only to develop, but also to launch and commercially operate LLMS/IRIS for an initial period of 3 years. This concept is in line with the evolution of ESA's procurement approach in which industry fully assumes the programmatic, technical and financial responsibility for close-to-market missions.

Development of this advanced communication payload under the leadership of SAIT systems, was carried out by European companies in Belgium (SAIT Devlonics, Alcatel Bell), Germany (OHB), Spain (SEMA), and the UK (Warberry Communications). IMEC vzw, Barco-Silex and Verhaert D&D, also of Belgium, were involved at the level of the LLMS modem, while subcontracts with NPP WNIIEM of Moscow (R) and with the Norwegian Space Centre covered the payload accommodation with launch and the hub station installation in Spitsbergen, respectively.

European Astronaut Selected for Third Hubble Space Telescope Servicing Mission

ESA astronaut Claude Nicollier from Switzerland will be aboard the US Space Shuttle Columbia when it lifts off from Cape Canaveral in May 2000, on flight STS-104, for the third servicing mission to the Hubble Space Telescope. Nicollier has been selected as one of the four mission specialists for STS-104, together with three NASA astronauts - Steven L. Smith, Michael Foale and John M. Grunsfeld.

The STS-104 crew will rendezvous with the orbiting Hubble Space Telescope, capture it using the Shuttle's robot arm, and secure it in Columbia's payload bay. Then, working in teams of two, the four astronauts will leave the Shuttle's pressurised cabin and venture into the payload bay, where they will perform a variety of tasks that will improve both Hubble's performance and its reliability.

To increase Hubble's scientific capability, Nicollier and his fellow crew members will remove the European-built Faint Object Camera (FOC), which has worked faultlessly since the launch in 1990, and replace it with a new-generation instrument known as the Advanced Camera for Survey. With its three electronic cameras and complement of filters, this camera is expected to improve the telescope's sensitivity tenfold.

Other primary tasks to be accomplished during the STS-104 mission include the replacement of the existing solar arrays with rigid, high-efficiency arrays for which ESA will deliver the mechanisms, manufactured by Daimler-Benz Aerospace/Dornier, and the replacement of Fine Guidance Sensor no. 2, one of three such devices that help to point the telescope at a celestial target with an accuracy of 0.007 arcsec. This is equivalent to keeping Hubble pointed at a candle in Amsterdam from Vevey, Switzerland, about 700 km away, where Nicollier was born.

Both Smith and Nicollier have previous in-orbit experience with Hubble: Smith performed three EVA sorties during the STS-82 mission to Hubble, and Nicollier operated the Shuttle's robot arm during the first servicing mission on the STS-61 mission in 1993. Foale has conducted EVAs from both the Space Shuttle and the Russian Mir space station. Grunsfeld has two previous space flights to his credit.

Claude Nicollier

For Nicollier, who was selected by ESA in 1978 as one of the first group of European astronauts, it will be his fourth flight into space, more than any other European astronaut to date. Prior to taking part in the first Hubble servicing mission in December 1993, he was a Mission Specialist on the August 1992 STS-46 mission during which Eureca — ESA's European Retrievable Carrier platform — was deployed and the first Tethered Satellite System test flight conducted. In February 1996, he participated in STS-75, which carried the US Microgravity Payload experiments and undertook the second flight test of the Tethered Satellite System.

Commenting on Claude Nicollier's selection, Mr Jörg Feustel-Büechl who, as ESA Director of Manned Spaceflight and Microgravity, is responsible not only for the European Astronaut Corps, but also for the European participation in the International Space Station, said:

"Together with the selection of Pedro Duque for the STS-95 mission in October this year,......the selection of Claude Nicollier, who is one of ESA's most experienced astronauts, is a clear signal of the high esteem in which NASA holds the high professional skills and human qualities of Claude and the other European astronauts. This is a sound basis for fruitful cooperation of mutual benefit on the International Space Station, where astronauts from the USA, Russia, Europe, Japan and Canada will work together closely as a single integrated crew. It is also very useful to the development work on the European-built Station elements."

Jörg Feustel-Büechl also pointed out that: *"The Hubble servicing mission shows that men and women can significantly augment the efficiency and lifetime of complex systems in space. Humans have two essential 'built-in tools' that make them superior to any robot: their brain and their hands. No robot offers a comparable combination of high intelligence, adaptability to unexpected situations, mobility, dexterity and tactility. Robotic systems can perform pre-defined routine tasks and even support astronauts in their work, as the Shuttle's robotic arm shows, but they soon reach their inherent limitations when it comes to evaluating results and deciding what to do next. That is one of the key reasons why we are building and operating a manned Space Station."* esa

Emergsat Contract Signed

The signing of the Emergsat (Emergency Management satellites) project took place on 15 July at the offices of the Spanish Delegation (CDTI, Madrid). The contract was signed by Mr Anthony Dickinson, representing ESA's Director of Applications, and Mr José Martín Fluxá, CEO of Indra Espacio. Acting as witnesses were Mr Vicente Gómez, Head of the Spanish Delegation to ESA, Mr Juan San Nicolás, Director General of the Spanish Civil Protection Agency, Mr Juan Pedró, Technical Counsellor of the Spanish Civil Protection Agency and permanent Correspondent of Spain at the EUR-OPA Agreement on Major Hazards and Mrs Emilia Buergo, Director of Strategic Planning at CDTI.

The aim of the Emergsat project is to demonstrate the use of near-real-time (space-borne) Earth observation data in the management of emergency situations.

Additionally, meteorological updates and information from GIS databases will be delivered via satellite links to the emergency manager at the Control Centre to aid the decision-making process. The Emergsat Pilot Network will be implemented making maximum use of existing technologies. The emergency applications selected will offer a concrete opportunity for later migration to an operational Decision Support Network using satellite communication links with realisable cost benefits.

The project will be based on a Spanish-French consortium of industries led by Indra Espacio (E). Acting as subcontractors are INSA (E), GMV (E), Alcatel (F) and Scot-Conseil (F). Active support is provided by the Spanish Civil Protection Agency and the Regional Centre of Civil Protection of the Southwest of France which will host Control Centres in Spain (Madrid) and France (Bordeaux) respectively. This architecture will serve to make the pilot validation even more representative of the operational network.

Left to right: Mr Juan San Nicolás, Spanish Civil Protection Agency, Mr Vicente Gomez (CDTI), Mr Anthony Dickinson (ESA) and Mr José Martin Fluxá (Indra Espacio)

This collaboration is the result of several months of fruitful discussions and joint work. It is expected to lead to a future, wider cooperation with ESA as its possible focal point. Therefore, the project should be seen within the framework of the current policy of rapprochement with all organisations involved either directly or indirectly as potential users of satellite technologies, in Europe and beyond, and it should serve as a template in the search for new partners for advanced applications

The ESTEC Site

ESTEC Celebrates 30 Years

The festivity at ESTEC was a successful 'family event', prepared by staff for staff. The full day's activities included sporting events, demonstrations, entertainment, international food, and relaxation for both children and adults, rounded off with dancing in the evening. It was also a time for reflection and recognition for the commitment of all ESTEC staff over the past 30 years.

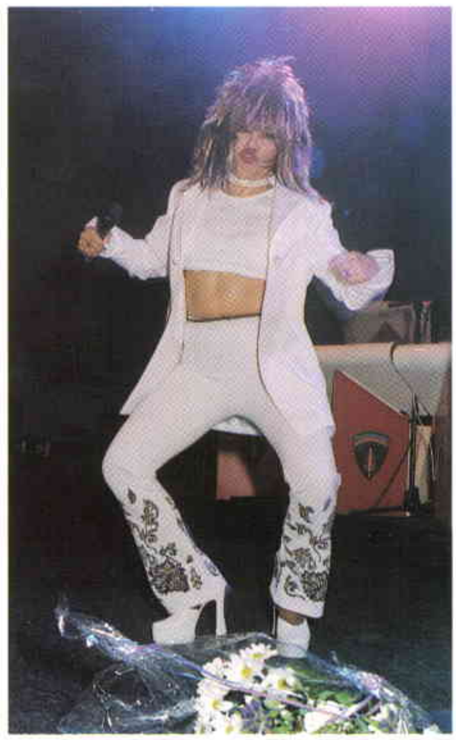
People and projects: these are the keywords when looking back with pride at the ESA success story in which the Noordwijk establishment continues to play a very important part.

A small history exhibition recalled the many highlights, emphasizing the European team spirit. Six ESA Directorates are strongly represented at ESTEC with their specialists, project groups and extensive technical support facilities such as the unique Test Centre.

Starting with ESRO-1, 39 spacecraft have been designed and placed into orbit with the backing of ESTEC expertise. A further 8 satellites and various elements for the International Space Station are under development at Noordwijk at the present time.

Thirty years to remember – and still going strong – with the enthusiasm for a fortuitous future for Europe in space. esa


T'ai Chi Ch'uan

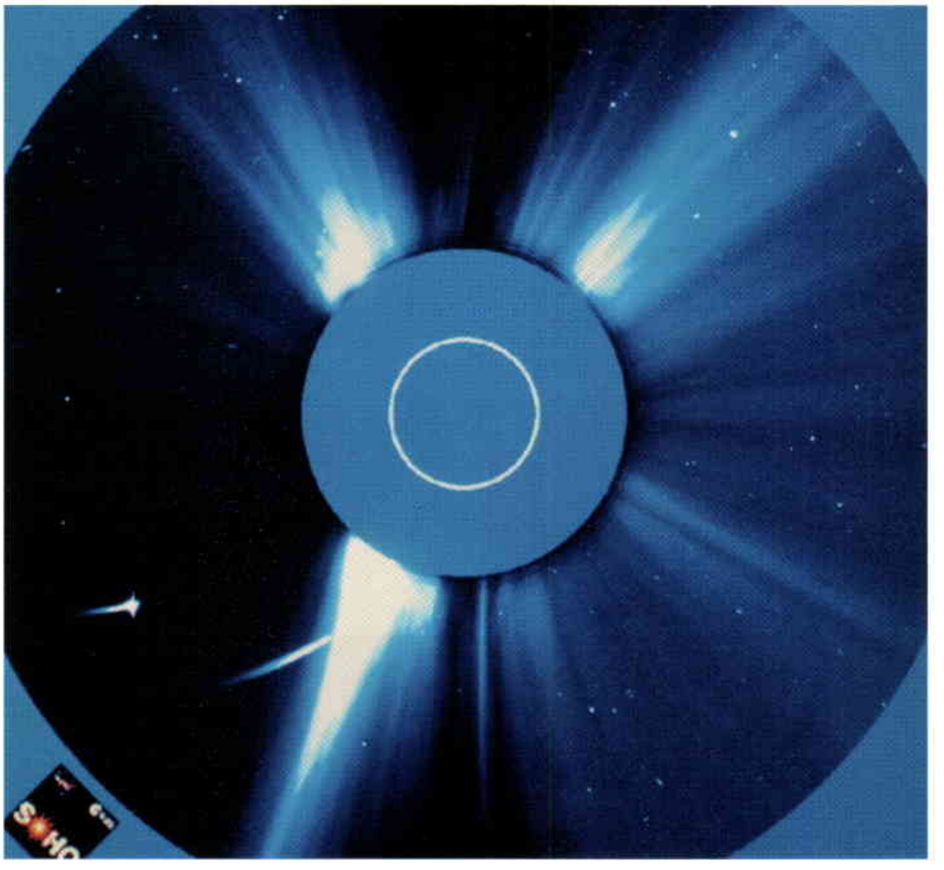


SOHO Observes Solar-Deaths of Two Comets

In a rare celestial spectacle, two comets have been observed plunging into the Sun's atmosphere in close succession, on 1 and 2 June 1998. This unusual event was followed on 2 June by a probably-unrelated but dramatic ejection of solar plasma and magnetic fields on the southwest limb of the Sun.

All the observations were made by the LASCO coronagraph aboard the ESA/NASA SOHO spacecraft. The observatory has discovered more than 50 comets, including many so-called Sun-grazers, but none in such close succession. The eruption of solar plasma was directed away from Earth and posed no hazard to our planet or orbiting astronauts.

Development of the LASCO instrument was coordinated by the US Naval Research Laboratory. Dr. Donald Michels of the LASCO science team led the team that observed this rare phenomenon. Images of these events can be seen via the World Wide Web at:
http://sci.esa.int/missions/soho/

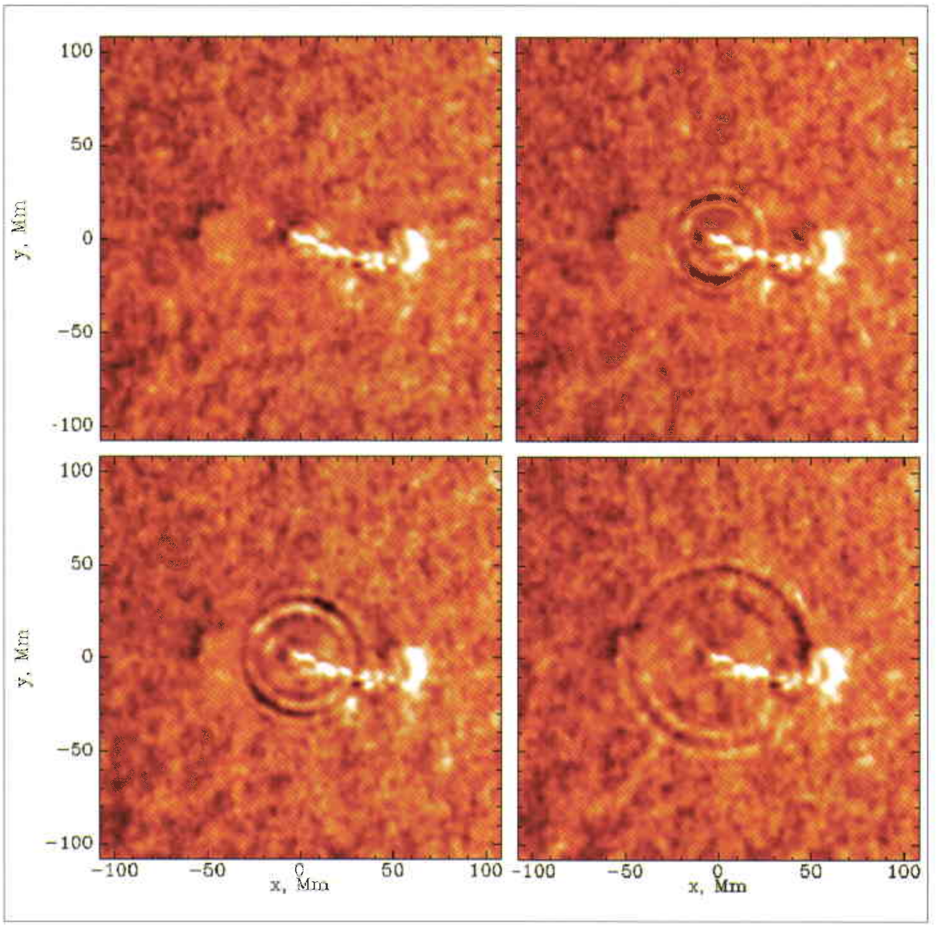


Two comets plunging into the Sun's atmosphere in close succession in June 1998

Solar Flare Leaves Sun Quaking

Scientists have shown for the first time that solar flares produce seismic waves in the Sun's interior that closely resemble those created by earthquakes on our planet. The researchers observed a flare-generated solar quake that contained about 40 000 times the energy released in the great earthquake that devastated San Francisco in 1906. The amount of energy released was enough to power the United States for 20 years at its current level of consumption, and was equivalent to an 11.3 magnitude earthquake, scientists calculated.

Solar flares producing seismic waves in the Sun's interior, which ripple outwards for thousands of kilometres



Dr. Alexander G. Kosovichev, a senior research scientist from Stanford University (US), and Dr. Valentina V. Zharkova from Glasgow University (UK) found the tell-tale seismic signature in data on the Sun's surface collected by the Michelson DOPPLER Imager aboard the ESA/NASA SOHO spacecraft immediately following a moderate flare on 9 July 1996. Over the course of an hour, the ripples travelled a distance equal to 10 Earth diameters before fading into the fiery background of the Sun's photosphere. Unlike water ripples that travel outward at a constant velocity, the solar waves accelerated from an initial 35 000 km/h to a maximum of 400 000 km/h before disappearing.

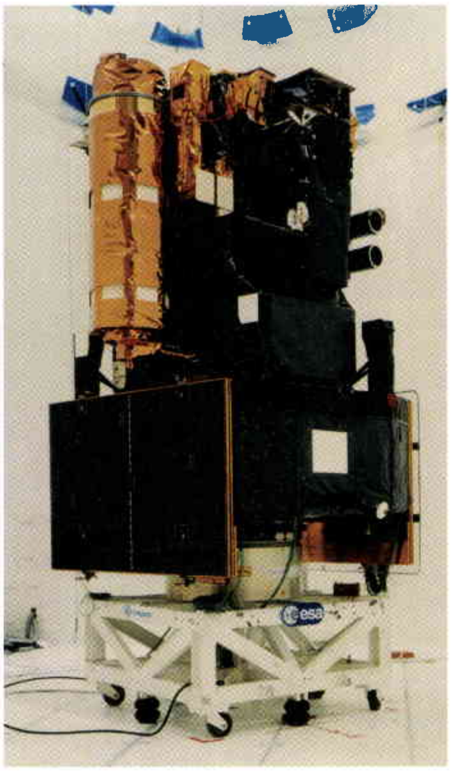
"People have looked for evidence of seismic waves from flares before, but they didn't have a theory so they didn't know where to look," says Kosovichev. Several years ago, Kosovichev and Zharkova developed a theory that can explain how a flare can generate a major seismic wave in the Sun's interior. According to the currently accepted model of solar flares, the primary explosion creates high-energy electrons. These are funnelled down into a magnetic flux tube and generate X-rays, microwaves and a shock wave that heats the solar surface. Kosovichev and Zharkova developed a theory that predicts the nature and magnitude of the shock waves that this beam of energetic electrons should create when they slam down into the solar atmosphere.

Although their theory directed them to the right area to search for the seismic waves, the waves they found were 10 times stronger than they had predicted. *"They were so strong that you can see them in the raw data,"* Kosovichev commented. The solar seismic waves appear to be compression waves like the 'P' waves generated by an earthquake. They travel throughout the Sun's interior. In fact, they should recombine on the opposite side of the Sun to create a faint duplicate of the original ripple pattern, Kosovichev predicts.

Now that they know how to find them, the SOHO investigators say that the seismic waves generated by solar flares should allow them to verify independently some of the conditions in the solar interior that they have inferred from studying the pattern of waves that continually ruffle the Sun's surface.

SOHO – Lost and Found

In April, ESA's Solar and Heliospheric Observatory (SOHO), launched on 2 December 1995, successfully completed its nominal two-year mission to study the Sun's atmosphere, surface and interior. The major scientific highlights of this joint ESA/NASA mission have included: the detection of rivers of plasma beneath the surface of the Sun; the discovery of a magnetic "carpet" on the Sun's surface that seems to account for a substantial part of the energy that is needed to cause the very high temperatures in the corona, the Sun's outermost layer; the first detection of flare-induced solar quakes; the discovery of more than 50 Sun-grazing comets; the most detailed view to date of the solar atmosphere; and spectacular images and movies of Coronal Mass Ejections, which are being used to improve our ability to forecast the "weather in space".



The SOHO spacecraft shortly before launch

SOHO's mission had only recently been extended to 2003 – to cover the period of maximum solar activity that is expected to occur in 2001 – when, on 25 June, during routine maintenance operations, the ground controllers at NASA Goddard Space Flight Center (GSFC) in Maryland lost contact with SOHO and the spacecraft went into Emergency Sun Reacquisition (ESR) mode. This mode is activated automatically when an anomaly occurs and the spacecraft loses its orientation towards the Sun. The spacecraft then tries to point itself towards the Sun again by firing its attitude control thrusters under the guidance of an onboard Sun sensor.

The immediate efforts to re-establish nominal operations did not succeed and telemetry was lost. Subsequent attempts using the full NASA Deep Space Network (DSN) capabilities were also unsuccessful. A team of experts from ESA and Matra Marconi Space, prime contractor for the SOHO spacecraft, therefore gathered at GSFC to assist the NASA Flight Operations Team in assessing the situation and analysing the spacecraft status should contact be re-established.

The engineers concentrated first on gaining a complete understanding of the events that had led to the loss of signal, information that might help them to devise procedures which could re-establish contact with SOHO. Commands were sent to SOHO about once per minute, using the DSN's 34 m antennas, instructing the spacecraft to activate its transmitters. Based on the last telemetry data that had been received from SOHO, the engineers thought it likely that the spacecraft was spinning slowly in such a way that its solar arrays were not receiving adequate sunlight to generate power. It appeared, however, that SOHO's solar panels might be exposed to increasing amounts of sunlight each day as it orbited the Sun, in which case within a few weeks sufficient sunlight might be shining on the solar panels to generate enough power to charge the spacecraft's batteries.

In the meantime, the SOHO incident had become the subject of a joint ESA/NASA inquiry, by a Board co-chaired by Prof. Massimo Trella, ESA's Inspector General, and Dr. Michel Greenfield, NASA Deputy Associate Administrator for the Office of Safety and Mission Assurance, and with members drawn from ESA, NASA and the scientific community. This SOHO Mission Interruption Joint ESA/NASA Investigation Board focussed in on three errors that seemed to have led to the loss of communications with SOHO. The first error was in a pre-programmed command sequence that lacked a command to enable an on-board software function designed to activate a gyro needed for control in Emergency Sun Reacquisition mode. The second error, which was in a different pre-programmed command sequence, resulted in incorrect readings from one of the spacecraft's three gyroscopes, which in turn triggered an ESR. At that stage of the investigation, the Board believed that these two anomalous command sequences, in combination with an errroneous decision to send a command to SOHO to turn off a gyro in response to unexpected telemetry values, caused the spacecraft to enter a series of ESRs, and ultimately led to the loss of control. The efforts of the Investigation Board were then directed at identifying the circumstances that had led to the errors, and at identifying and effecting the necessary changes and pursuing corrective actions to prevent similar occurrences in the future.

ESA and NASA engineers still believed the spacecraft was spinning with its solar panels nearly edge-on to the Sun, and thus not generating any power, but that the power situation would improve over the next few months, increasing the probability of successfully establishing contact. In an attempt to recover SOHO as soon as possible, the Flight Operations Team at Goddard began uplinking commands to the spacecraft for approximately 12 hours every day.

With the encouragement of Dr. Alan Kiplinger of NOAA's Space Environment Center in Boulder, researchers at the US National Astronomy and Ionosphere Center in Arecibo, Puerto Rico, used their facility's 305 m-diameter radio telescope to transmit a signal towards SOHO on 23 July. The DSN's 70 m dish in Goldstone (USA) acted as a receiver, locating the spacecraft's echo and tracking it using radar techniques for more than an hour. SOHO had finally been found. Preliminary analysis of the radar data indicated that SOHO was still in its nominal halo orbit, near the L1 Lagrangian point, and turning at roughly one revolution per minute.

To facilitate the recovery procedure, a joint team was established at GSFC under the direction of ESA's Francis Vandenbussche, the ex-SOHO System Engineering Manager. The team consists of ESA, Matra Marconi Space, NASA and Allied Signal staff.

On 3 August, signals sent to SOHO via the DSN station in Canberra, Australia, were answered at 22:51 GMT in the form of bursts of signal lasting from 2 to 10 seconds. These signals were recorded both by the NASA station in Canberra and ESA's own ground station in Perth (W. Aus.). Although the signals were intermittent and did not contain any data information, they showed that the spacecraft was still capable of receiving and responding to ground commands. The slow process of regaining control of the spacecraft and restoring it to an operational attitude commenced immediately, with attempts to initiate data transmissions and to coax information from the spacecraft concerning its on-board status.

The spacecraft initially responded to the attempts to activate its on-board telemetry data system only by sending a simple carrier signal in 10 second bursts. These signals were, however, tracked consistently from ESA's Perth and Redu (Belgium) ground stations, as well as by NASA DSN stations around the world. Initially, the carrier-signal bursts were too short to allow the sensitive ground-station receivers to 'lock-on' to the signal and ESA engineers began assessing ways of obtaining a more continuous signal from the spacecraft. The intermittent nature of the signal is caused by the cyclic variation in the on-board power supply as the solar arrays are shadowed due to the spacecraft's unintentional spin motion.

ESA's Head of Scientific Projects, John Credland, assessed the situation at that point as follows:

"Recovery will be a slow and careful operation. The main thing is that the spacecraft is now responding to us and we will take one step at a time to bring it into a more favourable attitude before assessing any damage which may have been caused by its unforeseen six-week hibernation".

On 8 August, at 23:15 h GMT, six days after receiving the first signal from the dormant SOHO, several blocks of telemetry data giving the spacecraft's on-board status were acquired, prompting Roger Bonnet, ESA's Director of Science, to comment:

"This is the best news I've heard since we lost contact with SOHO on 25 June. I never gave up hope of some recovery of this fantastic mission. We must just hope that the damage sustained due to SOHO's enforced period of deep freeze does not affect the scientific payload too much."

Following analysis of the expected on-board conditions by ESA and Matra Marconi Space (builders of the SOHO spacecraft) engineers, a series of command sequences was up-linked to the spacecraft to divert all available solar array power into a partial charging of one of the on-board batteries. After 10 hours of such battery charging, SOHO's telemetry was commanded on and seven full sets of onboard-status data were received. After just 1 minute, the telemetry was switched off again by the ground controllers in order to conserve onboard resources. Further data on the onboard conditions were obtained the next day (9 August) in two telemetry acquisitions lasting 4 and 5 minutes, respectively. These data included payload temperature and voltage information, which is currently still being analysed.

With the battery-charging technique having proved successful, the SOHO team requested full 24-hour coverage of the spacecraft in an attempt to achieve more complete charging. During this period extensive data sets were obtained detailing the current onboard status, including temperatures, which were much as expected. Further data has been acquired on the current spacecraft attitude, following the successful switching on of one of the Attitude Control Units. The team is currently (12 August) working on the next series of procedures, aimed at thawing out the spacecraft's hydrazine fuel, currently at 0°C, to enable attitude control to be re-established. This will only be attempted once full charging of both onboard batteries can be confirmed, hopefully in the next few days.

Birthday Wishes for a Former ESA Director General from Helmut Schmidt*

When Reimar Lüst was born on 25 March 1923, a wave of passive resistance against the French occupation was sweeping across the Ruhr region. That autumn, the old paper currency was replaced by a new German mark, at the rate of a million millions to one! Sixty years on, Lüst was appointed Director General of the European Space Agency in Paris, where scientists and engineers from Germany and France work together in harmony alongside other European colleagues. Between those two dates lie the calamities unleashed upon the European peoples by Hitler, but also the process of conciliation generously carried out by France.

When Lüst left ESA at the age of 67, he might have been justly proud of a life dedicated to the pursuit of excellence: as a scientist, as a research administrator, as a pioneer in Franco-German co-operation, and as a proponent of internationalism. But he refused to rest on these laurels. Today he leads the Alexander von Humboldt Foundation, supporting talented scientists from all over the World who come to Germany to conduct their research.

Lüst is himself a dedicated research scientist. He started out in nuclear physics, then changed his field of work to plasma physics and astrophysics. He has an office in the Max-Planck Institute that investigates global climate change. He has served as Professor at universities in Germany and the USA. Before going to Paris, he was Chairman of the Scientific Council of the Max-Planck Society for three years running. He headed the Society as President for a total of twelve years. In both of these offices he combined a quiet, modest manner with single-minded tenacity, establishing a legacy that continues to inspire respect.

Lüst never yielded to the temptation to justify basic research (including space exploration) with the promise of technical, economic or military spin-offs. Instead, his main preoccupation has always been the quest for scientific advancement. At the same time, he has worked to promote international co-operation and exchanges between research scientists from different countries. He started to forge personal ties to Russian scientists in the 1950s and to Chinese colleagues in the 1970s. Still, he is a staunch champion of competition in scientific research. "Competition is indispensable", he says.

.... When interviewed by FAZ-Magazin and asked to fill out their questionnaire, he described his motto thus: *"Stay on course, show the flag whenever necessary, fire a shot across the bows if needed"*. And yet, Reimar Lüst is a sincere and friendly individual. He possesses a gift for communicating to others his enthusiasm for science. When I first met him, a quarter of a century ago, it was thanks to the scientific curiosity of my wife. I remember how Lüst showed us the giant parabolic antenna in Effelsberg and explained to us how it had been used to find protein molecules deep in interstellar space. Since then we have become firm friends, jointly founding the German National Foundation for contributing to the re-emergence of a joint national identity for Germans from East and West alike. Much remains to be done.

To Reimar Lüst, my warmest congratulations - Ad multos annos!

* Translated extract from an article in the German daily newspaper "Die Zeit" on 27 March 1998

Cassini/Huygens

The Cassini/Huygens spacecraft performed its first Venus flyby on schedule on 26 April 1998 so successfully that the planned 14 May trajectory correction manoeuvre was not needed. The spacecraft is continuously monitored through NASA's Deep Space Network (DSN) and its health remains excellent. Over the past few months, Cassini's routine flight operations have been devoted mainly to housekeeping and maintenance activities. The spacecraft continues to fly with its fixed High Gain Antenna (HGA) pointing towards the Sun in order to keep Cassini and the Huygens Probe in shadow.

The second Huygens Probe check-out was executed on 27 March in the blind, as the HGA could not be used for high-rate communications with Earth. The data were recorded on the craft's Solid State Recorder (SSR) and played back to Earth during nine DSN passes.

The Probe's housekeeping data processed at ESOC showed nominal behaviour except for some Automatic Gain Control (AGC) levels on both receiver chains: a drop of 3-5 dB and periodic fluctuations. Similar behaviour was noted during the first check-out on 23 October 1997 and was already under investigation. Based on these new measurements, an investigation team under project chairmanship was created and met on 16 April 1998.

The first findings indicated a strong correlation between the induced solar noise picked up by Cassini's HGA and the observed AGC variations during both check-outs. In order to confirm this possible cause, a special contingency check-out with the HGA pointed at least 10 degrees from the Sun was performed on 28 May. The complete set of test measurements was successfully retrieved at ESOC. The AGC values measured on both chains were found to be highly stable, with values by far the best ever obtained during on-ground and in-orbit tests. These confirmed that both receivers performed as expected in a radio noise-free environment and in the presence of solar-induced noise.

It can be concluded that the Probe and associated receivers are in excellent state of health. The next Huygens check-out is scheduled for 22 December 1998.

Publications

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RAPPORT ANNUEL '97
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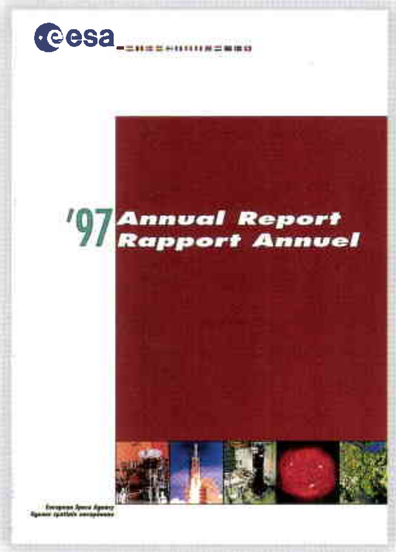
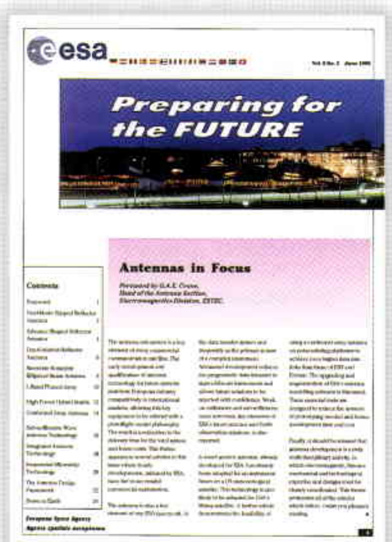
BI-LINGUAL ENGLISH/FRENCH, 166 PAGES
NO CHARGE



ESA Newsletters

EARTH OBSERVATION QUARTERLY
NUMBER 59, JUNE 1998
EDS. T.D. GUYENNE & D. DANESY
NO CHARGE

PREPARING FOR THE FUTURE
VOLUME 8, NUMBER 2 (JUNE 1998)
ED. M. PERRY
NO CHARGE



ESA Brochures

STANDARD PAYLOAD COMPUTER FOR
THE INTERNATIONAL SPACE STATION
(MARCH 1998)
TAYLOR C., KOENIG H. & SCHLOSSSTEIN U.
(ED. B. BATTRICK)
ESA BR-131 // 14 PAGES
PRICE: 15 DFL

SUPPORTING EUROPE'S ENDEAVOURS
IN SPACE: THE ESA DIRECTORATE OF
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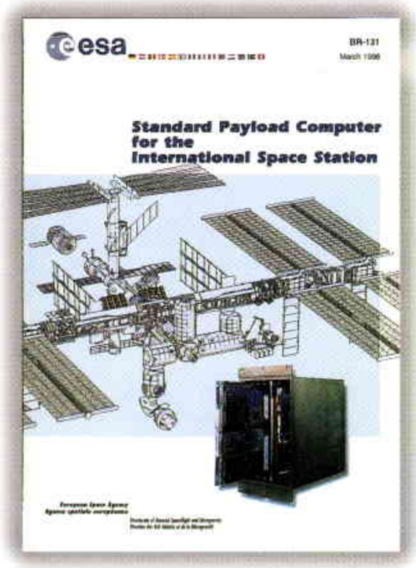

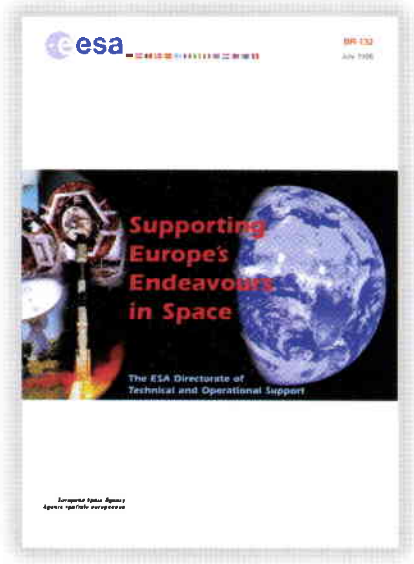

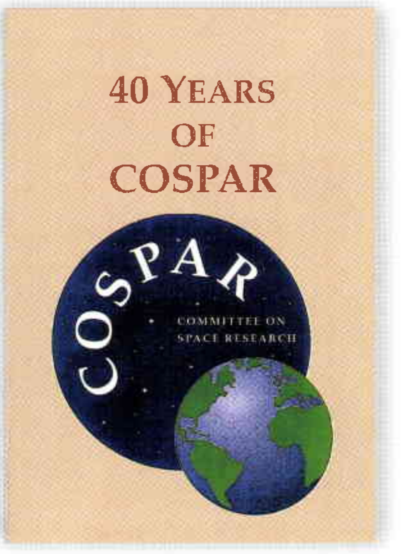

40 YEARS OF COSPAR (JUNE 1998)
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INTERNATIONAL SPACE SCIENCE INSTITUTE (ISSI)
PASCHMANN G. & DALY P.W. (EDS.)
ESA/ISSI SCIENTIFIC REPORT SR-001 // 501 PAGES
PRICE: 70 DFL

THE THIRD EURO – LATIN AMERICAN SPACE CONFERENCE: PROC. ESA/COMISION FEDERAL DE TELECOMMUNICACIONES MEXICO INTERNATIONAL CONFERENCE, 10 – 14 NOVEMBER 1997 (MAY 1998)
GUYENNE T.D. (ED.)
ESA SP-412 // 462 PAGES
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SPACE POWER: PROC. FIFTH EUROPEAN SPACE POWER CONFERENCE, TARRAGONA, SPAIN, 21-25 SEPTEMBER 1998 (AUGUST 1998)
HARRIS R.A. (ED.)
ESA SP-416 // 2 VOLS. 762 PAGES
PRICE: 150 DFL

A CROSSROADS FOR EUROPEAN SOLAR AND HELIOSPHERIC PHYSICS – RECENT ACHIEVEMENTS AND FUTURE MISSION POSSIBILITIES: PROC. ESA/IAC CONFERENCE, PUERTO DE LA CRUZ, CANARY ISLANDS, 23-27 MARCH 1998 (JUNE 1998)
PRIEST E.R., MORENO-INSERTIS F. & HARRIS R.A. (EDS.)
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ECSS SPACE PRODUCT ASSURANCE – MATERIAL SELECTION FOR CONTROLLING STRESS-CORROSION CRACKING (JANUARY 1998)
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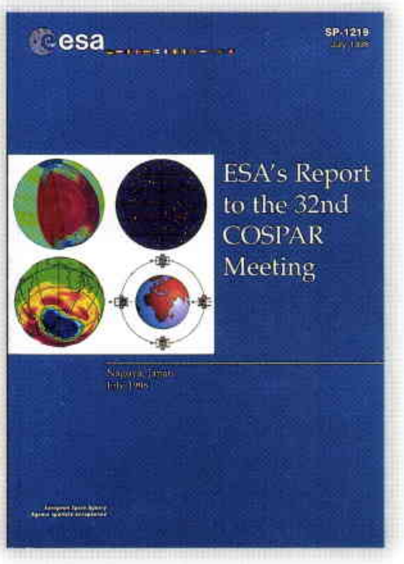

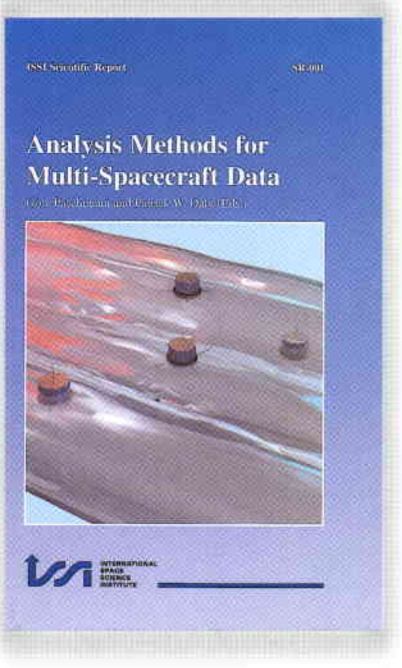

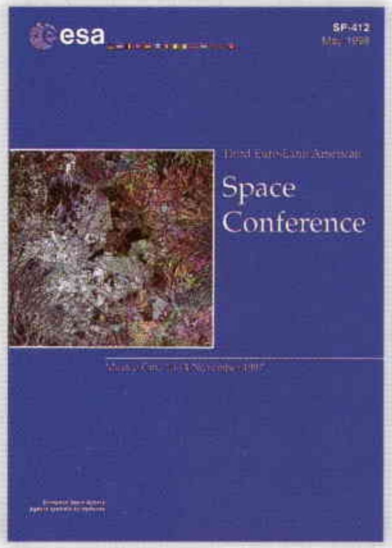

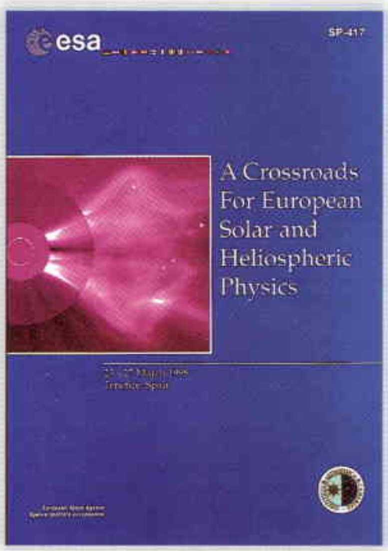

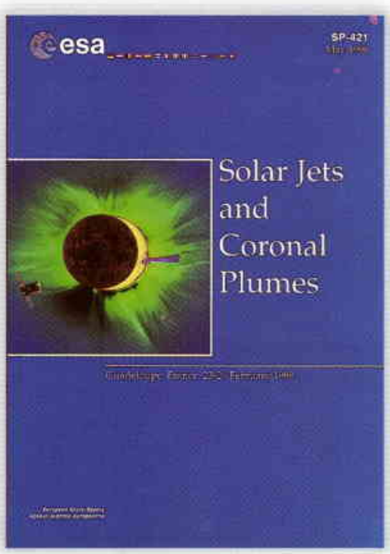

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The Hipparcos and Tycho Catalogues

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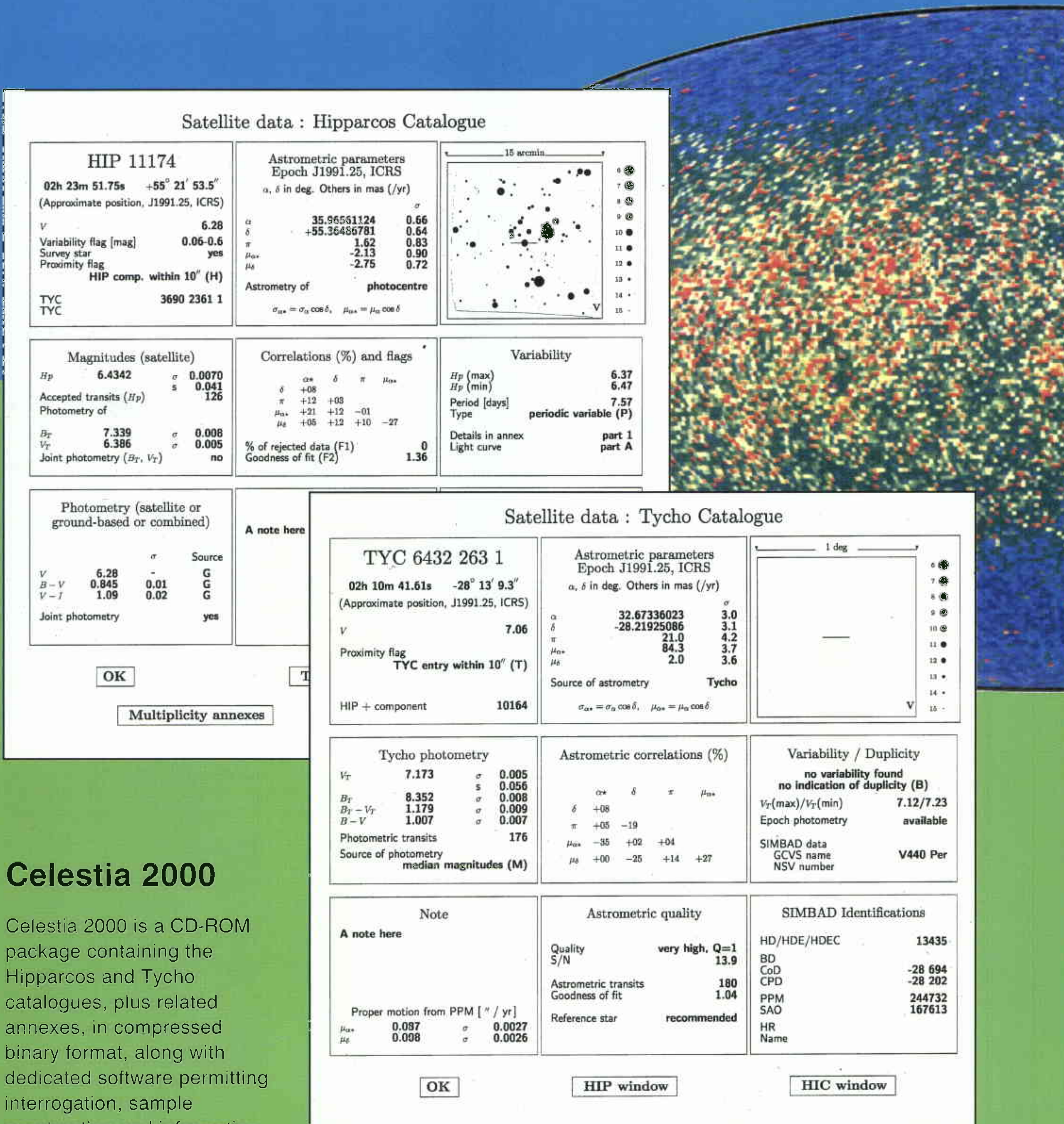

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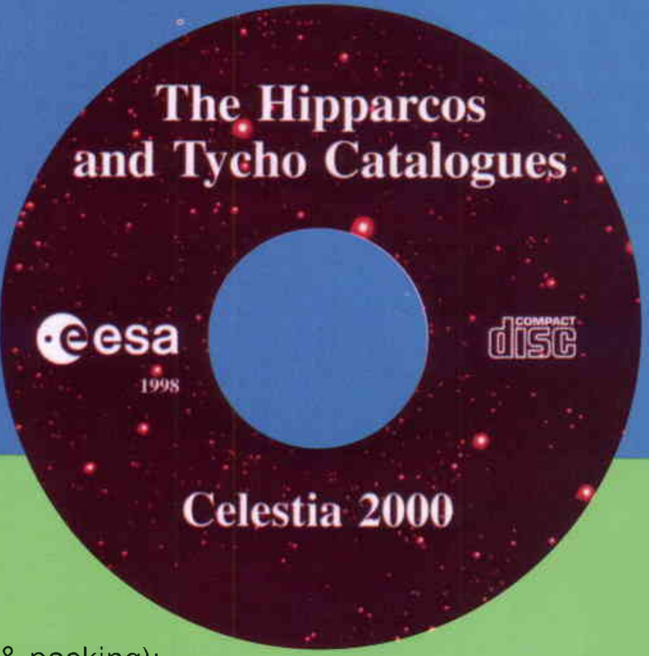

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