esa bulletin

COS-B SPECIAL

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1975

EUROPEAN SPACE AGENCY
AGENCE SPATIALE EUROPEENNE
114 avenue Charles-de-Gaulle
92522 Neuilly-sur-Seine France

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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.

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The Directorate of the Agency consists of the Director General; the Director of Planning and Future Programmes; the Director of Administration; the Director of Scientific and Meteorological Satellite Programmes; the Director of Communication Satellite Programmes; the Director of the Spacelab Programme; the Technical Inspector; the Director of ESTEC and the Director of ESOC.

The ESA HEADQUARTERS are in Paris (Neuilly-sur-Seine).

The major establishments of ESA are:

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

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

EUROPEAN SPACE RESEARCH INSTITUTE (ESRIN), Frascati, Italy.

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(a) en élaborant et en mettant en oeuvre une politique spatiale européenne à long terme, en recommandant aux Etats membres des objectifs en matière spatiale et en concertant les politiques des Etats membres à l'égard d'autres organisations et institutions nationales et internationales;

(b) en élaborant et en mettant en oeuvre des activités et des programmes dans le domaine spatial;

(c) en coordonnant le programme spatial européen et les programmes nationaux, et en intégrant ces derniers progressivement et aussi complètement que possible dans le programme spatial européen, notamment en ce qui concerne le développement de satellites d'applications;

(d) en élaborant et en mettant en oeuvre la politique industrielle appropriée à son programme et en recommandant aux Etats membres une politique industrielle cohérente.

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L'INSTITUT EUROPEEN DE RECHERCHES SPATIALES (ESRIN), Frascati, Italie.

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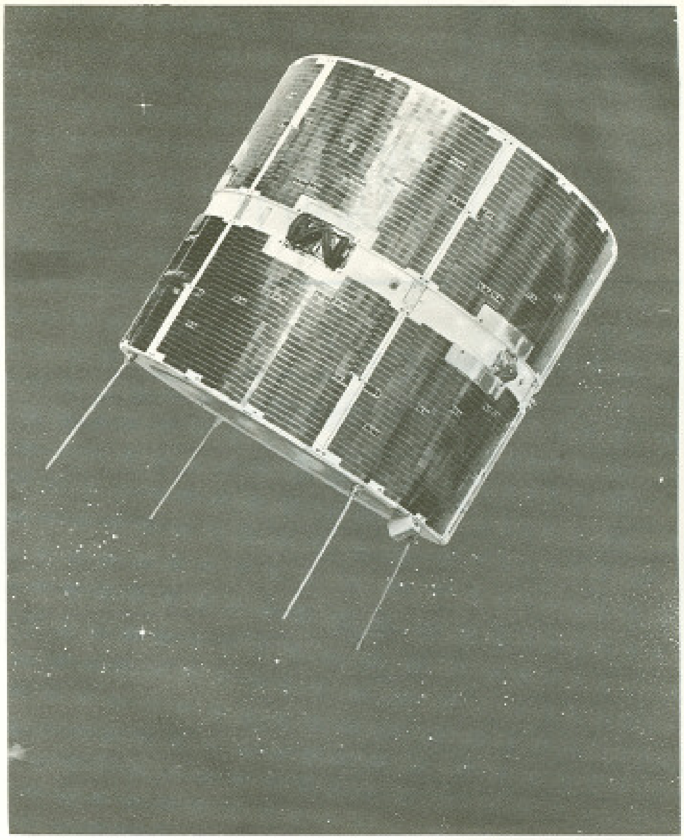
Introduction



R. Gibson, Director General, ESA

A series of feasibility studies aimed at selecting ESRO's next scientific missions was concluded in the spring of 1969. Of the eight prospects found to be feasible, two were alternative versions of a satellite for the study of gamma rays and were known as COS-A (a joint X- and gamma-ray mission) and COS-B (a gamma-ray-only mission). Further studies by ad hoc scientific groups led to the 'A' version being eliminated. Continuation of the selection process resulted in the Launching Programme Advisory Committee's choice of three candidate projects for consideration by the Scientific and Technical Committee (STC). Of these three, the STC recommended two (COS-B and GEOS) to the Council, and in July 1969 the Council formally approved these two projects. COS-B was to be the Organisation's first satellite dedicated to a single experiment, previous satellites having been of the multi-experiment variety.

Une série d'études de faisabilité a été menée au printemps de 1969 en vue de choisir les prochaines missions scientifiques du CERS. Parmi les huit propositions jugées réalisables, figuraient deux variantes d'un satellite d'étude des rayons gamma, baptisées respectivement COS-A (mission astronomique pour l'étude combinée des rayonnements X et gamma) et COS-B (mission d'étude du seul rayonnement gamma). Un supplément d'étude, confié à des groupes scientifiques ad hoc, a conduit à l'élimination de la version A. La poursuite du processus de sélection a abouti au choix, par le Comité consulatif des programmes de lancement, de trois projets pouvant être soumis au Comité scientifique et technique (STC). Sur ces trois projets, le STC en a recommandé deux (COS-B et GEOS) au Conseil et, en juillet 1969, ce dernier les a formellement adoptés. COS-B devait être le premier satellite de l'Organisation voué pour l'essentiel à une seule expérience d'observation astrophysique, les précédents satellites ayant tous emporté plusieurs expériences.

In July 1970, the Organisation awarded Phase-B pre-development contracts for the COS-B project to the CESAR (prime contractor MBB) and EST (prime contractor EASAMS) consortia.

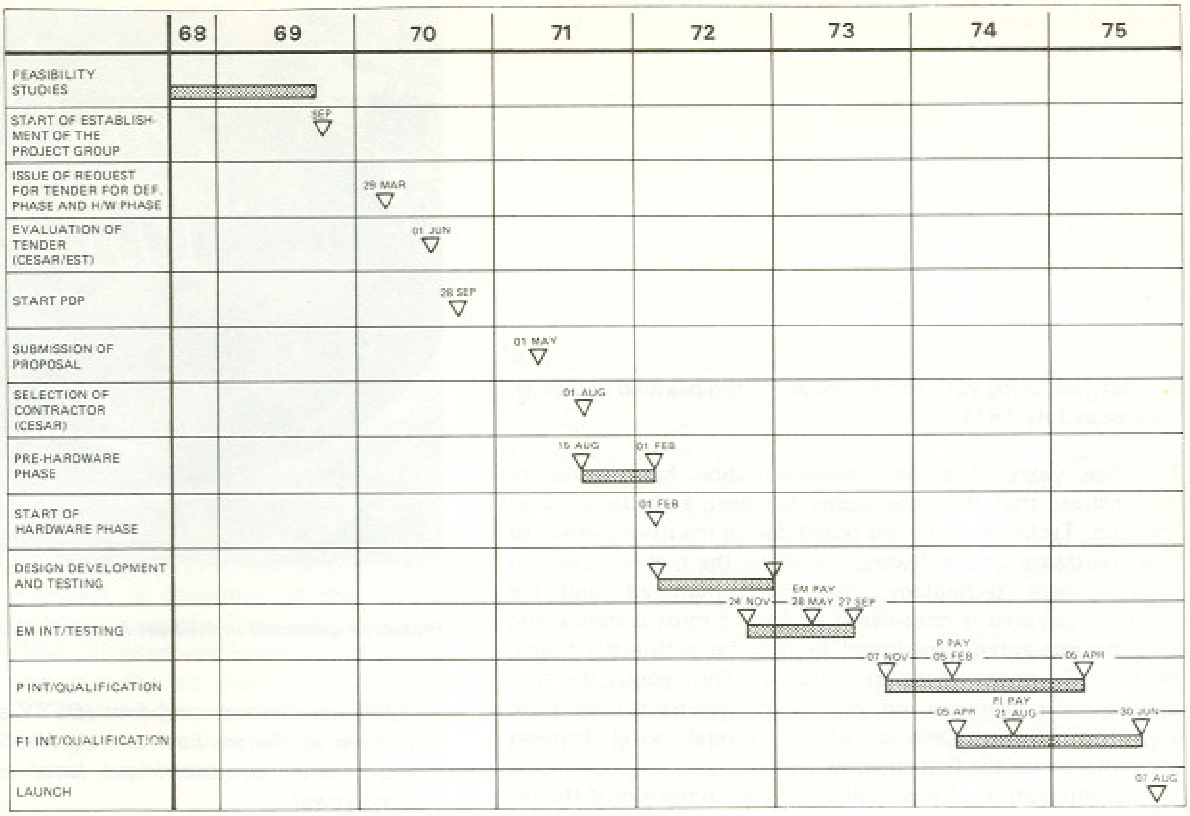
By the summer of 1971, the Phase-B contracts had been completed and the CESAR Consortium was selected to carry out

En juillet 1970, l'Organisation a passé des contrats de prédéveloppement de phase B pour le projet COS-B avec le consortium CESAR (chef de file: MBB) et le consortium EST (chef de file: EASAMS).

Les contrats de phase B une fois achevés, le consortium CESAR a été retenu en été 1971 pour procéder aux phases de développement et de construction du projet. La phase de développement a démarré en janvier 1972 après approbabion définitive par le Comité administratif et financier.

Au cours des deux années suivantes jusqu'au début de 1974, de grands efforts ont été faits afin de respecter la date de lancement prévue (1er février 1975). Malgré la nécessité de remplacer le lanceur Europa II par un Thor-Delta, l'introduction dans la charge utile d'un détecteur de bouffées de rayons gamma et une série de défaillances affectant des composants, la date objectif n'avait glissé que de six semaines. Toutefois, en juillet 1974, les répercussions de conflits du travail dans l'industrie et les retards accumulés qui en ont résulté pour la livraison d'unités de vol ont entraîné une nouvelle révision de la date de lancement. Elle a été repoussée à la mi-juillet 1975, ouverture d'une fenêtre de lancement de deux mois et demi. Un dernier report au 7 août 1975 a été imposé par une révision du calendrier des lancements Delta par la NASA, résultant d'un conflit du travail survenu aux Etats-Unis au début de 1975 dans les ateliers du constructeur du lanceur et sur la base de lancement de Western Test Range (Californie).

Les préparatifs des opérations sur cette dernière base ont



Satellite project history - major events.

the development and construction phases of the project. The development phase started in January 1972 after final approval by the Administrative and Finance Committee.

During the following two years up to early 1974, concerted efforts were made to maintain the envisaged launch date (1 February 1975). In spite of the need to change from a Europa II to a Thor Delta launch vehicle, the introduction of a gamma-burst detector into the payload, and, in particular, a series of component failures, the planned launch date slipped by only six weeks. However, by July 1974 the effects of industrial disputes and consequent accumulated delays in flight-unit deliveries forced a further revision of the launch date. It was moved to mid-July 1975, the opening of a 2½-month launch window. A last change to 7 August 1975 was imposed by NASA's revision of the Delta launch schedule because of an industrial dispute in the USA during early 1975 at the launch vehicle manufacturer's plant and at the launch site (Western Test Range, California).

Preparations for the operations at the launch site culminated in April 1975 when tests performed with the prototype successfully proved the compatibility and effectiveness of the Range facilities.

One particularly significant feature of the programme was the degree of effort devoted to the calibration of the payload. This included beam tests at five accelerators and a high-altitude balloon flight. These calibration tests were conducted on payload models prior to their delivery for satellite integration,

atteint leur point culminant en avril 1975 lorsque les essais menés sur le prototype ont permis de démontrer la compatibilité et le bon fonctionnement des installations de la base.

Parmi les caractéristiques les plus marquantes du programme, il faut souligner l'accent qui a été mis sur l'étalonnage de la charge utile, comportant notamment des essais sous faisceaux sur cinq accélérateurs et un lancement de ballons à haute altitude. Les essais d'étalonnage ont été menés sur les modèles de charge utile avant leur livraison pour intégration dans le satellite, le dernier essai ayant été effectué en juillet 1974, au CERN (Genève), sur le modèle F1 de la charge utile.

En conclusion de ces cinq années de mise en oeuvre du projet, il ressort que ce programme a été un défi pour tous les intéressés. Les problèmes techniques posés au cours du développement du matériel comme du logiciel, faisant intervenir les niveaux les plus élevés de la technologie spatiale actuelle, ont été maîtrisés et la charge utile scientifique est considérée comme l'expérience intégrée la plus délicate et la plus complexe qui ait été construite à ce jour dans le cadre d'une coopération spatiale européenne. Tout au long du programme, les exigences imposées à la gestion du projet ont été exceptionnellement astreignantes en raison de plusieurs caractéristiques rencontrées pour la première fois, par exemple:

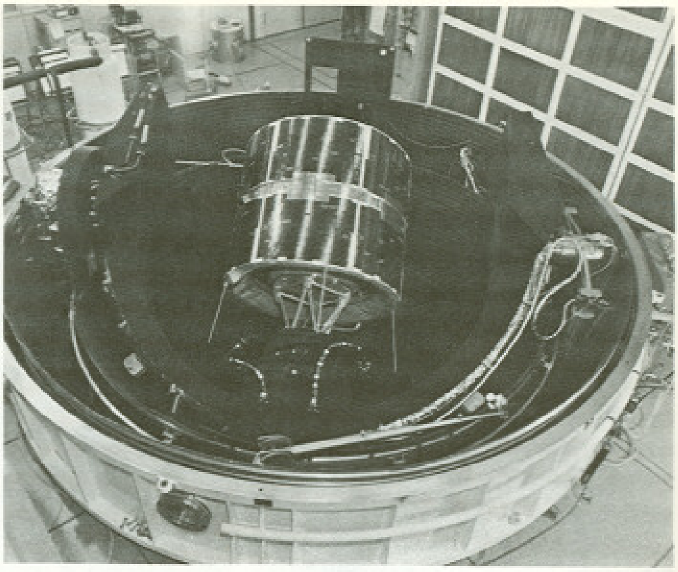
- *première intégration d'une charge utile complexe réunissant des unités différentes provenant de six institutions distinctes;*
- *premier étalonnage d'une expérience intégrée dans trois*

the last test being with the F1 model of the payload at CERN, Geneva in July 1974.

The five years of project implementation have served to demonstrate that this programme has been a challenge to all involved. Technical problems posed during the development of both hardware and software, involving the highest levels of current space technology, have been mastered, and the scientific payload is considered to be the most complex and intricate integrated experiment built so far within the framework of European space co-operation. Throughout the programme, the demands on project management have been unusually exacting because of the several novel features encountered for the first time, such as:

- first integration of a complex payload comprising different units from six different institutes;
- first calibration of an integrated experiment at three different locations in Europe (DESY, Hamburg; CERN, Geneva and the Nuclear Centre, Neuherberg) and by means of a stratospheric balloon flight (Sioux City, Iowa, USA);
- first European satellite requiring special measures for in-orbit control and data reduction (observatory-type satellite).

In all these areas, the Organisation had either no, or very limited, experience. It is therefore not surprising that COS-B has provided more headaches than any other previous satellite. Nor was it always easy to develop a management scheme for the payload which had to be established by mutual and voluntary agreement between ESRO and the members of the payload collaboration, particularly as ESRO was not financing the payload. The fact that the institutes were depending on separate funding had in fact already almost killed COS-B in the cradle, since one of the groups involved could not obtain funding and their part of the experiment had to be taken over in an emergency action by the Space Science Department of ESTEC. Later on, another institute could not get its funds released for a considerable time, and I can recall that, together with Dr. Trendelenburg, I had, in my capacity then as Director of Administration, to fly to several places within 48 hours in order to resolve this problem. At least this gave me a chance to see at first hand the circumstances under which scientists have to carry out an experiment in an international collaboration. This particular experience has been most helpful in obtaining a better understanding of the problems of scientists. The Organisation has also drawn certain conclusions from this experience, such as that for observatory satellites ESA hardware financing is a must. This philosophy has been adopted for the Exosat payload.



Prototype spacecraft in the Heat-Balance Facility at ESTEC.

différents Centres européens (DESY à Hambourg, CERN à Genève et Centre nucléaire de Neuherberg) et au moyen d'un ballon stratosphérique lancé aux Etats-Unis (Sioux City, Iowa);

- *premier satellite européen exigeant des mesures exceptionnelles pour la commande en orbite et le dépouillement des données (satellite du type observatoire).*

Dans tous ces secteurs, l'expérience de l'Organisation était nulle, ou très limitée. Il n'est donc pas surprenant que COS-B nous ait donné davantage de migraines que n'importe quel autre satellite précédent. Il n'a pas non plus toujours été facile de développer un plan de gestion pour la charge utile, plan qui devait être établi par accord mutuel et volontaire entre le CERS et les membres de la 'Collaboration' responsable de la charge utile, et ce en particulier dans la mesure où le CERS ne finançait pas cette dernière. Le fait que les institutions dépendaient de sources de financement distinctes avait déjà pratiquement étouffé COS-B au berceau, car l'un des groupes participants ne put obtenir de crédits et sa part de l'expérience dut être reprise en catastrophe par le Département Science spatiale de l'ESTEC. Par la suite, une autre institution ne put obtenir le déblocage de ses crédits pendant un temps considérable, et je me souviens encore que, avec le Dr Trendelenburg, j'ai dû, à titre de Directeur de l'Administration, voler de ville en ville pendant 48 heures pour tenter de résoudre ce problème. Cela m'a donné au moins l'occasion de voir de mes propres yeux dans quelles conditions des scientifiques doivent travailler dans le cadre d'une collaboration internationale. Cette expérience a été très précieuse pour mieux comprendre les problèmes des scientifiques. L'Organisation en a également tiré certaines conclusions, par exemple celle que, pour des satellites d'observation, le financement des matériels par l'ASE est une condition sine qua non. C'est pourquoi cette doctrine a été adoptée pour la charge utile d'Exosat.

Je tiens à profiter de l'occasion qui m'est donnée pour remercier les Directeurs des institutions participantes (le

I should like to take this opportunity to thank the Directors of the co-operating Institutes (Prof. Lüst and later Prof. Pinkau, Garching; Prof. van de Hulst, Leiden; Profs. Occhialini and Scarsi, Milan and Palermo, and Prof. Labeyrie, Saclay, and the former Head of the Space Science Department, Dr. Trendelenburg) and their collaborators for the excellent spirit in which they managed to overcome the intrinsic difficulties of such a venture. We owe particular thanks to Prof. van de Hulst, who acted throughout the project as Chairman of the COS-B Steering Committee and from whom the Organisation, as well as the collaboration, often obtained extremely useful advice and assistance. I should also like to thank the Directors General of CERN, DESY and the Nuclear Centre at Neuherberg, Germany, for making their facilities available for the beam tests. □

Professeur Lüst, auquel a succédé le Professeur Pinkau, à Garching, le Professeur Van de Hulst à Leyde, les Professeurs Occhialini et Scarci à Milan et Palerme, et le Professeur Labeyrie à Saclay, sans oublier l'ancien Chef du Département Science Spatiale, le Dr Trendelenburg) ainsi que leurs collaborateurs, pour l'esprit remarquable avec lequel ils ont réussi à surmonter les difficultés propres à une telle entreprise commune. Nous devons une reconnaissance particulière au Professeur Van de Hulst qui, pendant toute la durée du projet, a présidé le Comité directeur COS-B et qui a très souvent fourni à l'Organisation comme à la 'Collaboration Caravane' une assistance et des conseils extrêmement utiles. Je tiens également à remercier les Directeurs généraux du CERN, du DESY et du Centre nucléaire de Neuherberg, pour avoir prêté leurs installations pour les essais au rayonnement. □

COS-B Launched

COS-B was successfully launched from Western Test Range, California, at 0147 hours (GMT), 9 August 1975. On 12 August, the following telex about its orbital performance was received from ESOC, Darmstadt:

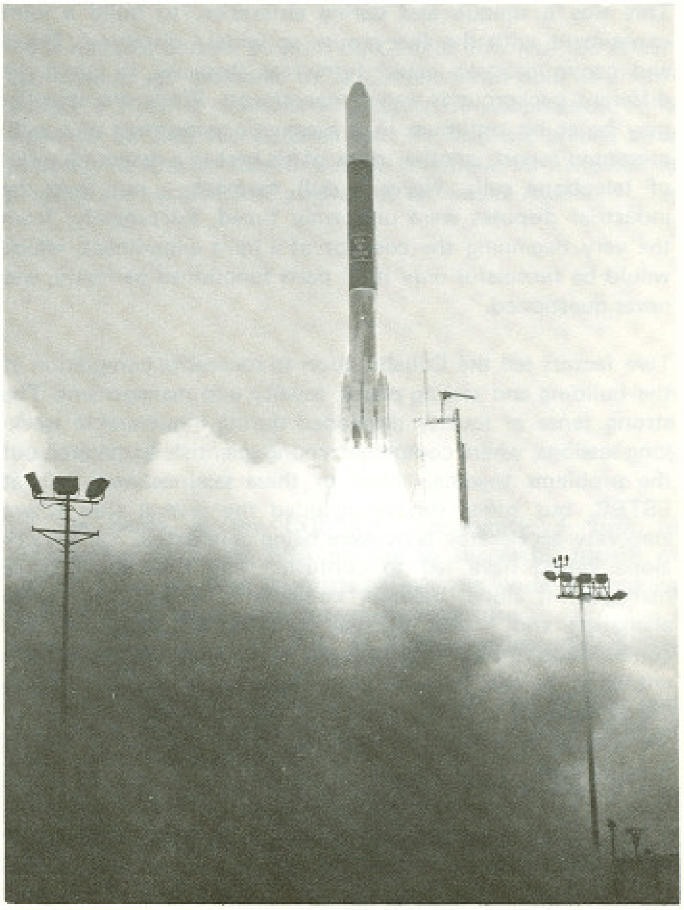
as of 1530 hrs today 12 august 1975 the status of cos-b was as follows:

1. orbit, spot-on nominal.
2. spacecraft subsystems, all operating correctly with a good margin on the telemetry link for operation at 320 bps at apogee.
3. main experiment, all units operating correctly with no change in technical functions as measured prior to launch.
4. pulsar synchronizer, operating correctly.
5. gamma burst, operating correctly.

we have completed our first proton and gamma runs and have 'pictures' of the first proton and gamma ray events.

perhaps the most important news is that the orbital trigger rate is compatible with the 160 bps telemetry rate. for example for telescope in narrow angle mode, we have a rate of 0.24/second and with ei at approx 12 mev in coincidence we have a rate of 0.13/second.

we seem to be in business. □



The Venture of a Joint Experiment

Réflexions sur les aléas d'une expérience à participation multiple

Prof. H. van de Hulst, Chairman, COS-B Steering Committee

On 16 May 1969, a group of five university and research institutes approached ESRO with a letter of intent proposing that they should build jointly the experiment conceived for the COS-B satellite. It transpired subsequently that one of these institutes would not be able to obtain national funding and its place in the Collaboration was taken by Space Science Department, ESTEC. The four remaining members of the proposing Collaboration (in alphabetical order of location) were:

Max-Planck-Institut für Physik und Astrophysik, Institut für Extraterrestrische Physik, Garching

Cosmic-Ray Working Group, University of Leiden

Istituto di Scienze Fisiche, University of Milan, in collaboration with the University of Palermo

Centre d'Etudes Nucléaires, Saclay

This was a unique and daring enterprise, to build a joint experiment with the five groups so widely dispersed. Travel and communication could form real obstacles, as could the different backgrounds and temperaments. While one scientist may be at his optimum in a pragmatic assessment of a well-presented report, another gives of his best in a desperate series of telephone calls. Never a dull moment — not even the industrial disputes were uniformly timed. Fortunately, from the very beginning the concept of a joint experiment, which would be successful only if all parts functioned perfectly, was never questioned.

Two factors led the Collaboration to successful completion of the building and testing phase: loyalty and management. The strong sense of loyalty developed during innumerable week-long sessions, where competent young scientists hammered out the problems together. Most of these sessions were held at ESTEC, but other venues included the several sites where elaborate accelerator tests were being conducted. Yet loyalty alone would have led to confusion and frustration, while management alone, however competent, would have led to alienation and a lack of real involvement: only the right combination of both factors could work. The management was entrusted to the Space Science Department, ESTEC. It was conducted with a fine sense of equilibrium, making full use of the possibilities for close contact with the entire project management.

Finally, there was the COS-B Steering Committee, made up by the Heads of the Institutes involved in the Collaboration. It met 18 times in the past seven years, chaired first by Reimar

Le 16 mai 1969, un groupe de cinq universités et instituts de recherche adressait au CERS une déclaration d'intention dans laquelle il proposait de réaliser en commun la charge utile destinée au satellite COS-B. On apprenait par la suite que l'un des instituts en question ne serait pas à même d'obtenir les crédits gouvernementaux requis; c'est le Département Science Spatiale de l'ESTEC qui vint occuper la place laissée vacante au sein de la Collaboration scientifique, dont les quatre autres membres étaient les suivants (dans l'ordre alphabétique de leur lieu d'établissement):

Max-Planck-Institut für Physik und Astrophysik, Institut für extraterrestrische Physik, Garching

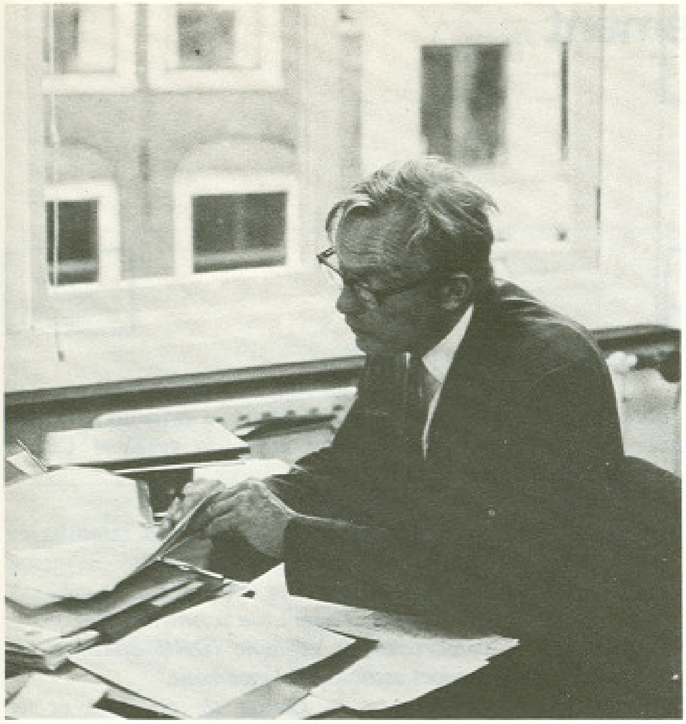
Groupe d'études des rayons cosmiques, Université de Leyde

Istituto di Scienze Fisiche, Université de Milan (en collaboration avec l'Université de Palerme)

Centre d'Etudes Nucléaires, Saclay.

Vouloir construire en commun un appareillage scientifique embarqué représentait une entreprise aussi nouvelle qu'audacieuse vu l'éloignement géographique des différents participants. Les déplacements et les communications nécessaires risquaient d'occasionner une grande gêne, tout comme la diversité des formations et des tempéraments. En effet, tel scientifique peut être particulièrement à son aise quand il s'agit de porter un jugement à tête reposée sur un rapport en bonne et due forme, alors que tel autre donnera le meilleur de lui-même au milieu d'une série de conversations frénétiques au téléphone. En tout cas, jamais le temps de s'ennuyer, puisque même les conflits du travail survenus dans l'industrie n'étaient pas synchronisés d'un pays à l'autre. Heureusement, l'idée d'une expérience à participation multiple exigeant pour réussir un fonctionnement parfait de tous ses éléments n'a été mise en question à aucun moment.

Deux facteurs ont permis à la 'Collaboration' de mener à bien la réalisation et les essais des équipements, à savoir un dévouement sans faille et une gestion bien comprise. Le premier s'est affirmé à l'occasion d'innombrables réunions au cours desquelles, des semaines durant, de jeunes et talentueux hommes de science se sont attachés à aplanir ensemble les difficultés. Ces réunions se sont tenues pour la plupart à l'ESTEC mais plusieurs visites ont également eu lieu dans divers centres où se déroulaient des essais complexes à l'aide d'accélérateurs de particules. Cependant, le seul dévouement aurait abouti à la confusion et à un climat de frustration; de même, la seule



Professor van de Hulst is Professor in Astrophysics at the University of Leiden, having held that chair since 1955, and is Chairman of the Netherlands National Committee on Geophysics and Space Research. A former chairman of COSPAR, he has very recently retired as chairman of ESA's Launching Programmes Advisory Committee. From 1968 to 1970 he was Chairman of the ESRO Council.

Lüst, and later by myself. During this time, it suffered its full share of the ups and downs of the project. Its task, in retrospect, can best be defined as that of removing all impediments to the proper functioning of the loyal co-operation outlined above.

On behalf of the Steering Committee, I wish to thank each member of the Collaboration for his contribution, members whose unrelenting input and caution in safeguarding the technical and scientific quality of the experiment are the best guarantee of ultimate success. □

gestion, aussi compétente qu'elle puisse être, aurait engendré une situation aliénante et un manque d'intérêt véritable pour le projet; ce qu'il fallait, c'est un dosage judicieux de ces deux éléments. La gestion du projet, confiée au Département Science Spatiale de l'ESTEC, a été conduite avec un remarquable sens de l'équilibre, en tirant profit au maximum des possibilités de contact suivi avec l'ensemble des administrateurs du projet.

Enfin, il faut mentionner le Comité directeur du programme COS-B, formé par les Directeurs des instituts participants. Ledit Comité s'est réuni 18 fois en sept ans, d'abord sous la présidence de Reimar Lüst, puis sous la mienne. Durant tout ce temps, il a eu largement sa part des heurs et malheurs du projet. Rétrospectivement, on peut dire que sa tâche aura consisté à écarter tous les obstacles qui s'opposaient au bon fonctionnement de la collaboration franche et loyale évoquée plus haut.

Qu'il me soit permis, au nom du Comité directeur, de remercier chacun des membres de la Collaboration pour sa contribution à l'oeuvre commune. L'esprit de coopération et la vigilance de tous les instants dont ils ont fait preuve pour préserver la qualité scientifique et technique de l'expérience projetée sont la meilleure garantie de sa réussite finale. □

Congratulations

At the time of going to press, the Director General had received the following congratulatory messages:

Je suis heureux de vous adresser les plus vives félicitations du Centre National d'Etudes Spatiales pour le lancement réussi du premier satellite de l'Agence Spatiale Européenne.
Prof. M. Lévy, Président du CNES, Paris

Delighted to hear orbit is good and that you have a good spacecraft with all experiments working well. Congratulations and best wishes for a complete scientific success.
W. P. Murphy, NASA European Representative, American Embassy, Paris

In the name of the COSPAR Community, I wish to congratulate you and ESA on the so successful launch of COS-B. I am sure that scientists all over the world are looking forward to the results of this exciting enterprise.
Prof. C. de Jager, President of COSPAR

Delighted to hear of successful launch of COS-B and functioning of on-board systems, the first of our ESA satellites and a good omen for the future.
H. Robinson, Head of UK Delegation to ESA

Congratulations on the first ESA launch. Eurosat wish a long and successful mission for COS-B.
Dr. P. Blassel, Director General of Eurosat

Project Organisation and Management
Organisation et gestion du projet

G. Altmann, Project Manager

The organisation and management of an international aerospace project like COS-B forms a vital and integral part of the overall effort needed for successful project implementation. The complexity of the hardware and associated software, as well as the manifold operations to be performed by the geographically divorced participants, require the setting-up of a single centre (Project Division) responsible for the co-ordination, supervision and control of all activities and resources.

In the case of a scientific satellite programme, the ultimate goal of this group of staff is to complete the project task within a given schedule and given financial envelope, carefully ensuring that all technical requirements emanating from the scientific objectives are met without degrading or unnecessarily improving the quality or reliability of the end product, i.e. it is to provide and operate a satellite capable of carrying out the defined mission.

Pour mener à bien un projet aérospatial international comme COS-B, organisation et gestion sont des éléments essentiels de l'effort global. La complexité des matériels et du logiciel connexe, ainsi que la multiplicité des opérations que doivent exécuter des participants éloignés géographiquement nécessitent la mise en place d'un centre de décision unique (Division de projet) assurant la coordination, la supervision et le contrôle de toutes les activités et ressources.

Dans le cas d'un programme de satellite scientifique, l'objectif d'un tel organe est en définitive de mener le projet à bonne fin, dans un délai spécifié et dans des limites financières données, en veillant à ce que tous les impératifs techniques découlant des objectifs scientifiques soient respectés, sans altérer ni améliorer inutilement la qualité et la fiabilité du produit final, autrement dit de fournir et d'exploiter un satellite capable d'exécuter la mission définie.

PROJECT ORGANISATION

Three basic areas of programme effort are reflected in the organisational scheme selected for development of the overall COS-B system:

Satellite — comprising all hardware and software and

ORGANISATION DU PROJET

Pour l'exécution du programme, le schéma organique retenu pour le développement de l'ensemble du système COS-B comporte trois domaines principaux:

Satellite — comprenant toutes les activités relatives au matériel, au logiciel et aux activités connexes touchant au satellite, c'est-à-dire: le véhicule spatial et la charge utile scientifique.

Lanceur — comprenant le véhicule (Delta 2913) et les services associés au lancement.

Segment sol — comprenant le Centre de contrôle et les stations au sol (Redu et Fairbanks) nécessaires à des opérations comme l'acquisition et la transmission des données ainsi que la poursuite pendant la phase orbitale.

La Figure 1 montre l'organisation générale du projet. A l'origine du programme, un bureau spécial a été créé à l'ESTEC afin d'assurer, directement ou indirectement, la liaison avec toutes les parties intéressées à l'exécution du travail. La première tâche du Bureau du projet COS-B a été de tracer les grandes lignes du concept de référence du projet, et notamment:

- *la description des tâches (objectifs)*
- *l'énoncé des travaux (spécification des impératifs)*
- *la planification des ressources (budget)*
- *la mise en oeuvre des tâches (moyens et plans)*
- *le contrôle de l'exécution (gestion).*

Une fois que tous les éléments du projet ont été correctement définis et que les travaux de développement ont pu démarrer, le rôle du Chef de projet et de son équipe est devenu un rôle de coordination et de supervision; disposant d'un soutien fonctionnel et intégré, il leur fallait faire en sorte que les objectifs de référence soient atteints et les impératifs respectés par les institutions scientifiques, l'industrie aérospatiale, les Etablissements du CERS et les organismes internationaux participant au projet.

Quant à la Division de projet, son rôle a été celui d'un point de convergence entre:

- *la collaboration scientifique ('Collaboration Caravane')*
- *l'industrie aérospatiale (consortium CESAR)*
- *le soutien fonctionnel, technique et administratif assuré par l'ESTEC*
- *le soutien fonctionnel assuré par l'ESOC pour les opérations en orbite, et*

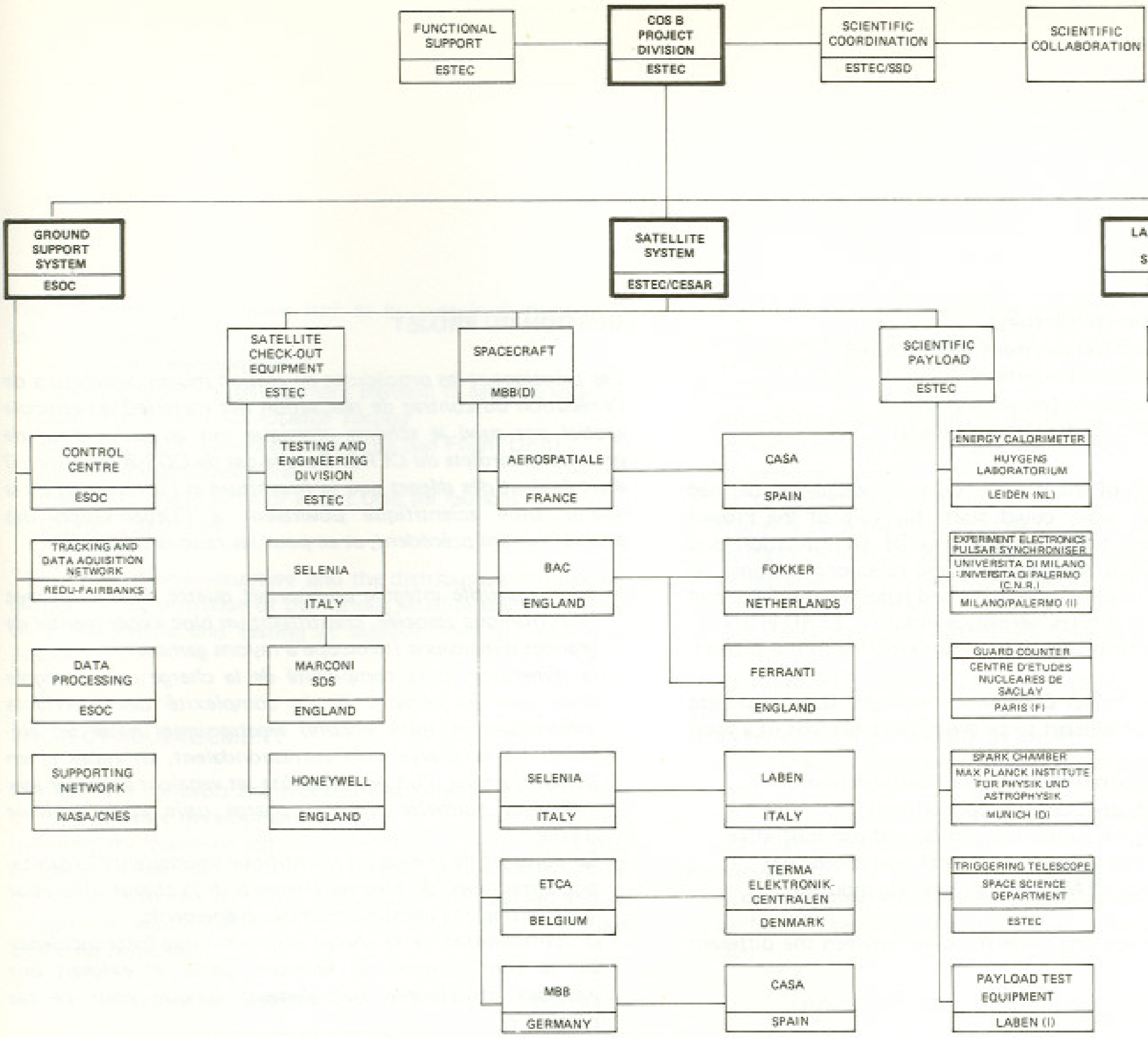


Figure 1 — COS-B satellite project — organisation chart

associated satellite activities, i.e. spacecraft *and* scientific payload

Launcher — comprising the launch vehicle (Delta 2913) and the associated services for launch

Ground Segment — comprising the Control Centre and ground stations (Redu and Fairbanks) for such operations as data acquisition and transmission, as well as tracking during the orbital phase.

Figure 1 shows the overall organisation of the project. At the outset of the programme, a special office was set up at ESTEC, interfacing directly and/or indirectly with all parties involved in the execution of the work.

The first task of the Project Office was to outline the baseline concept for the project, including:

— *l'agence responsable du lanceur (NASA) et l'industrie de soutien*

de façon à assurer, compte tenu des différents types et niveaux de soutien à fournir, une harmonisation parfaite du travail entre les différentes parties (Fig. 2).

La Division de projet a dû soutenir son effort tout au long des quatre phases principales:

— Conception et développement
(travaux portant sur les modèles d'identification, jusqu'au niveau du satellite)
— Essais de qualification et de recette
(travaux portant sur le prototype et le modèle de vol)
— Opérations sur la base de lancement
(préparation du modèle de vol pour le lancement)
— Opérations en orbite

La structure organique et la répartition des responsabilités pour la fourniture des différents sous-systèmes du satellite ainsi que pour leur intégration et les essais au niveau du satellite sont indiquées à la Figure 3.

- Task description (objectives)
- Work statement (requirement specification)
- Resource planning (budgeting)
- Task implementation (means and plans)
- Implementation control (management).

Once all elements of the project had been adequately defined and development work could start, the role of the Project Manager and his team became one of co-ordination and supervision, assisted by integrated and functional support, to ensure that the baseline objectives and requirements were met in the scientific institutes, aerospace industry, ESRO establishments and international agencies participating in the project.

The role of the Project Division, in the light of the different types and levels of support to be given, has been that of a focal point for
- scientific collaboration (Caravane Collaboration)
- spacecraft industry (CESAR Consortium)
- ESTEC functional support, technical and administrative
- ESOC functional support for orbital operations, and
- launcher agency (NASA) and supporting industry

to ensure a full working understanding between the different parties (Fig. 2).

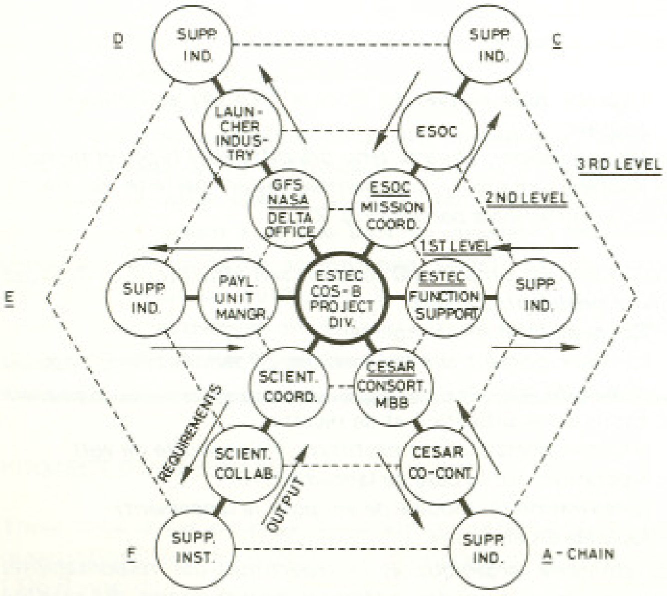


Figure 2 — Co-ordination chains for first, second and third support levels.

GESTION DU PROJET

Les principes et les procédures de gestion mis en oeuvre lors de l'exécution du contrat de réalisation des matériels du véhicule spatial ont suivi le schéma classique mis au point pour de précédents projets du CERS. Dans le cas de COS-B toutefois, il était évident dès départ que la fourniture et l'intégration de la charge utile scientifique poseraient à l'Organisation des problèmes sans précédent, et ce pour les raisons suivantes:

- *la charge utile intégrée comportait quatre détecteurs avec l'électronique associée, constituant un bloc expérimental de grandes dimensions (télescope à rayons gamma);*
- *la dimension et la complexité de la charge utile intégrée ainsi que le nombre et la complexité des interfaces mécaniques et (plus encore) électroniques entre les éléments de la charge utile correspondaient, en types et en nombre, à ceux d'un petit satellite, et venaient s'ajouter aux interfaces normales entre la charge utile et le véhicule spatial;*
- *les objectifs de la mission scientifique imposaient l'exploitation simultanée de tous les éléments de la charge utile pour la définition et l'identification des événements;*
- *la configuration de la charge utile avait une forte incidence sur la configuration du véhicule spatial et exigeait une interface structurelle spécialement conçue pour ce cas particulier;*
- *l'intégration des éléments de la charge utile en une seule expérience, prête à être réceptionnée par le contractant chargé du satellite, était considérée comme une tâche majeure du programme;*
- *l'étalonnage de la charge utile intégrée pour vérifier la qualité de ses performances scientifiques consituait une innovation pour le programme de développement et devait être effectuée sur trois modèles (scientifique, d'identification et de vol) dans des installations situées en Europe (accélérateurs de Bonn, du DESY à Hambourg et du CERN à Genève) et aux Etats-Unis (vol de brève durée en ballon stratosphérique à Sioux City);*
- *des efforts particuliers devaient être effectués sur une période de plusieurs années pour mettre au point le logiciel nécessaire au traitement et à l'évaluation des données, à la fois pendant les essais au sol et pendant l'exploitation en orbite du satellite.*

Comme le montre la Figure 2, la gestion a été assurée par le biais de deux 'chaînes' de coordination:

La CHAINE E, qui a trait à la gestion technique de la charge utile, *fait appel:*

The Division's efforts have had to be sustained throughout four main phases:

- *Design and Development*
  (covering work on development models, to satellite level)
- *Qualification and Acceptance Testing*
  (covering work related to Prototype and Flight Unit)
- *Launch-Range Operations*
  (geared to preparation of Flight Unit for launch)
- *Orbital Operations*

The organisational structure and the distribution of responsibilities for the provision of the various satellite subsystems and their integration and testing at satellite level are shown in Figure 3.

PROJECT MANAGEMENT

Management concepts and procedures applied in the execution of the hardware development contract for the spacecraft have followed the standard pattern developed for previous ESRO projects. In the case of COS-B, however, it was evident from the outset that the provision of the scientific payload and its integration would present the Organisation with a unique challenge because:

- *à la Section charge utile COS-B (ESTEC)*
- *aux responsables des éléments de la charge utile*
- *à l'industrie de soutien*

et couvre:

- *les spécifications d'interface des éléments de la charge utile*
- *les spécifications d'interfaces de la charge utile intégrée et du véhicule spatial*
- *les spécifications des essais et des procédures d'essais des éléments de la charge utile et de la charge utile intégrée*
- *les essais de recette des éléments de la charge utile*
- *l'intégration et l'essai de la charge utile complète (avec soutien de l'industrie)*
- *l'assurance de qualité relative aux activités ci-dessus.*

La CHAINE F, qui a trait à la gestion scientifique de la charge utile, *fait appel:*

- *au responsable scientifique du projet*
- *à la collaboration scientifique (responsables des expériences)*
- *aux institutions et organismes scientifiques pour la réalisation pratique de l'étalonnage*

et couvre:

- *la définition des objectifs de la mission scientifique, et plus particulièrement la définition d'un programme d'observation*

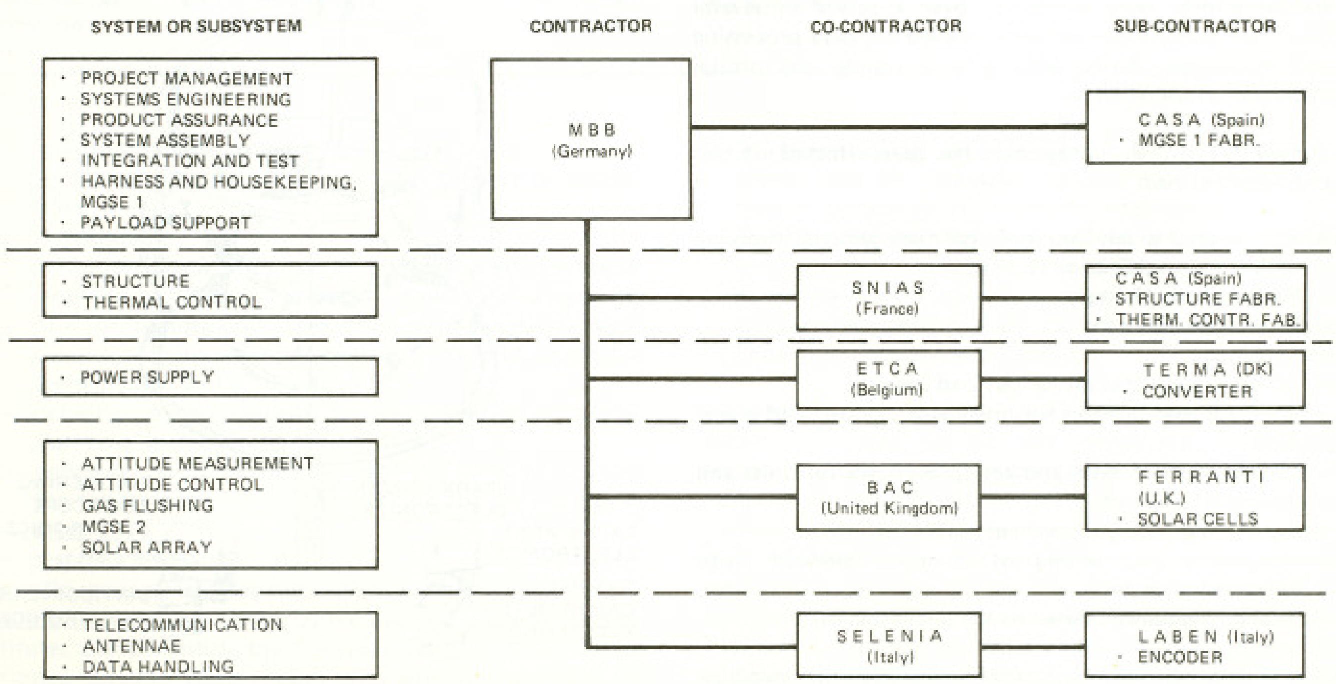


Figure 3 – Industrial organisation and task distribution.

– the integrated payload comprises four detector units and associated electronics, which constitute a large experiment package (gamma-ray telescope);
– the size and complexity of the integrated payload and the number and complexity of the mechanical and (particularly) electronic interfaces between payload units are equivalent in type and number to those of a small satellite and are additional to the normal interfaces between the payload and the spacecraft;
– the scientific mission objectives require the simultaneous operation of all payload units for event definition and recognition;
– the payload configuration had a strong impact on the configuration of the spacecraft and called for a specially designed structural interface;
– the integration of the payload units to form a single experiment, ready for acceptance by the satellite contractor, was considered a major programme task;
– the calibration of the integrated payload to verify its scientific performance was a novel feature of the development programme and was undertaken for three models (scientific, engineering and flight) at locations in Europe (accelerators at Bonn, at DESY, Hamburg and CERN, Geneva) and in the USA (Sioux City; short stratospheric balloon flight);
– special efforts were necessary, over a period of several years, to develop the software needed for data processing and evaluation during both ground testing and orbital operation of the satellite.

As shown in Figure 2, management has been effected via two co-ordinatory chains:

CHAIN E, related to *payload technical management,* involving
  – COS-B Payload Section (ESTEC)
  – Payload-Unit Managers
  – Supporting Industry
and comprising:
  – interface specification for payload units
  – interface specification for integrated payload and spacecraft
  – specification of tests and test procedures for units and integrated payload
  – acceptance testing of payload units
  – integration and testing of complete payload (with industrial support)
  – product assurance related to the above activities.

CHAIN F, related to *payload scientific management,* involving
  – Project Scientist

Figure 4 – Integrated central detector package being tested with the payload test equipment at ESTEC.

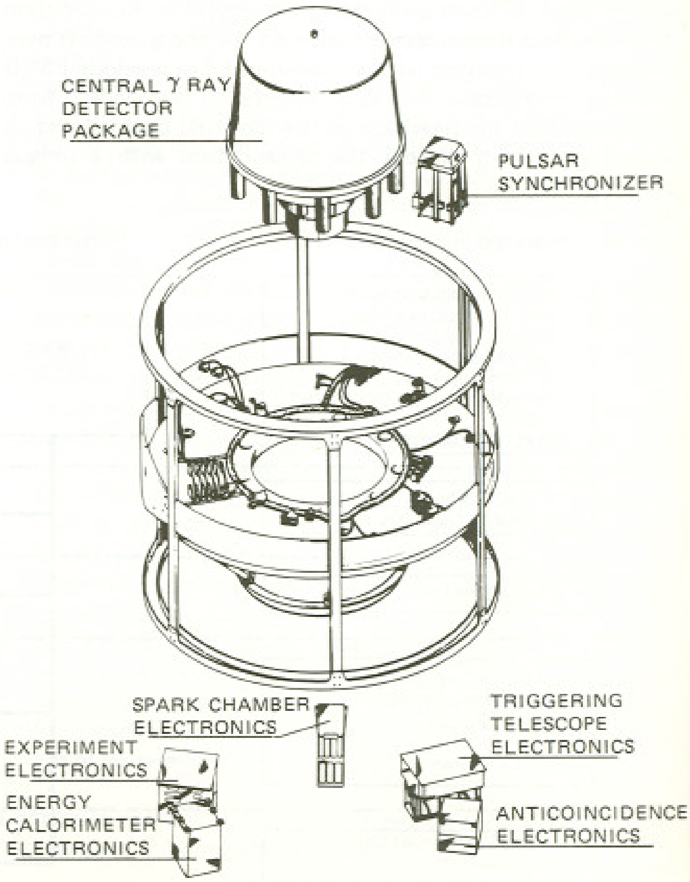


Figure 5 – Subsystems of the scientific payload.

TABLE 1

Institutes and personnel of the Caravane Collaboration participating in the COS-B programme (group leaders indicated with an asterisk)

Cosmic-Ray Working Group Huygens Laboratory Leiden, The Netherlands	J.A.M. Bleeker J.J. Burger W. Hermsen H.C. v.d. Hulst* P.J. de Korte A. Scheepmaker B.N. Swanenburg
Laboratorio di Fisica Cosmica e Tecnologie Relative del CNR, Istituto di Scienze Fisische dell'Università di Milano, Via Celoria 16, 20133 Milan, Italy	G.F. Bignami G. Boella P. Cortellessa P. Mussio G. Occhialini* C. Occhialini-Dilworth G. Sironi R. Stiglitz
Universita di Palermo, Istituto Fisica Universita, Via Archirafi 36, Palermo, Italy	R. Buccheri P. Coffaro D. Molteni L. Scarsi
Max Planck Institut für Physik und Astrophysik, Institut für Extraterrestrische Physik, 8046 Garching-bei-München, Germany.	N. Heinecke K. Herterich H. Kanbach G. Kettenring H.A. Mayer-Hasselwander E. Pfeffermann K. Pinkau* P.G. Shukla W. Voges
Service d'Electronique Physique, Centre d'Etudes Nucléaires de Saclay, 91 Gif-sur-Yvette, France.	M. Cretolle R. Duc P. Faiche M. Gorisse P. Keirle L. Koch J Labeyrie* J. Paul
Space Science Department, European Space Research and Technology Centre, Noordwijk, The Netherlands.	R.D. Andresen I. Arens K. Bennett B.G. Taylor E.A. Trendelenburg* R.D. Wills

– Scientific Collaboration (experiment officers)
– Scientific Institutes and Agencies in Support of Calibration

and comprising:

– definition of scientific mission objectives, with particular emphasis on the definition of an observation programme
– payload performance parameter determination (particularly background-rejection capability and acceptable event trigger rate)
– definition of requirements for and execution of calibration tests, including the balloon flight
– definition and implementation of the software required for testing scientific performance on the ground and in orbit
– test-data evaluation.

Scientific management for the COS-B project has been in the nature of a joint undertaking by six leading European research institutes that constitute the 'Caravane Collaboration'. The six institutes, listed in Table 1, have been directly responsible for the design and provision of payload units and the software for

– *la détermination des paramètres de performance de la charge utile (en particulier capacité d'éliminer le bruit de fond et cadence de déclencement acceptables)*
– *la définition des impératifs et des modalités des essais d'étalonnage, y compris le vol en ballon*
– *la définition et la mise en oeuvre du logiciel nécessaire pour éprouver les performances scientifiques au sol et en orbite*
– *l'évaluation des données d'essais.*

La gestion scientifique du projet COS-B a été une entreprise commune menée par six des principales institutions de recherche européennes groupées au sein de la 'Collaboration Caravane'. Ces six institutions, dont la liste figure au Tableau 1, ont été directement responsables de la conception et de la fourniture des éléments de la charge utile et du logiciel nécessaire à l'analyse des données après le lancement. Il s'agit, dans tous les cas, d'institutions créées de longue date et très au fait de la réalisation et de l'exploitation d'expériences embarquées sur satellite, pour avoir participé à de précédents programmes européens, nationaux ou de la NASA.

post-launch data analysis. All are long-established institutes, well experienced in the production and operation of satellite-borne experiments, for previous European, national or NASA programmes.

The heads of the institutes involved form the 'COS-B Steering Committee' which constitutes the ultimate authority of the Collaboration. The Committee's main tasks have been to assign responsibilities within the Collaboration concerning the work defined under scientific management, to maintain a watchful eye on the consequent progress, and to direct efforts as and when dictated by the needs of the programme.

For the definition of the mission requirements and the payload hardware, each institute nominated an experiment officer to the Experiment Group. This Group worked closely with the Organisation's Project Team and the Project Scientists, particularly with regard to the experiment configuration, interfaces, integration, testing and calibration.

Each institute supplied one or more personnel to the Data Reduction Group, whose task it was to define all data-processing software for pre-launch calibrations and post-launch analysis and to analyse the data from the numerous accelerator tests and the balloon flight.

The costs of payload-unit development for COS-B have been borne by the collaborating institutes themselves and for this reason one representative from each institute (local payload manager) was charged with supervision of the development of the appropriate payload unit, either in industry or in his own institute.

As the programme has progressed, changes of staff have been unavoidable and, instead of the 15–20 involved at the start, some 40 scientists and engineers (not including technicians) have now been involved in the COS-B project.

An important aspect of the management of any ESA project, and one demanding close co-operation, is the interface between the Project Office and the staff of the establishments responsible for the project's ground segments, the provision of the launcher and the availability of associated launch services (see Fig. 1).

The ESOC Mission Co-ordinator has been responsible throughout for interpreting Project Office requirements into workable plans for implementation under his supervision, and regular co-ordination meetings have been held to review progress, covering the following topics:

Les dirigeants des institutions en question ont formé le 'Comité directeur de COS-B', instance supérieure de la 'Collaboration', qui a eu pour tâches principales de répartir entre les membres de la 'Collaboration' les responsabilités relatives aux travaux définis sous l'égide de la gestion scientifique, de suivre avec vigilance l'avancement des travaux et d'orienter les efforts dans le sens et au moment où les nécessités du programma l'imposaient.

Pour la définition des impératifs de la mission et des équipements de la charge utile, chaque institution a désigné un responsable auprès du Groupe 'expériences'. Ce groupe a travaillé en étroite collaboration avec l'équipe de projet et le responsable scientifique du projet de l'Organisation, notamment en ce qui concerne la configuration, les interfaces, l'intégration, l'essai et l'étalonnage des expériences.

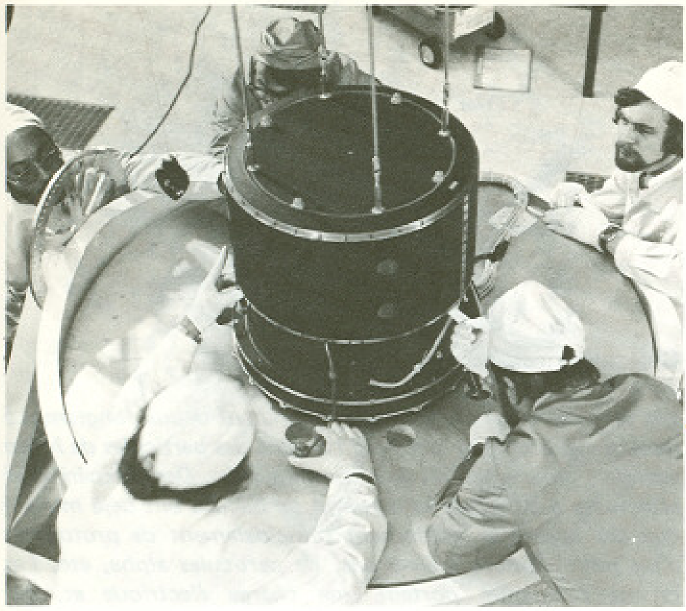
Chaque institution a également fourni un ou plusieurs membres à un Groupe 'dépouillement des données' qui avait pour tâche de définir tout le logiciel de traitement des données pour l'étalonnage avant lancement et l'analyse après lancement ainsi que d'analyser les données provenant des nombreux essais au rayonnement et du vol avec ballon.

Les coûts de développement des éléments de la charge utile de COS-B ont été pris en charge par les institutions participantes elles-mêmes, et c'est pour cette raison qu'un représentant de chaque institution (responsable local de la charge utile) a été chargé de superviser, soit dans l'industrie soit dans sa propre institution, le développement de l'élément de charge utile qui lui était confiée.

A mesure que le programme progressait, d'inévitables changements de personnes intervenaient, de sorte qu'au lieu des 15 à 20 scientifiques et ingénieurs qui participaient au projet au départ, il y en a maintenant, en tout, une quarantaine (techniciens non compris).

L'un des aspects importants de la gestion de tout projet de l'ASE – et qui exige une étroite coopération – est l'interface entre le Bureau du projet et le personnel des établissements responsables des segments sol, de la fourniture du lanceur et de la disponibilité des services de lancement connexes (voir Fig. 1).

Le Coordinateur de la mission à l'ESOC a eu la charge permanente de traduire les impératifs définis par le Bureau du projet en plans qui soient effectivement réalisables sous sa propre supervision et des réunions de coordination se sont tenues régulièrement pour passer en revue l'avancement des



- Mission analysis and optimisation
- Orbit definition and determination
- Attitude measurement and reconstitution
- Ground equipment readiness and compatibility
- Simulations and training of staff involved in operations
- Processing of satellite, and in particular of scientific payload, data
- Post-launch technological evaluation of satellite
- Performance evaluation for incentive calculations.

Managerial co-ordination for the launcher has been provided by NASA/GSFC – Delta Project Office in Greenbelt, Maryland, USA, which in turn interfaced with the vehicle manufacturer McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, California. Meetings have been held twice per year (average), alternating between Europe and USA, to ensure that the development work on the satellite remained compatible in all respects with the launcher, and to facilitate the definition and planning of activities and resources required in support of range operations at the time of the launch.

Major topics that have received attention in this context have been:
- Mission plan, comprising overall and specific mission analysis
- Launch-vehicle performance and compatibility
- Launch-range facilities, readiness and effectiveness.

ACKNOWLEDGEMENT

I take this opportunity to record my appreciation of the manner in which this project has been supported by all parties concerned, whether within the Agency or external to it. The successful completion of the project is due to their spirit, determination, and devotion to their tasks. □

Figure 6 – Integration of prototype payload (spark chamber) at MBB, Munich.

travaux, notamment sur les points suivants:
- *analyse et optimisation de la mission*
- *définition et détermination d'orbite*
- *mesure et restitution d'attitude*
- *mise à disposition, en temps opportun, et compatibilité de l'équipement au sol*
- *simulations et formation du personnel participant aux opérations*
- *traitement des données provenant de la charge utile du satellite, en particulier pour sa partie scientifique*
- *évaluation technologique du satellite après lancement*
- *évaluation de performances pour le calcul des primes d'intéressement.*

En ce qui concerne le lanceur, la coordination de la gestion a été assurée par le Bureau du projet Delta au GSFC de la NASA à Greenbelt, Maryland, qui assurait la liaison avec le constructeur du lanceur, McDonnell Douglas Astronautics Company (MDAC), Huntington Beach, Californie. Des réunions se sont tenues deux fois par an (en moyenne), alternativement en Europe et aux Etats-Unis, pour s'assurer que les travaux de développement portant sur le satellite restaient compatibles à tous égards avec le lanceur et pour faciliter la définition et le planning des activités et ressources nécessaires au soutien des opérations sur la base au moment du lancement.

Les principales questions étudiées à cet égard ont été les suivantes:
- *plan de la mission, comprenant une analyse globale et une analyse spécifique de la mission*
- *performances et compatibilité du lanceur*
- *installations de la base de lancement: état de préparation et efficacité.*

REMERCIEMENTS

Je profite de l'occasion qui m'est donnée pour exprimer mes remerciements pour la façon dont ce projet a reçu l'appui de tous les intéressés, que ce soit à l'intérieur de l'Agence ou à l'extérieur. C'est grâce à leur enthousiasme, à leur détermination et à leur dévouement que le projet a pu être mené à bonne fin. □

The Mission

La mission

B.G. Taylor, Project Scientist

Major Aims

An answer to the question of the origin of the high-energy particles known as 'cosmic rays' has long been of interest to the world's physicists. Experiments conducted from satellites and balloons have already shown that cosmic rays are composed principally of protons, with small proportions of electrons, alpha particles, etc. Cosmic rays are electrically charged and therefore their direction of arrival bears no relation to their point of origin, since their trajectories will have been modified by the magnetic and electric fields in space. Hence, their paths cannot be used as tracers for their own origin. As a measure of the intensity of the phenomenon in which we are interested, the incident cosmic-ray flux at the top of the atmosphere is about one cosmic ray per square centimetre, per second, per steradian.

Experiments conducted to date show that the intensity of gamma rays in space is only 10^{-4} of the total cosmic-ray flux. Gamma rays, being uncharged, are not deflected by fields and since they can penetrate considerable quantities of matter, their arrival direction is an indication of their origin. As gamma rays with energies of $\sim$ 30 million electron volts (MeV) or more can be produced only by primary cosmic rays (protons or electrons) of comparable energy, cosmic gamma rays can provide a tracer for the origin of the charged cosmic rays. It is known that the disc of our Galaxy (the Milky Way) emits gamma rays and that there is enhancement of this emission in the direction of the galactic centre. The Crab nebula (in the direction of the galactic anticentre) and the Vela supernova remnant are perhaps the only certainly identified point-like sources of gamma emission.

There are thought to be two principal mechanisms for the production of gamma rays: firstly the proton/proton interaction in which a cosmic-ray proton collides with a hydrogen nucleus (hydrogen being the principal constituent of the gas that fills space to a density of roughly 1 atom/cm^3) to yield π° mesons which decay to produce gamma rays of about 70 MeV energy; and secondly, the inverse Compton process in which a cosmic-ray electron 'collides' with a starlight or low-energy photon to yield a low-energy electron and a high-energy photon or gamma ray. The distributions of gamma-ray energies resulting from these two processes are quite different, so that measurement of the gamma-ray energy spectrum will throw light on the method of production, and hence on the constituents of the source region. Measurement of the gamma-ray arrival directions will indicate the location of their origin.

The strength of gamma-ray sources might well vary with time;

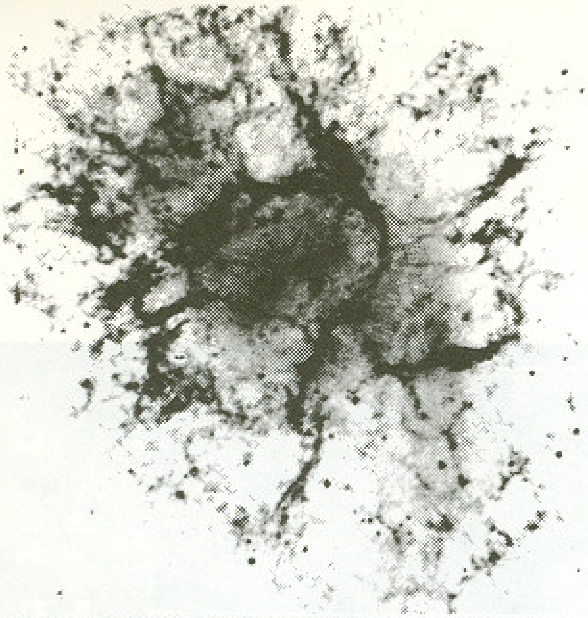
Objectifs principaux

Les physiciens du monde entier cherchent depuis longtemps à résoudre le problème posé par l'origine des particules de haute énergie appelées 'rayons cosmiques'. Des expériences effectuées à partir de satellites et de ballons ont déjà montré que ces rayons se composent principalement de protons et d'un petit nombre d'électrons, de particules alpha, etc. Les rayons cosmiques portent une charge électrique et, par conséquent, leur direction d'arrivée est sans rapport avec leur point d'origine, car leurs trajectoires ont été modifiées par les champs magnétiques et électriques régnant dans l'espace. De ce fait, on ne peut pas utiliser leurs trajectoires pour remonter à leur origine. Pour donner une idée de l'intensité du phénomène qui nous intéresse, disons que le flux incident de rayons cosmiques à la partie supérieure de l'atmosphère est d'environ une particule par centimètre carré par seconde par stéradian.

Les expériences effectuées jusqu'ici montrent que l'intensité des rayons gamma dans l'espace n'est que le dix-millième du flux total de rayons cosmiques. Les rayons gamma, n'étant pas chargés, ne sont pas déviés par les champs; et comme ils peuvent traverser des épaisseurs considérables de matière, leur direction d'arrivée donne une indication de leur origine.

Comme des rayons gamma d'une énergie d'environ 30 MeV (million d'électronvolts) ou plus ne peuvent être produits que par des rayons cosmiques primaires (protons ou électrons) d'énergie comparable, les photons gamma du rayonnement cosmique peuvent servir à déterminer l'origine de ses particules chargées. On sait que le disque de notre Galaxie (la Voie Lactée) émet des rayons gamma et que cette émission s'intensifie dans la direction du centre de la Galaxie. La nébuleuse du Crabe (dans la direction de l'anticentre de la Galaxie) et les restes de la Supernova de Vela sont peut-être les seules sources ponctuelles d'émission gamma identifiées avec certitude.

On pense qu'il existe deux mécanismes principaux de production des rayons gamma: (1) l'interaction proton/proton dans laquelle un proton du rayonnement cosmique entre en collision avec un noyau d'hydrogène (l'hydrogène étant le constituant principal du gaz de densité égale à environ 1 atome/cm^3 qui remplit l'espace pour donner des mésons π° dont la désintégration produit des rayons gamma d'une énergie d'environ 70 MeV; (2) l'effet Compton inverse, dans lequel un électron du rayonnement cosmique 'heurte' un photon stellaire ou photon de faible énergie pour donner un électron de faible énergie et un photon de haute énergie ou photon gamma. Les distributions d'énergie des rayons gamma qui



Crab nebula, recently observed to emit gamma rays, will be studied early in the COS-B observation programme.

for instance, it is known that the Crab emits a proportion of gamma rays correlated with the frequency of the pulsar, a rapidly spinning neutron star, near its centre. Correlation of intensity variations at other wavelengths, i.e. in the X-ray region, can yield information on the source as well as helping to locate and identify it.

Thus, the major aims of the COS-B mission are:

(i) study of the angular structure of gamma emission from the galactic plane,
(ii) measurement of the flux of the diffuse radiation from high galactic latitudes, which is probably of extragalactic origin,
(iii) examination, in detail, of known or postulated point sources of radiation, and
(iv) determination of the energy spectra and temporal structure of all identified sources.

Technical Approach

Gamma rays with energies above 20 MeV can be detected indirectly following their interaction with material in which they interact to form two electrons (one positively charged, the other negatively) which share unequally the energy of the incident gamma ray. The electrons travel in essentially the same direction as the incoming gamma ray and since they are charged and produce ionisation along their tracks their direction can be determined (e.g. in a spark chamber). Their energy can be measured by absorbing them in an 'energy calorimeter'.

Cosmic gamma rays are absorbed by the atmosphere at very high altitudes, so that in order to study them at all, a satellite- or balloon-borne instrument must be used. The major drawback to balloon-borne studies is the fact that the charged

résultent de ces deux processus sont tout à fait différentes, de sorte que la mesure du spectre d'énergie des rayons gamma apportera quelque lumière sur leur mode de production et, par conséquent, sur les constituants de la région d'où ils proviennent. La mesure des angles d'arrivée des rayons gamma indiquera leur lieu d'origine.

L'intensité des sources de rayons gamma peut très bien varier avec le temps; par exemple, on sait que la nébuleuse du Crabe émet des rayons gamma dont l'intensité est en corrélation avec la fréquence du pulsar (étoile à neutrons animée d'une rotation rapide) situé près de son centre. La corrélation des variations d'intensité sur d'autres longueurs d'ondes, c'est-à-dire dans le domaine du rayonnement X, peut fournir des renseignements sur la source et aussi aider à la localiser et à l'identifier.

Les objectifs principaux de la mission COS-B sont donc les suivants:

(i) étude de la structure angulaire de l'émission de rayons gamma provenant du plan de la Galaxie,
(ii) mesure du flux du rayonnement diffus provenant des hautes latitudes galactiques, lequel est probablement d'origine extragalactique,
(iii) examen détaillé des sources ponctuelles connues ou postulées de rayonnements et
(iv) détermination du spectre d'énergie et de la structure temporelle de toutes les sources identifiées.

Méthode technique

Les rayons gamma d'énergie supérieure à 20 MeV peuvent être détectés indirectement du fait que leur interaction avec la matière donne lieu à la formation de deux électrons (l'un chargé positivement, l'autre négativement) qui se partagent à égalité l'énergie du rayon gamma incident. La direction de la trajectoire suivie par les électrons est sensiblement la même que celle du rayon gamma incident et comme ces électrons sont chargés et produisent ainsi une ionisation sur leur parcours, on peut déterminer leur direction (par exemple dans une chambre à étincelles). Leur énergie peut également être mesurée par absorption dans un calorimètre.

Les photons gamma du rayonnement cosmique sont absorbés par l'atmosphère à très haute altitude, de sorte que leur étude nécessite un instrument emporté par un satellite ou par un ballon. L'inconvénient majeur des expériences faites à l'aide de ballons tient au fait que les particules cosmiques chargées cosmic rays produce gamma rays within the atmosphere above the balloon. This constitutes a very high background, making it exceedingly difficult to detect and measure extraterrestrial gamma-ray fluxes with certainty.

As mentioned earlier, there are ten thousand times as many charged cosmic rays as gamma rays and these cosmic rays can interact in or around a detector to produce gamma rays or to simulate interactions resembling gamma rays. This therefore constitutes another serious form of background disturbance. It is principally due to these high background or 'noise' levels, and the low flux of gamma rays or 'signal', that gamma-ray astronomy has not advanced as quickly as astronomy conducted at other wavelengths.

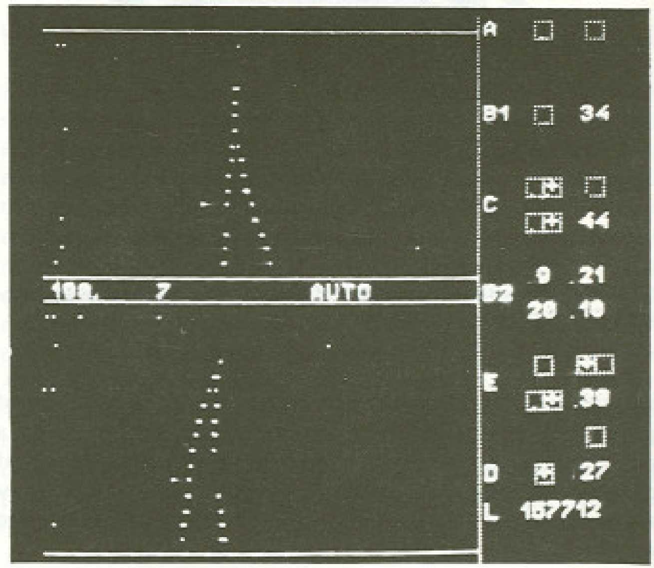
Orbit and Observation Programme

A highly eccentric orbit (100 000 km apogee) has been chosen as this will permit long, uninterrupted observations of selected cosmic gamma-ray sources, will avoid the problem of atmospheric gamma rays, and will permit real-time data recovery at the two ESA ground receiving stations (thus removing any need for data storage, such as a tape recorder, on board the spacecraft).

The spacecraft's attitude-control system can orient the experiment to view almost any part of the celestial sphere during some part of the experiment's lifetime. Not all points can be viewed at any given time, due principally to constraints imposed by the need to point the spacecraft's solar cells towards the Sun, or by the accuracy of knowledge of the viewing direction. Given the expected flux of gamma rays, a target source can be maintained in the experiment's field of view for a continuous period of one month. During the two-year lifetime of the mission, it will be possible to conduct a detailed survey of the whole galactic plane and to investigate selected high-latitude sources.

Secondary Aims

In order to correlate the emission of gamma rays with photons at other wavelengths, COS-B is equipped with a small X-ray detector, sensitive in the region above 2 keV, called a 'pulsar synchroniser'. While the main aim of the pulsar synchroniser is to provide vital timing information, it will be able to view known X-ray sources for successive uninterrupted 30 h periods for up to one month. This facility represents a unique tool with which to study the long-term behaviour of X-ray sources, something not previously attempted in such a systematic manner.



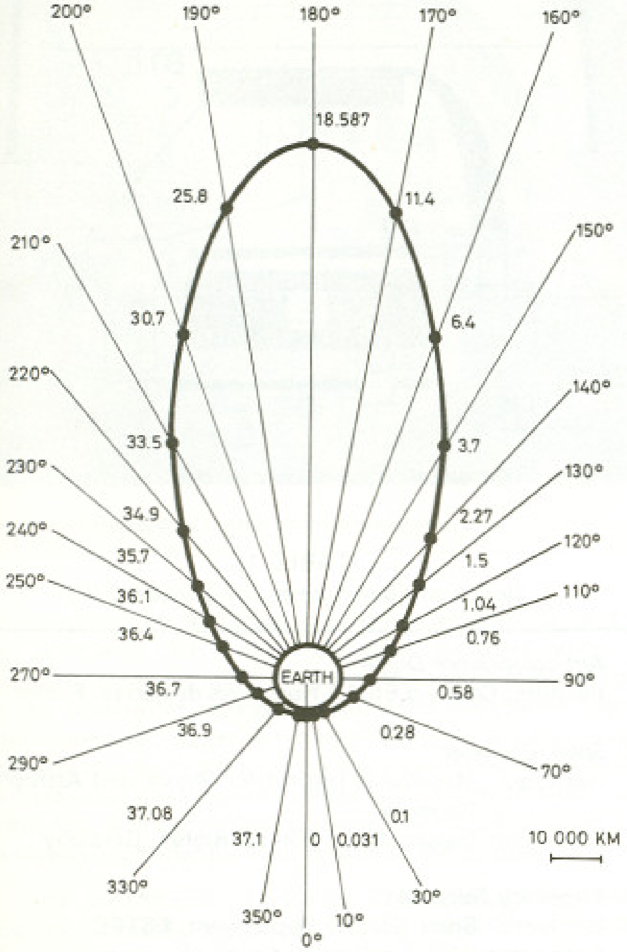
Display of two orthogonal views of a 500 MeV gamma event in the spark chamber, recorded at DESY, Hamburg

produisent des rayons gamma dans l'atmosphère au-dessus du ballon. Il en résulte un bruit de fond très intense par suite duquel il devient extrêmement difficile de détecter et de mesurer avec certitude les flux de rayons gamma extraterrestres.

Comme on l'a indiqué plus haut, il y a dix mille fois plus de particules cosmiques chargées que de photons gamma et ces particules cosmiques peuvent réagir à l'intérieur ou autour d'un détecteur pour produire des rayons gamma ou pour simuler des interactions ressemblant à des rayons gamma. Ce phénomène constitue donc une autre forme importante de perturbation par bruit de fond. C'est principalement à cause de ces hauts niveaux de 'bruit' et du faible flux de rayons gamma constituant le 'signal' que l'astronomie dans le rayonnement gamma n'a pas fait des progrès aussi rapides que celle qui est pratiquée dans d'autres longueurs d'ondes.

Orbite et programme d'observations

On a choisi une orbite fortement excentrique (apogée: 100 000 km) parce qu'elle permettra d'observer pendant longtemps et sans interruption des sources choisies de rayons gamma cosmiques, qu'elle supprimera le problème des rayons gamma atmosphériques et qu'elle permettra la réception des données en temps réel par les deux stations sol de l'ASE (rendant ainsi inutile la présence d'équipements de stockage de



Nominal initial orbit as a function of time (hours).

During the development of the COS-B satellite, the discovery of cosmic gamma-ray bursts has been announced. The Vela satellite system has detected a number of short (typically 1s), intense bursts of gamma rays in the energy range 100 keV -- 1 MeV. A number of models have been proposed by theoreticians to explain their origin, but most cannot be proved or disproved due to lack of data. The 'anticoincidence' detector, used to veto charged particles entering the main instrument on COS-B, makes an efficient detector for gamma rays at this energy. By adding appropriate electronics to this detector, COS-B will be able to measure cosmic bursts down to a few percent of the typical intensity of those measured so far, with a time resolution for the burst structure of about 2 ms. □

données — par exemple, enregistreur magnétique — à bord du véhicule spatial).

Le système de commande d'attitude du véhicule spatial permet d'orienter l'expérience pour observer à peu près n'importe quelle région de la sphère céleste pendant une partie déterminée de la durée de vie de cette expérience. Il n'est pas possible d'observer tous les points à un instant donné, en raison principalement des contraintes imposées par la nécessité d'orienter les cellules solaires du véhicule spatial en direction du Soleil ou par la précision avec laquelle on connaît la direction d'observation. Le flux escompté de rayons gamma étant donné, on peut maintenir une source prise comme objectif dans le champ de visée de l'expérience pendant une période continue d'un mois. Au cours des deux années que durera la mission, il sera possible d'effectuer une étude détaillée de tout le plan de la Galaxie et d'étudier des sources choisies à haute latitude.

Objectifs secondaires

Afin d'établir la corrélation entre l'émission de rayons gamma et les protons à d'autres longueurs d'ondes, COS-B est équipé d'un petit détecteur de rayons X, sensible à partir de 2 keV, appelé 'synchroniseur de pulsar'. Son but principal est de fournir des informations chronologiques essentielles, mais il sera aussi en mesure d'observer des sources connues de rayons X pendant des périodes ininterrompues de 30 heures se succédant sur un laps de temps qui pourra aller jusqu'à un mois. Cet appareil constitue un moyen unique pour étudier le comportement à long terme des sources de rayons X, travail qui n'a pas été tenté jusqu'ici de façon systématique.

Au cours du développement du satellite COS-B, on a annoncé la découverte de bouffées de rayons gamma cosmiques. Le satellite américain Vela a détecté un certain nombre de bouffées courtes (généralement 1 seconde) et intenses de rayons gamma dans la gamme d'énergies de 100 keV à 1 MeV. Un certain nombre de modèles ont été proposés par les théoriciens pour expliquer leur origine, mais la plupart ne peuvent être confirmés ou infirmés faute de données. Le détecteur à anticoïncidences, utilisé pour interdire aux particules chargées l'entrée de l'instrument principal de COS-B, constitue un détecteur efficace de rayons gamma à ces énergies. L'adjonction à ce détecteur d'une électronique appropriée permettra à COS-B de mesurer des bouffées de rayons cosmiques d'une intensité représentant seulement quelques centièmes de celle des rayons mesurés jusqu'ici, et cela avec une résolution temporelle de la structure des bouffées qui sera d'environ 2 millisecondes. □

The Experiment

B.G. Taylor, Project Scientist

Technical Details

The experiment is shown schematically in Figure 1. The central detector package illustrated in Figure 2 weighs 95 kg and the associated electronics and the small X-ray detector a further 20 kg. The power consumption of the complete experiment is 25 W.

The heart of the experiment is the *spark chamber* (SC in Fig. 1), which has a sensitive volume of 24 x 24 x 24 cm^3. It is filled with neon and a small percentage of ethane, to a pressure of 2 atm. Sixteen pairs of wire grids define 16 'gaps', between which thin sheets of tungsten are placed to provide the conversion material for the gamma rays to generate the electron pair. When a high-energy charged particle passes through the gas, it leaves a trail of ionisation. If a high voltage (several kV) is applied across the pairs of grids within a millionth of a second of the passage of the charged particle, a spark discharge will occur along the ionisation trail, thereby 'marking' the track of the original particle. By using suitable electronics in association with the grids, the positions of the sparks can be determined in two orthogonal directions.

The field of view of the experiment is defined by the *triggering telescope*, an array of scintillation (B1/B2) and Cerenkov (C) counters, mounted directly below the spark chamber. Associated with each counter element is a photomultiplier tube. Due to the directional properties of the Cerenkov counters, only particles moving in a downward direction are accepted. If the B1, C and B2 counters generate signals simultaneously, a trigger signal is transmitted to the spark chamber to apply the high voltage to the grids.

The spark chamber and telescope are screened above and at the sides by an *anticoincidence scintillation counter* (A) with 9 associated photomultipliers. If this counter detects a charged particle in time coincidence with the telescope counters, the trigger to the spark chamber is inhibited. Hence, charged cosmic rays cannot trigger the chamber, but cosmic gamma rays can.

The electron pair emanating from the gamma ray traverses the telescope and enters the *energy calorimeter* (E/D), where E is a crystal of caesium iodide. This crystal has the ability to absorb electrons up to an energy of some 300 MeV. For higher energies, the electrons start to leak through, but are detected by the scintillator D. Each detector in the calorimeter is viewed by four photomultipliers. In absorbing the electrons in the E counter, visible light is emitted proportional to the energy loss, so that the size of the signal from the photomultipliers is a measure of the gamma-ray energy.

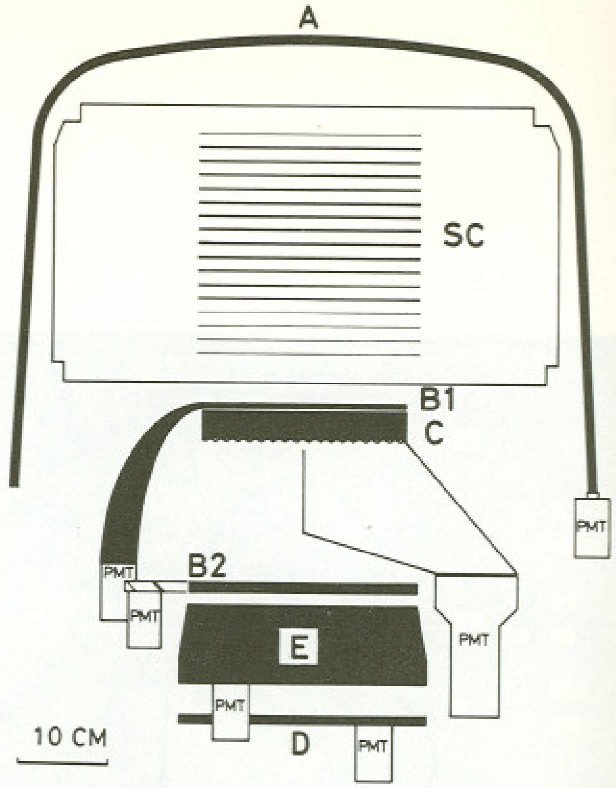


Figure 1 – Schematic of central detector package.

TABLE 1
Design and development of payload units

1. *Anticoincidence Dome*
   Institute: Centre d'Etudes Nucléaires de Saclay, France

2. *Spark Chamber*
   Institute: Max-Planck-Institut für Physik und Astrophysik, Germany
   Contractor: Messerschmitt-Bölkow-Blohm, Germany

3. *Triggering Telescope*
   Institute: Space Science Department, ESTEC
   Contractor: AEG-Telefunken, Germany

4. *Energy Calorimeter*
   Institute: Huygens Laboratorium, Netherlands
   Contractor: Ball Brothers Research Corp., USA

5. *Experiment Electronics*
   Institute: Università degli Studi di Milano, Italy
   Contractor: Laben, Italy

6. *Burst Detector*
   Institutes: Centre d'Etudes Nucléaires de Saclay, France, and Space Science Department, ESTEC

7. *Pulsar Synchroniser*
   Institute: Università di Palermo, Italy
   Contractor: Laben, Italy

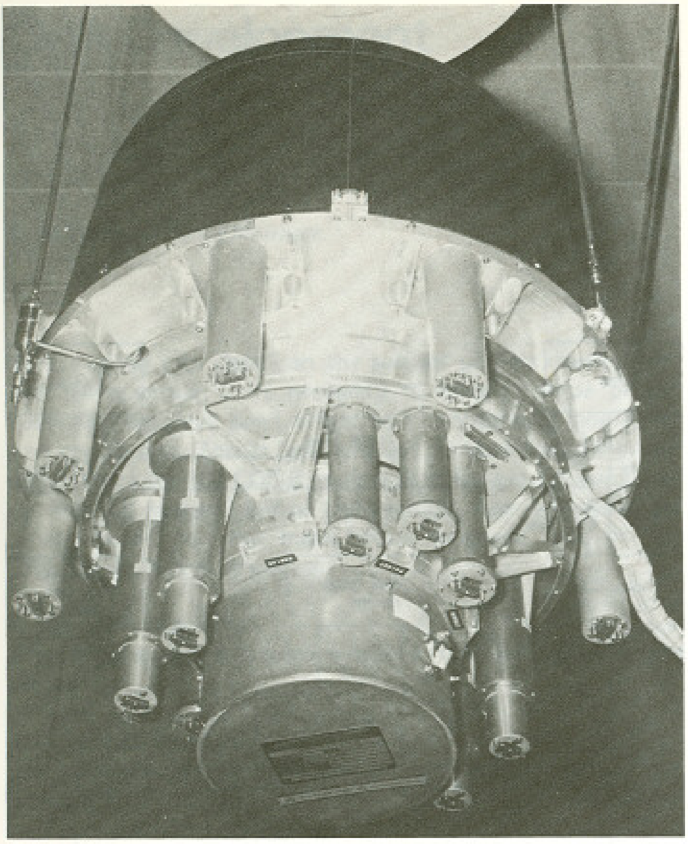


Figure 2 — Photograph of central detector package.

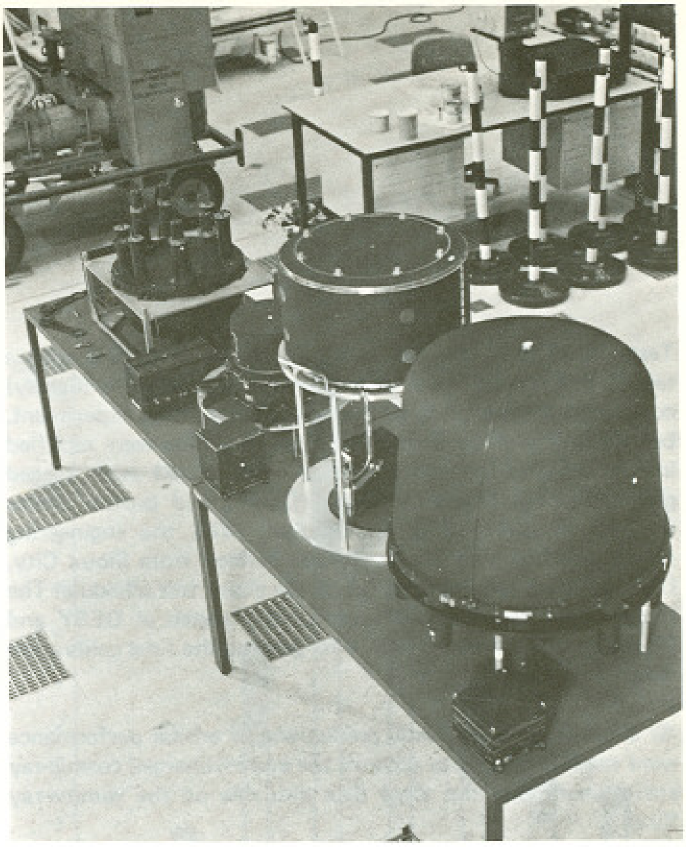


Figure 3 — Principal components of central detector package ready for integration.

Each triggering of the spark chamber is referred to as an 'event' and with each event is associated the spark position information from the spark chamber, the energy information from the calorimeter, energy loss and status information from the telescope and the precise timing of the event to better than a millisecond. The function of the *experiment electronics* is to interrogate the other payload elements following an event, to put the data into the correct sequence, and to pass them on to the spacecraft encoder for transmission to the ground.

The *pulsar synchroniser* is an array of proportional counters containing primarily argon gas. X-rays above about 2 keV enter the counters through a 25 μm thick beryllium window. The detector has a sensitive area of 80 cm^2 over a field of view of about 1°. When an X-ray is detected, the time of detection is measured and transmitted to ground, where the temporal behaviour of the X-ray source is reconstructed and compared with the arrival times of the gamma rays to determine correlations.

The counting rate in the anticoincidence detector, due to cosmic-ray particles and photomultiplier noise, is normally about 1000 count/s and is automatically monitored on-board the satellite. When a sudden increase in rate is detected perhaps due to a gamma burst, the buffer memory of the data-handling system is erased and filled with data from the *gamma-burst electronics* at a very high rate. The count/time profile of the burst stored in the memory is subsequently read out at the normal (much slower) telemetry frequency, while the experiment reverts to the normal gamma-ray mode.

The experiment is controlled over the telecommand link from the ground. The high-voltage supplies to the photomultipliers and the spark chamber, the voltage level of the discriminators, the event selection logic, etc., can be controlled individually, giving considerable flexibility for experiment operation.

Pre-Flight Calibration

COS-B is the first ESRO or ESA satellite mission to be solely dependent on a single experiment. All earlier spacecraft have carried five or more experiments, so that malfunctioning of any one experiment unit has not been catastrophic to the mission. This mission-criticality aspect, together with the limited success of earlier gamma-ray astronomy experiments, prompted the inclusion of an extensive pre-flight calibration programme in the satellite's development schedule.

Three types of test have been conducted:

(a) Exposure to gamma-ray beams at particle accelerators to determine instrument response to gamma rays incident in well-defined directions and at well-defined energies.
(b) Exposure to electron and proton beams at particle accelerators to determine response to the charged cosmic-ray flux.
(c) Exposure to the radiation environment near the top of the atmosphere, this approximating reasonably to orbital conditions.

Tests in 1970/71 on the scientific model of COS-B with a tagged gamma-ray beam (Bonn) and a proton beam (Saclay) confirmed the adequacy of the basic design of the experiment, but also highlighted certain deficiencies. These were rectified in the engineering model, which was tested with tagged gamma-ray and electron beams (DESY) and proton beams (CERN) in early 1973. In October 1973, the engineering model was flown on a high-altitude balloon from Sioux City, USA, to meet requirement (c) of the above test schedule. The flight-model payload was subsequently tested at DESY and CERN in the summer of 1974 to provide the final calibration data.

As a result of these tests, predictions of orbital performance were made, taking into account the known charged cosmic-ray environment and the scant data available on the gamma-ray flux.

Experiment Data Analysis

Data from COS-B will be received at the ESA ground stations in Redu, Belgium and Fairbanks, Alaska. The data received at Redu will be transmitted, shortly after recording, to the European Space Operations Centre (ESOC), Darmstadt, where some 40% of it will be analysed in the so-called 'Fast Routine Facility'. Preliminary scientific results will thus be available within a few days of data collection. These results will be invaluable in assessing the performance of the experiment — so that immediate corrective action can be taken if necessary — and in optimising the satellite's observational programme.

Data gathered during the first few months of operation will be analysed in parallel at all institutes collaborating in the programme and the results compared to ensure that no data processing peculiarities, due for example to computer hardware or software errors, at any one institute are corrupting or modifying the results. Thereafter, the data from one source direction will be analysed at only one institute, although publication of results will still be undertaken jointly by the collaborating institutes.

The computer programs to be used for analysis of the experiment data have been developed and tested using data retrieved from the accelerator tests in Europe and the balloon flight in the United States, and so, barring unforeseen difficulties, data analysis will begin immediately after experiment switch-on.

The data from the pulsar synchroniser, which will allow the long-term variability of X-ray sources to be studied, will be made available to interested institutes outside the COS-B collaboration that have proven expertise in X-ray astronomy.

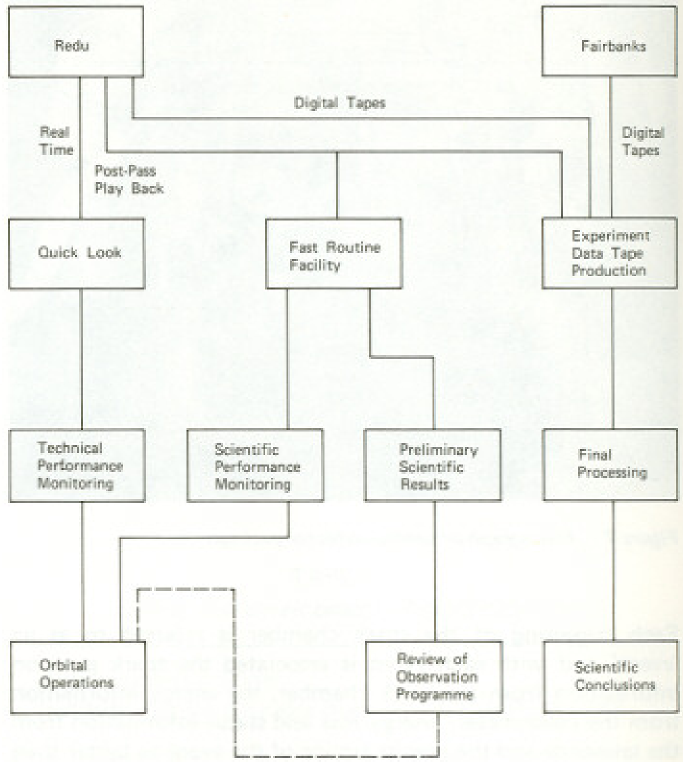


Figure 4 — Experiment data processing.

Given a successful two-year operational life, COS-B will provide a detailed map of the gamma-ray sky, showing the broad features of the emission and point-like sources, down to the limit of the instruments' sensitivity of about 5×10^{-7} photons/cm^2/s for point sources. This map will be in 'colour', in that it will show structure at different wavelengths or energies and may also show the temporal behaviour of certain regions.

As in all other fields of scientific research, the COS-B mission can be expected to stimulate the need for more detailed investigation of interesting phenomena discovered by the spacecraft's experiment payload. One already foreseeable extension will be the need for increased instrument sensitivity, not simply by increasing instrument size, but by improving angular resolution, i.e. being more precise about the arrival direction of each gamma ray, so that weak point sources can be more easily distinguished in the gamma-ray background. □

Cost Development

G. Altmann, *Project Manager*

Before going into detail on the subject of cost development and performance, it is necessary to identify those project elements that have been subjected to continuous monitoring and negotiation. This is best achieved by considering the total expenditure for the COS-B project as it has been documented for internal budget control and revision. Figure 1 shows the yearly totals for the major cost categories used in the ESRO/ESA budget structure:

I. *Direct Internal Costs*
Staff salaries, etc. and mission costs of the ESRO/ESA Project Group.

II. *Direct External Costs*
Contracts placed with industries and agencies, including:
- Studies
- Spacecraft development
- Payload development (part – see Note 1 below)
- Launch vehicle and launch support

III. *Indirect Internal Costs*
All support provided to the COS-B Project Group by other ESRO/ESA units, whether by manpower (such as specialist advice in particular technological areas), or by the provision and use of facilities (such as ESTEC test facilities or ESOC Control Centre and ground network). These indirect costs are not always subject to direct project control and in some cases are apportioned somewhat arbitrarily.

(NOTE 1: This item, shown as 0.126 MAU* in Figure 1, does not include provision of the individual payload units and their test equipment, these being funded by the supplying Institutions. Also excluded is the industrial support to the COS-B Payload Section for payload integration and testing (included in spacecraft development costs), whilst some of the costs under Indirect Internal Costs relate to payload integration and testing. Essentially this item includes some of the integration and a contract for balloon purchase and associated launch services for a payload performance test. An *estimate* for the total payload development, including all cost items, would be approximately 13 MAU, of which 3 MAU is financed by ESA and 10 MAU by supplying institutes.

In comparing the various cost elements it is apparent that the expenditure for the continuous effort of the direct project staff is a very minor part of the total and is seemingly a reasonable and acceptable outlay (6%) for a fair return, namely a fully compatible satellite system.

* 1 AU = 1.26 US Dollars (as per January 1975)

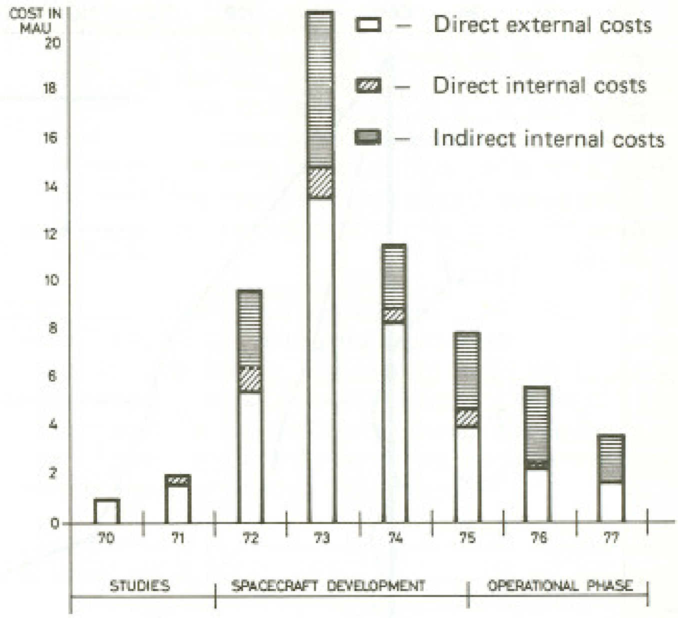


Figure 1 – Annual expenditures (all costs – actual & expected) as of 1 June 1975.

EXPECTED COST TO COMPLETION (IN MAU)

I.	Direct Internal Costs		3.712
II.	Direct External Costs		
	Studies	2.645	
	Main contract	25.610*	
	Payload development (see Note 1 in text)	0.126	
	Launch vehicle and launch support	10.109	
			38.390
III.	Indirect Internal Costs		20.960
			63.062

* Includes (i) cost escalation due to changed economic circumstances
(ii) incentive fee.

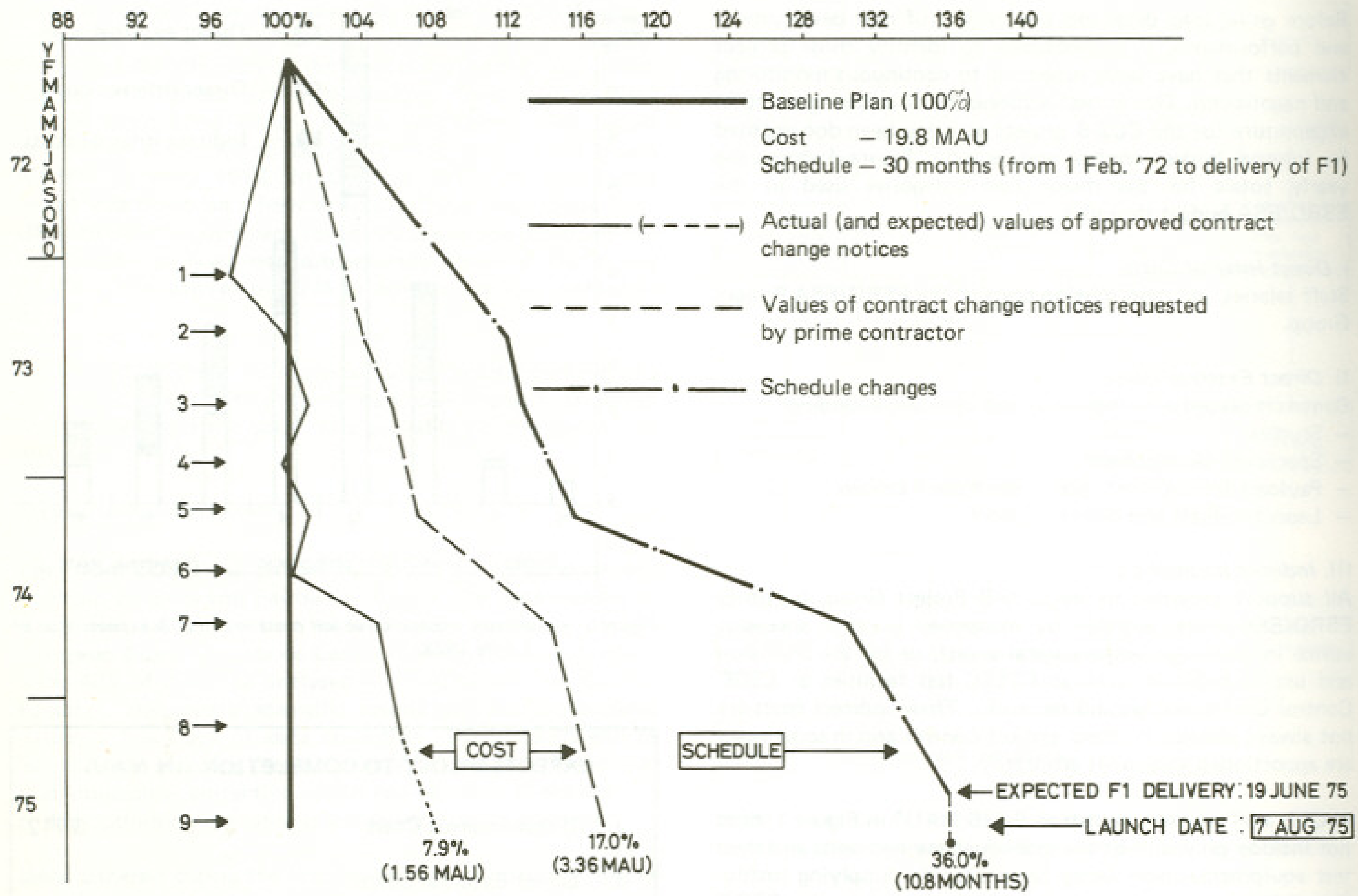


Figure 2 – Main spacecraft development contract costs and schedule trends.

The history and trends in cost development for COS-B are illustrated in Figure 2. Nine events of significant importance have had a noticeable impact on the actual costs incurred. These are noted in the figure and outlined below.

1. *Conversion of prices for subsystems*
   Following completion of an essential part of the design and test work on engineering models, negotiations were conducted with all co-contractors to convert ceiling prices into firm fixed prices. The agreements reached resulted in a saving of 0.5 MAU.

2. *Programme extension 1*
   Owing to the late placing of contracts for one experiment unit and test equipment for the PCM-telecommand subsystem, a consequence of the Organisation's revision of the overall programme in 1971, the end date of the flight satellite programme had to be shifted by 3.5 months, with a consequent cost increase of 0.5 MAU.

3. *Programme modification*
   When the Europa II launcher programme was discontinued in 1973, the project was obliged to turn to a Delta vehicle. Adaptation of the then existing satellite design to the Delta configuration and launch environment caused additional costs of 0.3 MAU, including a further delay in the end date of 2 weeks.

4. *Deletion of some spare units*
   In view of the higher reliability expected of the Delta launch vehicle, it was decided to delete spare units that were additional to two complete flight satellites. The resulting cost reduction was 0.25 MAU (materials and components and some effort had already been committed).

5. *Programme adjustment*
   Agreement on the final contract led to new programme end dates for Prototype and Flight Unit, which were firmly linked to a schedule incentive. Contract change notices for technical modifications and additional test requirements added further to the cost increase of 0.25 MAU.

6. *Programme modification*
   A reduction in the scope of tests for Flight Unit 2 and finalisation of transport requirements brought about a saving of 0.260 MAU.

7. *Programme extension 2*
   An accumulation of delays in the delivery of payload and spacecraft subsystems, due to various component failures, production problems and industrial disputes in firms in Italy and the UK, made it impossible to comply with the selected launch window closing at the end of March 1975. A new end date for the flight satellite programme of 7 May 1975 (launch date 17 July) was established, resulting in a cost increase of 0.950 MAU.

8. *Programme modification and adjustment*
   A succession of component failures made it necessary to repair and to rebuild several subsystem boxes. Furthermore, an exchange of payload units made test-schedule changes necessary, causing a cost increment of 0.210 MAU.

9. *Programme extension 3*
   A review by NASA of their schedule for Delta launchings (following the end of the industrial dispute in April) resulted in the COS-B launch being put back by three weeks. This, together with further reworking and retesting of the flight satellite, caused an overall delay of 1.5 months and led to the final launch date being 7 August 1975. The estimated cost increase incurred through this last delay was 0.360 MAU.

The trend-analysis chart reflects the efforts made by the project management during the negotiations of the relevant contract change notices. The total of all submitted changes represented an increase in baseline costs of 3.36 MAU or 17%. Following scrutiny by the Contract Change Review Board, the total of the changes finally agreed by the Organisation and industry was constrained to 1.56 MAU or 8%.

Bearing in mind that a significant part of this increase relates to extensions of the programme, as shown by the delay-trend line for the end date of the flight satellite programme, one can conclude that the total costs for satellite development, including escalation due to changed economic conditions, and the incentive fees for ground, schedule and particularly in-orbit performance, have been kept to a minimum. This reflects not only the results of strict management and project control, but also the concerted efforts of all those engaged in the project, at all levels, in striving for cost control.

It should be pointed out that the views and arguments expressed here are based only on material available at the time of writing. No significant changes are expected when the final cost analysis becomes available, which might be as late as 1977, when all incentives have been paid and assessment of the launcher and launch support costs has been completed. □

The Spacecraft

P. Hill, Satellite Manager

A basic principle, soon seen to have many advantages, in designing the spacecraft to carry and support the principal experiment package (gamma-ray telescope) was that of keeping all supporting subsystems as simple as possible, both to reduce development time and costs, and to meet the rather severe design reliability requirement of 85% probability of mission success for a planned 1 yr lifetime (provision being made for two years of operation).

The way in which this principle influenced the spacecraft's design will be outlined in the subsystem descriptions which follow a first general outline.

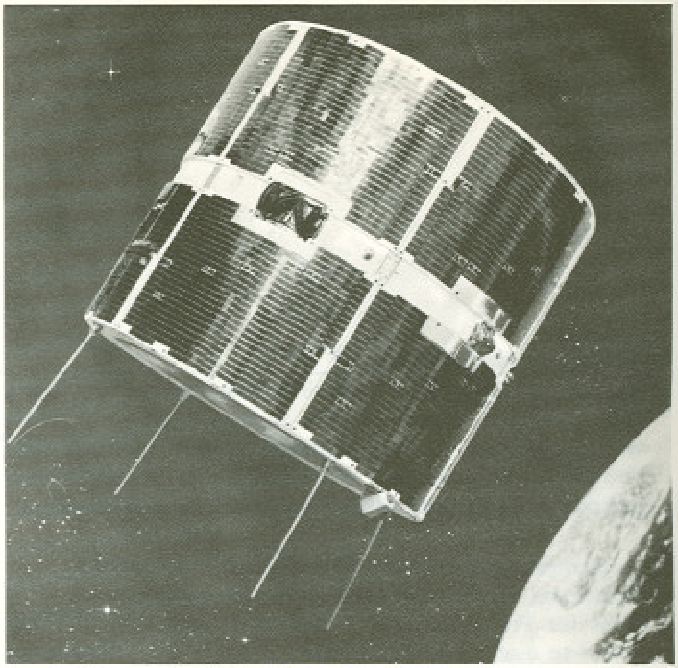
GENERAL OUTLINE

A cylindrical form is usual for a satellite that is to be maintained in a stable orientation with respect to inertial space by spinning. This means of stabilisation was chosen for COS-B in preference to more complex methods involving stabilisation relative to three axes, although it imposes special requirements on the degree of balance and principal moment of inertia of the complete spacecraft.

Two launch vehicles had to be considered for COS-B during the course of the programme, a Europa II, and a Delta 2000 series, but as the dimensions of the spacecraft were compatible with both vehicles, no major hardware or structural changes were necessary when the final decision was taken in 1973 to use a Delta 2913 launcher.

In the particular case of COS-B, the choice of spin stabilisation has led to the majority of the electronic components being arranged in a ring, around the central telescope assembly, and mounted on a central platform (Fig. 1). For most units, this arrangement has proved a good one because the field of view of the gamma-ray telescope must be obstructed as little as possible; in fact, only thin thermal insulation layers appear in the direct field of view outside the anticoincidence dome. The position of the telescope (with respect to the outer cylinder of the solar array) has been chosen so that the top ring of the structure is just outside its field of view.

Attitude-sensor units, fill and vent valves for the gas subsystems and test connectors are mounted on a central annular band, between the upper and lower halves of the cylindrical



solar array. The base of the spacecraft (in launch position) is occupied by the attachment ring and radiating surfaces used to dissipate excess electrical power from the power-supply subsystem.

External Form

The cylindrical exterior ,of the spacecraft is 1400 mm in diameter and 1200 mm long. Four antenna rods (90° spacing) project downwards (512 mm) and outwards (7½°) from the lower periphery. A pair of precession jets attached to the lower periphery extend 93 mm downwards and 25 mm radially outwards. Various sensors, valves, spin jets, vent pipes and connectors extend up to 35 mm radially outwards from the spacecraft's equatorial 'belt' (nominally 100 mm deep and 1380 mm in diameter).

Above and below the equatorial 'belt', the cylindrical surface is composed of solar panels. The top surface of the spacecraft is slightly concave and is formed of super-insulating thermal material. The lower surface, which is more strongly concave, is a composite of annular, conical and cylindrical sections, variously of super-insulating and radiative materials.

Internal Form

The internal shape of the spacecraft is determined by the structure that supports all the instrumentation. This comprises three sections — the primary, secondary and experiment support structures.

The *primary structure* consists of an annular platform mounted above a tapering conical tube. Six struts connect the base of the cone to the periphery of the platform.

The *secondary structure* forms the external cylindrical surface of the spacecraft and comprises:

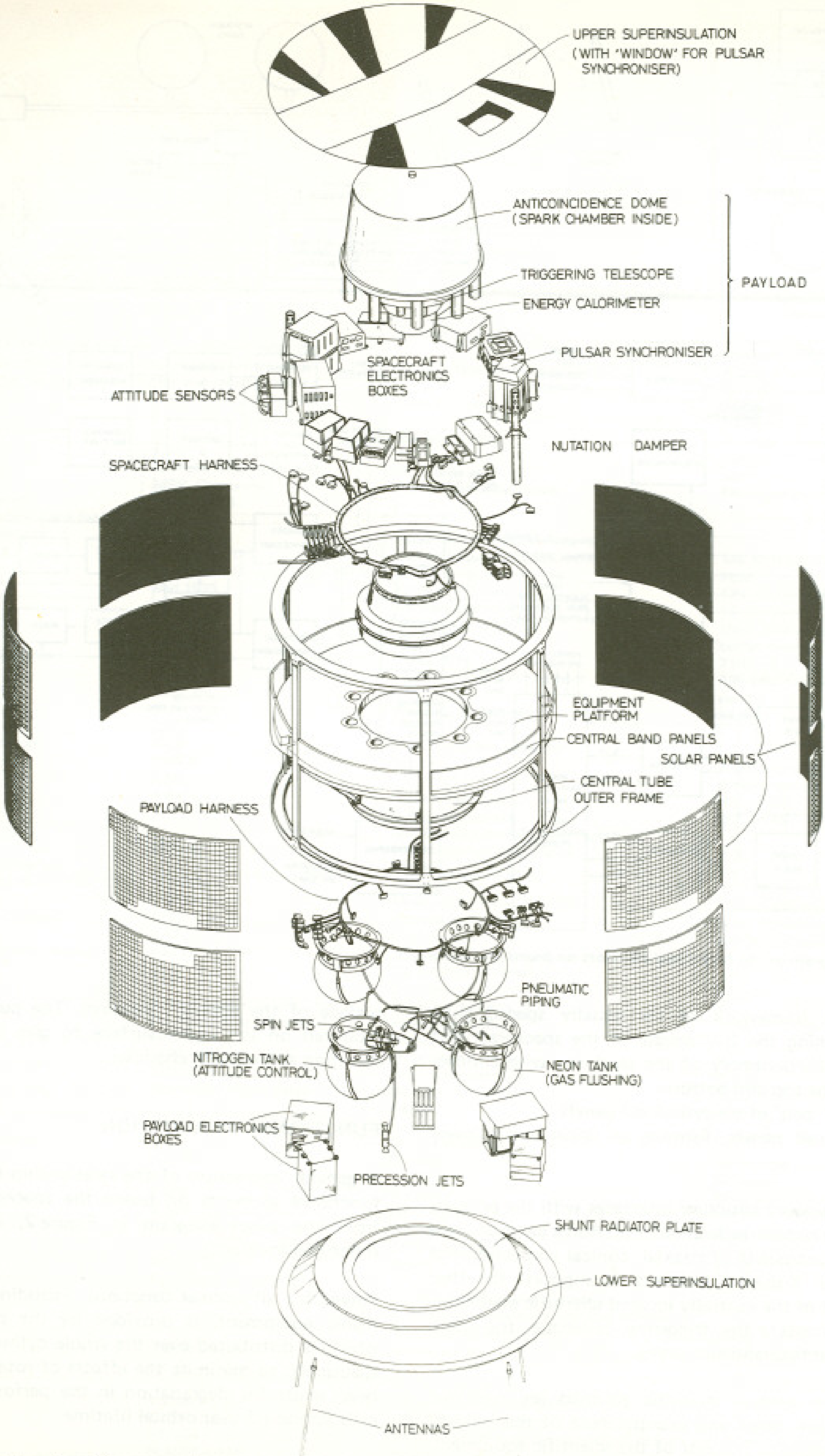


Figure 1 – Exploded schematic of the spacecraft.

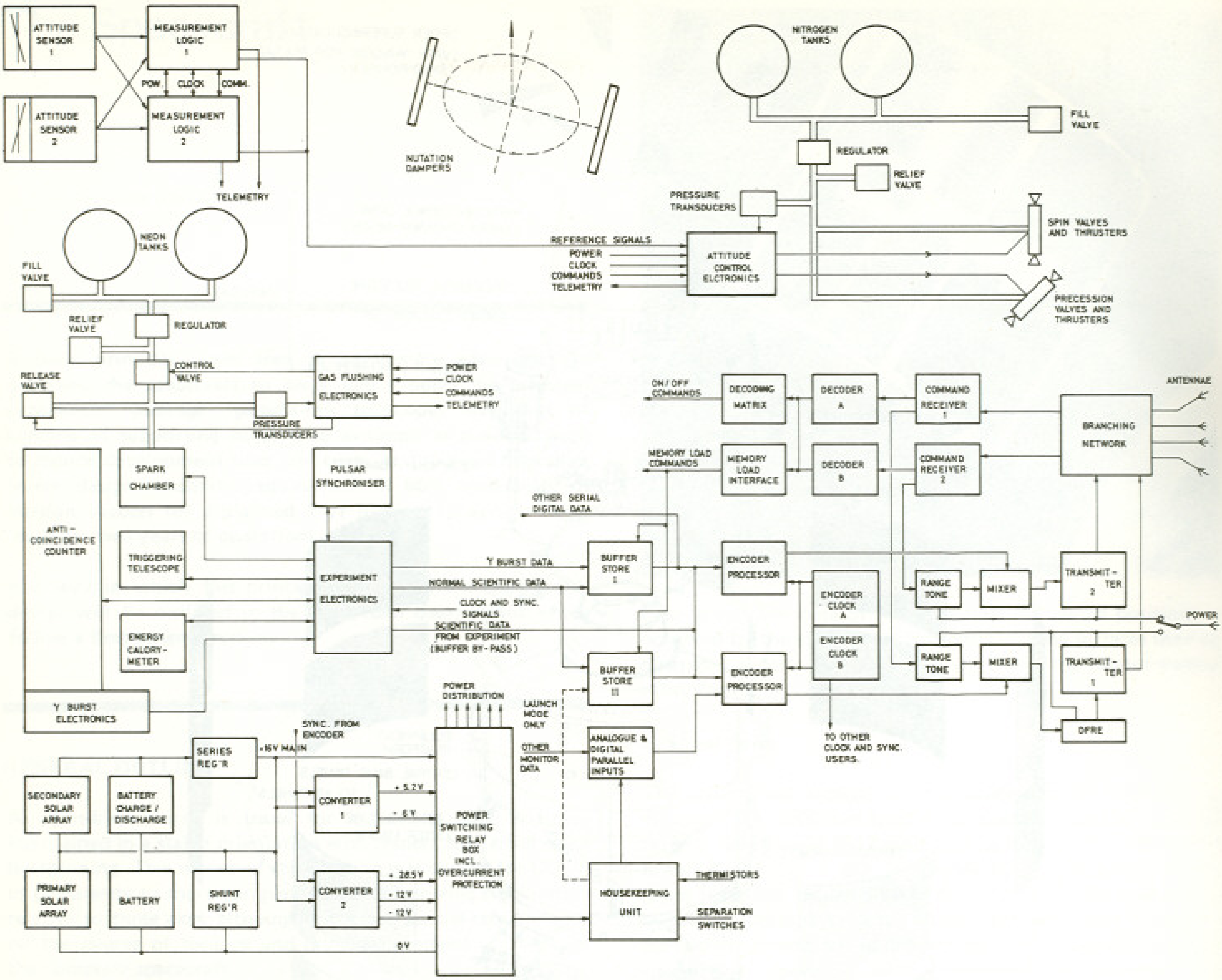


Figure 2 – Block diagram of the functional elements on board the spacecraft.

(a) A cylindrical framework of six equally spaced axial stringers, running the full height of the spacecraft and attached to the periphery of the platform, with connecting rings at the top and bottom.
(b) An equatorial 'belt' of six cylindrical panels.
(c) Twelve solar-cell panels, forming an upper and a lower cylinder.

The *experiment support structure* interfaces with the primary structure near the conical-tube/annular-platform junction. It is a fairly complex composite of coaxial, conical and cylindrical sections and four Y-shaped brackets. It supports the four principal elements of the centrally located scientific payload – the energy calorimeter, the triggering telescope, the spark chamber and the anticoincidence dome.

The units of the central scientific payload are mounted coaxially above one other and occupy most of the internal height of the spacecraft. The rest of the scientific equipment, consisting of various electronics units, is mounted on the lower surface of the annular platform. The pulsar synchroniser is mounted on the upper surface to give it the same viewing direction as the spark chamber.

FUNCTIONAL DESCRIPTION

A general impression of the relationship between the various functional elements on board the spacecraft can be gained from the block diagram in Figure 2, which is somewhat simplified for clarity.

Power for all normal functions, including all on-board electronic equipment, is provided by the primary solar array, which is distributed over the whole cylindrical surface of the spacecraft, to minimise the effects of rotation. Allowance has been made for degradation in the performance of the solar cells during a 2 year orbital lifetime.

In order to support the main satellite functions during eclipses,

SPACECRAFT DATA SHEET

1. *Mission Objective*

To make observations of extraterrestrial gamma radiation with the intention of assisting understanding of the location and mechanism of cosmic-ray sources, and the distribution of matter and radiation in the Universe.

2. *Development*

Customer	ESA
Project management	ESTEC, Noordwijk
Main contractor	MBB, Ottobrunn
Main development programme	1972–1975
Development and construction costs for two flight units plus provision of some spares	25.610 MAU
Launch vehicle	McDonnell-Douglas Delta 2913
Launch (planned)	Mid 1975
Launch site	WTR
Planned orbital lifetime	2 yr

3. *Orbit (typical during first year)*

Apogee	98 000 km
Perigee	2000 km
Inclination	91.8°
Argument of perigee	328°
Ascending node right ascension:	43.3°
Period	1.54 d
Eccentricity	0.85
Longest eclipse	1.6 h

4. *Main Satellite Characteristics*

Total mass at launch	278 kg
Total mass of gamma-ray telescope and associated experimental electronics	117.8 kg
Diameter (overall)	1488 mm
Height (overall including antennae)	1712 mm
Moment of inertia ratio	1.17
Beginning-of-life maximum array power	130 W

5. *Structure*

Basic structure	Central cone, one platform, struts and outer cylinder
Weight	42.2 kg
Outer cylinder diameter	1400 mm
Outer cylinder height	1200 mm
Central platform	Aluminium honeycomb

6. *Power*

Total array power at end-of-life, 120° solar aspect angle	83.1 W
Solar array weight	9.2 kg
Solar cells	9480
Solar cell type	Silicon, pulled crystal
Cover glass	Ce glass, 300 μm thick
Power storage	One NiCd battery, 18 cell, 6AH
Main bus voltage	16 V ± 2%
Solar cell panel arrangement	12 to form cylinder
Power conditioning weight	15.2 kg

7. *Telemetry*

Carrier frequency	136.95 MHz
RF output power (one transmitter)	6.5 W
Modulation index	1.3 rad
PSK subcarrier	5120 Hz
Data bit rates	80, 160 (normal) and 320 bps PCM/PSK/PM
Format type and size	8-bit words, 64 words/frame, 64 frames/format
Launch/housekeeping mode	4 housekeeping frames of normal format
Scientific data	Typical gamma event, 1100 bits, 60 frames of normal format allocated
Buffer memory	8 K bits, of which 2 K bits may be used to define noisy areas of the spark chamber, not to be transmitted
Primary ground stations	Redu (Belgium), Fairbanks (Alaska)

8. *Telecommand and Ranging*

Carrier frequency	148 MHz band
Command type	PCM
On/off commands	126
Memory load commands (16 bit)	16
Computer commands	Up to 128 words (16 bit) for buffer memory
Range tone	2160 Hz ± 180, 30, 5 Hz
Phase-difference experiment	535 kHz modulation on down-link carrier
Weight with telemetry	18.5 kg

9. *Attitude Measurement*

Sensors	2 redundant combined albedo/Sun sensors, double fan beam
Solar aspect angle	60° – 120°
Earth aspect angle	35° – 145°
Sun blinding protection in spin from sensor oblique planes	± 35°
Weight	3.8 kg
Data channels	12 x 16 bit
Measurement accuracy	1° full-cone-angle, 3σ
Ground processing	Selectable mathematical filters, including Kalman type

10. *Attitude Control*

Spin rate	10 rpm
Nutation dampers	2
Spin up/spin down	2 jets
Precession	2 jets
Propellant	Nitrogen, 9.9 kg
Max. initial pressure	250 bar
Manoeuvre capability	4200°
Weight	32.2 kg

11. *Gas Flushing*

Purpose	Refill experiment spark chamber as necessary
Contents	Neon plus 0.5% ethane; 1.1 kg
Refill cycles	13
Storage pressure	37 bar
Refill pressure	2 bar
Weight	7.4 kg

12. *Housekeeping and Harness*

32 temperature measurements by thermistor

Housekeeping weight	0.6 kg
Harness weight	15.2 kg

13. *Thermal Control*

Passive (spinning satellite)

Upper and lower thermal insulation

Paints, solar cells and second surface mirrors on cylinder. Radiator plates.

Weight	8.4 kg

a nickel-cadmium battery is provided. Charging current for the battery is provided by the secondary solar array, and charge/discharge is controlled by the charge/discharge logic and the series regulator. Automatic transition is possible between regulation modes, and the battery can provide back-up to the array-generated power should peak demands be made in sunlight.

Two converters (both fully redundant) provide alternative voltage lines from the 16 V main supply. Converter 1 gives +5.2 V, intended for the majority of digital logic circuitry, and −6 V, while converter 2 gives +28.5 V, +12 V and −12 V. These last two lines are intended for precision analogue purposes.

Switching, current limiting and overload protection and monitoring for housekeeping purposes are an integral part of the power supply.

Great care has been taken to minimise the weight of the *cable harness,* while maintaining satisfactory reliability of connections by redundancy, and satisfactory electromagnetic interference conditions by careful choice of screening and grounding elements. The *housekeeping unit* collects together a number of the resistive networks used in association with thermistors for temperature monitoring, and similar networks used in association with switches which monitor satisfactory separation of the satellite from the third stage of the launch vehicle.

The radiofrequency and data-handling subsystem provides for all communications to and from the satellite, and most functions are duplicated for reliability. Incoming signals from a ground station are separated in the branching network and passed to the command receivers, where they are demodulated. The signal is passed to two decoders, but only one will respond to the particular subcarrier and address code used.

From the addressed decoder, signals are passed out either as on/off commands on specific lines to specific users or as memory load commands, where an address, clock and data line approach is used. For transmission to ground (down-link) scientific data are normally assembled first in the buffer store, to match the variable experiment data rate to the constant telemetry data rate. Fifteen of every sixteen data frames are devoted to experiment information. In the event of buffer failure, a 'bypass' mode of operation can accept data direct from the experiment electronics unit. Analogue and digital housekeeping and similar data are processed for incorporation in the 16th data frame.

The processed data stream from the encoder is passed to the range tone unit, which contains the mixer, and thence to the transmitter. All of these units are redundant, and selection is made by telecommand. When tone-ranging is used, the tone signals are passed directly from the receiver to the range tone filters, and are then mixed with the telemetry data in the mixer.

The dual frequency ranging experiment, also known as the second phase shift difference experiment, operates on one transmitter only, by command. It generates a high-frequency tone (535 kHz) from the transmitter oscillator and applies this to the modulation input, so that coherent spectral lines are generated about 1 MHz apart, on either side of the carrier. From the phase differences in the arrival of these components on the ground, the propagation path followed by the signal can be calculated.

The *attitude-measurement subsystem* consists of two sensors and processing logic. Each sensor has a meridian and an oblique plane of view, and all measurements are made relative to the Sun pulse in the meridian plane. Output data to telemetry consists of timing information on the spacecraft spin period (nominally 10 rpm), Sun pulses relative to the datum pulse, and Earth pulses relative to the datum. On the ground, this timing information is converted into directly usable data on solar and Earth aspect angle.

The *attitude-control subsystem* allows the orientation of the satellite with respect to inertial space to be controlled and adjusted. Stabilisation of the spinning spacecraft (against nutation) is provided by two liquid-filled nutation dampers. Energy is dissipated as heat produced by viscous movement of the liquid. Precession of the spin axis is produced by releasing pressurised nitrogen from thrusters at the base of the spacecraft. The gas is stored in two spherical tanks, at up to 250 bar, and release (working pressure 1 bar) is controlled by solenoid-operated valves. Thrusting is applied twice per rotation of the satellite, the number of thrust pulses for a given manoeuvre and the delay angle required being computed on the ground and transmitted to the satellite.

A *gas-flushing subsystem* is carried by the spacecraft to allow the gas (neon with 0.5% ethane) in the experimental spark chamber to be replaced when it is no longer usable because of contamination. This gas is stored at 33 bar, and the nominal working pressure of the chamber is 2 bar. Enough gas is carried to fill the chamber 13 times, and adjustments to the chamber pressure can also be made. □

Launch Vehicle
and Nominal Sequence of Orbital Injection

LAUNCHER

At the start of the project-definition phase in 1970, the design of COS-B was based on the performance capability and launch environment of the Europa II launch vehicle still under development at that time. Owing to the cancellation of this programme in April 1973, steps had to be taken to adapt the satellite to the new interfaces and environment of the Delta launch vehicle. The change to the Delta launcher allowed a worthwhile modification to the mission in that its increased performance capability has made it possible to increase the inclination of the satellite's orbital plane from 28° to 90°. This has had the following major advantages:

- the useful time in orbit (part of orbit outside Van Allen belts) is increased;
- the ground coverage is improved, to approximately 90% of the useful time in orbit,
- gives greater flexibility for the observation programme.

The essential structural and propulsion elements of the Delta 2913 launch vehicle are shown in Figure 1.

THIRD STAGE

MOTOR	THIOKOL TE-364-3 (SOLID PROPELLANT)
CONTROL	SPIN-UP
FAIRING	8-FT DIAMETER

SECOND STAGE

AIRFRAME	8-FT DIAMETER
TANKAGE	4.5-FT DIAMETER
ENGINE	TRW TR-201 (9,850 LB THRUST)
PROPELLANTS	N_2O_4/AEROZINE 50
CONTROL	GIMBAL/COLD GAS
GUIDANCE	INERTIAL

FIRST STAGE

AIRFRAME	8-FT DIAMETER
ENGINE	ROCKETDYNE RS-27 (205K THRUST)
PROPELLANTS	LOX/RP-1
CONTROL	GIMBAL/VERNIERS
GUIDANCE	INERTIAL
SOLID AUGMENTATION	9 THIOKOL CASTOR II MOTORS (52K LB THRUST)

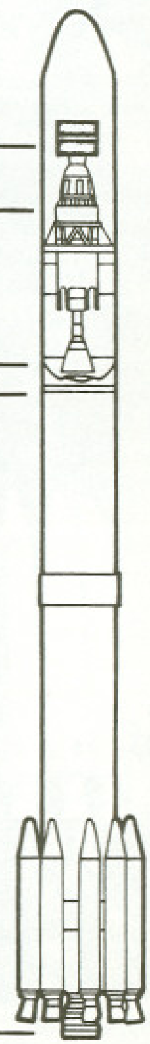
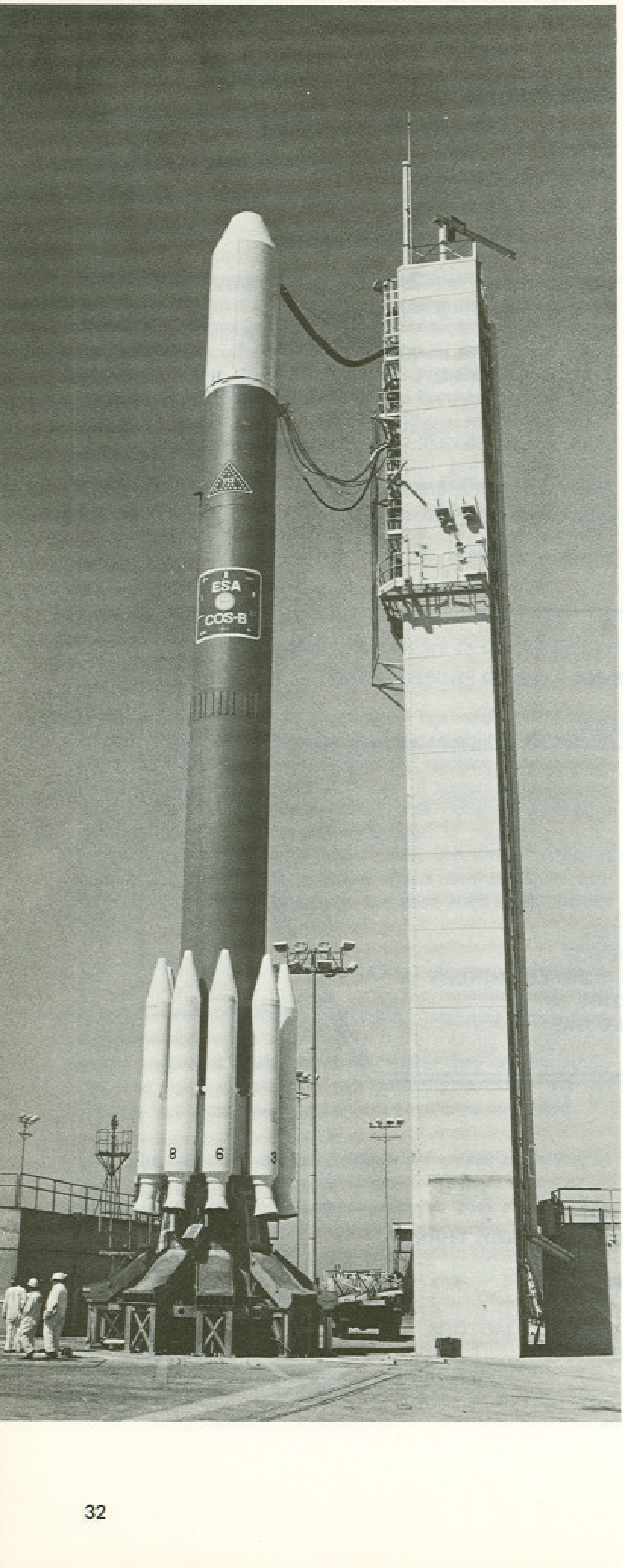


Figure 1 – Delta 2913 vehicle propulsion and guidance and control systems.



Propulsion

The first stage includes as its main engine the Rocketdyne RS-27 single start liquid bipropellant rocket with fixed calibrated thrust. Two vernier engines provide roll control. Nine Castor II solid motors are used for thrust augmentation.

The second stage uses the TRW TR-201 liquid bipropellant rocket with fixed calibrated thrust and multiple restart capability. The engine is rated at 9850 lb thrust; propellants are N_2O_4 as oxidiser and a mixture of 50 % UDMH/50 % hydrazine as fuel. Gaseous helium is used for pressurisation. A nitrogen cold gas jet system provides pitch, yaw and roll control during coast periods and roll control during powered flight. Separation of the third stage is provided by a cold gas retro system.

The third stage uses the Thiokol TE 364-3 solid-propellant rocket motor with a nominal thrust of 10 000 lb, delivering a total impulse of 418 000 lb s. A separation rate of about 6 ft/s is provided to the spacecraft by a spring separation mechanism. The third stage and spacecraft are spin-stabilised during third stage powered flight and coast phases.

Guidance and Control

Guidance and control equipment is housed in the forward section of the second stage and provides guidance, sequencing and stabilisation signals for both first and second stages. The guidance system is a strap-down all-inertial unit consisting of an inertial measurement unit (IMU) which contains three gyros, three accelerometers and conditioning electronics, and a guidance computer. The computer processes the IMU data to obtain attitude reference and navigation (position and velocity) information, and it provides continuous guidance correction signals based on a comparison of the instantaneous orbit to the desired mission orbit. The computer also issues preprogrammed sequence commands and provides control system stabilisation logic for both powered and coast phases of flight.

LAUNCH AND NOMINAL INJECTION INTO ORBIT

The COS-B mission profile is to be initiated with ignition of the main and vernier engines and six of the nine solid-propellant motors at lift-off. The subsequent sequence of events is illustrated in Figure 3. The three remaining solid-

Figure 2 — COS-B/Delta vehicle on launch pad.

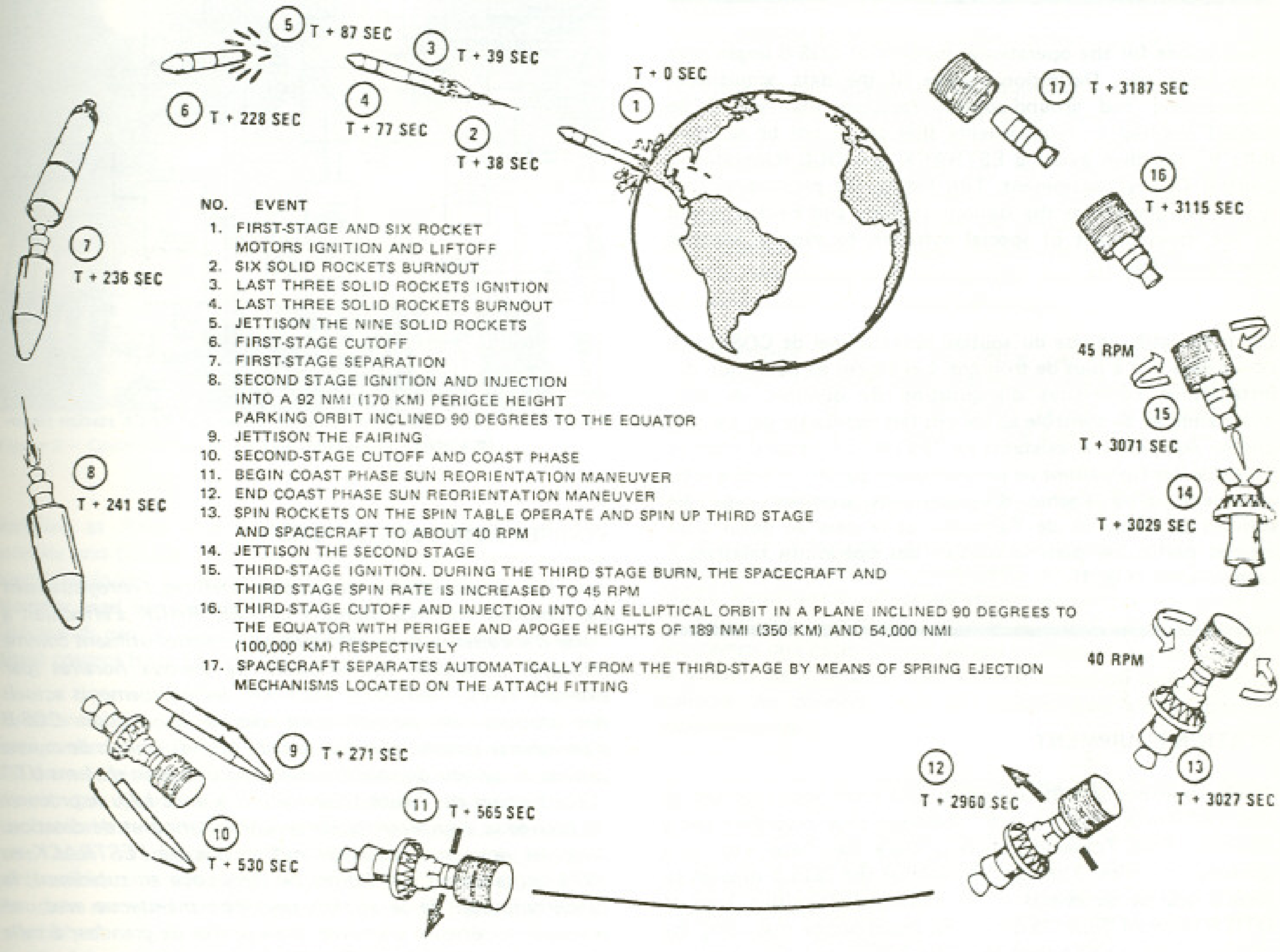


Figure 3 – COS-B launch and nominal orbital injection.

propellant motors are to be ignited following burn-out of the first six at approximately 39 s. Following burn-out of the last set, all nine expended motor cases are to be jettisoned at 87 s when range safety and flight-environment constraints are satisfied. The first stage will burn to propellant depletion, which occurs at approximately 228 s. First-stage main-engine cut-off will be followed by a brief vernier engine burn phase to stabilise the vehicle for second-stage separation.

The second stage is separated by a spring system and ignites 241 s after lift-off. The fairing separates at 271 s when the aerodynamic heating environment has fallen to a low level. Parking-orbit injection should occur 530 s after lift-off. After second-stage engine cut-off, a manoeuvre is to be performed to minimise the Sun exposure of the spacecraft. Following a 41 min coast phase to achieve the desired argument of perigee, the third stage is to be spun-up, separated, and ignited to provide the velocity required to achieve the desired 350 km perigee by 100 000 km apogee orbit. The Delta mission is completed by separation of the spacecraft 53 min after lift-off. □

Operational Support

Soutien operationnel

H. Bath, Mission Support Manager

Preparations for the operational support of COS-B began over three years ago. Definition studies of the data acquisition, commanding and ground-control facilities that would be needed resulted in requirements that could not be satisfied fully by the then existing ESTRACK and OCC (Operational Control Centre) equipment. This led to the procurement of special equipment for the stations at Redu and Fairbanks and to the development of special software to support mission operations (Fig. 1).

Les préparatifs en vue du soutien opérationnel de COS-B ont commencé il y a plus de trois ans. Les études de définition des installations nécessaires d'acquisition de données, de télécommande et de contrôle au sol ont fait apparaître des besoins que les équipements existants de l'ESTRACK et du Centre de Contrôle des Opérations ne permettraient pas de satisfaire intégralement: d'où l'achat d'équipements spéciaux pour les stations de Redu et de Fairbanks et la mise au point d'un logiciel particulier pour le soutien des opérations relatives à cette mission (Fig. 1).

STATION EQUIPMENT

During previous satellite missions, data have been recorded at the ESTRACK stations with analogue tape recorders using Standard Time Transmissions (e.g. WWV Neuchatel, etc.) as a primary reference. The requirement for the COS-B mission to record gamma-ray events at the spacecraft to within 1 ms of UTC (Universal Time Co-ordinates) could not be met using the existing station equipment and new timing and date-insertion units had therefore to be provided. With the new equipment installed at ESTRACK last year (including a rubidium frequency standard), station timing can be maintained approximately three orders of magnitude more accurately than before. As the existing analogue recorders could not provide sufficient resolution for 'events' to be unambiguously recorded, a new recording system has been installed at Redu and Fairbanks. It is based on a Dietz computer (digital data recording), which can be linked directly with the IBM system at ESOC. Intermediate steps involving analogue data conversion have thus been eliminated.

A Pulse-Code Modulated (PCM) commanding system was

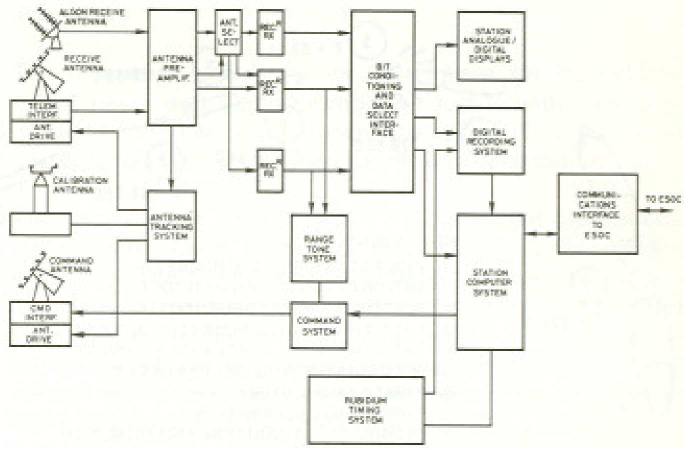


Figure 1 — Functional block diagram of an ESTRACK station (interferometer not shown).

EQUIPEMENTS DES STATIONS

Au cours de précédentes missions de satellites, l'enregistrement des données dans les stations de l'ESTRACK s'effectuait à l'aide d'enregistreurs magnétiques analogiques utilisant comme référence principale des émissions de signaux horaires (par exemple WWV, Neuchâtel, etc.). Or, les équipements actuels des stations ne permettraient pas à la mission COS-B d'enregistrer comme elle doit le faire les événements de rayons gamma au niveau du satellite avec une précision de 1 ms UTC (Coordonnées de Temps Universel), il a donc fallu se procurer de nouveaux équipements de synchronisation et de datation. Avec les nouveaux matériels mis en place à l'ESTRACK en 1974 (notamment un étalon de fréquence en rubidium), la synchronisation de la station peut être maintenue avec une précision supérieure d'environ trois ordres de grandeur à celle obtenue précédemment. Comme les enregistreurs analogiques existants ne peuvent assurer une résolution suffisante pour un enregistrement non équivoque des 'événements', un nouveau système a été mis en place à Redu et à Fairbanks. Il fait appel à un calculateur Dietz (enregistrement de données numériques) qui peut être relié directement au système IBM de l'ESOC. Cette solution permet d'éliminer certaines étapes intermédiaires impliquant la conversion des données analogiques.

Un système de télécommande en modulation par impulsions codées (PCM) a été installé à Redu et à Fairbanks pour l'exploitation du satellite néerlandais ANS et de COS-B. Ce système a été conçu de façon à permettre l'envoi au satellite aussi bien d'ordres isolés de marche/arrêt que d'instructions de

Figure 2 – Control room of ESTRACK station, Redu, Belgium.

installed at Redu and Fairbanks to serve the Dutch ANS satellite and COS-B. The station PCM Command Systems have been developed so that both single on/off commands and memory load commands can be transmitted to the satellite. Commands can be controlled remotely by the station or under direct control from ESOC.

An extensive programme of station-equipment refurbishing has been undertaken in the last two years. The antennae and station receiving equipment, which has been in use now for almost ten years, has been extensively overhauled. The mechanical structures of the command and receiver antennae have been strengthened. The telemetry receivers, whose performance and serviceability will determine the quality of the data recorded at the ground stations, have also been refurbished.

The VHF Range Tone systems have been specially calibrated to minimise errors in orbit determination. It should now be possible to pinpoint COS-B's position to within 75 km.

SPACECRAFT CONTROL FACILITIES

The bulk of the telemetry data transmitted by the spacecraft will be recorded at Redu (40% of total) and Fairbanks (50% of total). Redu will be the prime station for spacecraft control and all critical operations will be performed while Redu is in contact with the spacecraft; Fairbanks will be used mainly for data collection, but it has a command capability also.

stockage en mémoire. Les ordres peuvent être émis par l'intermédiaire de la station ou directement à partir de l'ESOC.

Un vaste programme de reconditionnement des équipements des stations a été entrepris ces deux dernières années. Les antennes et équipements de réception, qui sont utilisés depuis maintenant près de dix ans, ont fait l'objet d'une révision complète. Les structures mécaniques des antennes de télécommande et de réception ont été renforcées. Les récepteurs de télémesure, dont le fonctionnement et le bon état de marche détermineront la qualité des données enregistrées par les stations sol, ont également été révisés.

Les systèmes VHF de télémétrie par tonalité ont été spécialement étalonnés pour réduire au minimum les erreurs de détermination de la position sur orbite. Il devrait être désormais possible de localiser COS-B à moins de 75 km près.

INSTALLATIONS DE CONTROLE DU SATELLITE

La majeure partie des données de télémesure émises par le satellite sera enregistrée à Redu (40% du total) et à Fairbanks (50%). Redu sera la principale station de contrôle du satellite et toutes les opérations critiques y seront effectuées aussi longtemps que cette station restera en contact avec le satellite; la station de Fairbanks sera utilisée essentiellement pour la collecte des données, mais elle dispose aussi de moyens de télécommande.

Vingt pour cent au moins des données enregistrées à Redu seront exploitées à l'ESOC par le système du traitement rapide, appelé 'Fast Routine Facility'. Les données enregistrées à Redu pourront être transférées au système d'exploitation en temps réel (RTOS) de l'ESOC (Fig. 3) à mesure qu'elles seront enregistrées à la station (en temps réel) ou après interruption des opérations du satellite (après les passages). Ces données serviront au contrôle du satellite et au traitement des données fournies par les expériences. Les bandes numériques enregistrées à Fairbanks seront expédiées par la poste à l'ESOC pour y être traitées avec les données provenant de Redu.

Tandis que les stations de Redu et de Fairbanks enregistreront les données de télémesure, des 'situations' en visualisation instantanée ('quick-look') devront être transmises sur des canaux déterminés de télémaintenance de bord de façon à permettre aux contrôleurs de l'ESOC de suivre le fonctionnement du satellite. Ces situations seront établies par le calculateur principal de la station (Honeywell 316) à intervalles réguliers (par ex. toutes les 3 heures) et communiquées par télex à l'ESOC pour analyse.

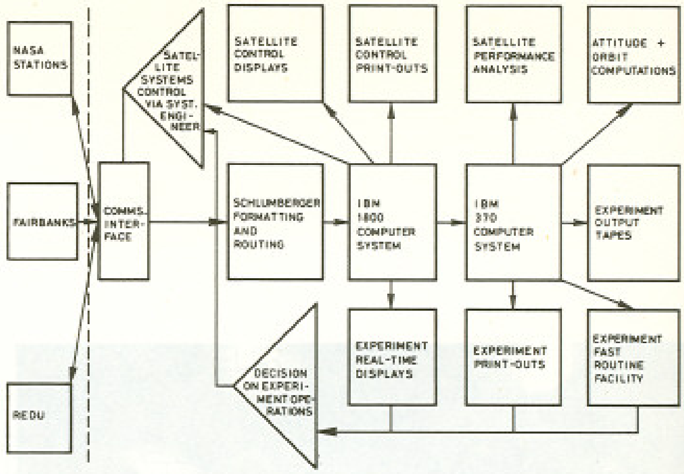


Figure 3 — Functional block diagram of data processing at ESOC.

At least 20% of the data recorded at Redu will be processed at ESOC using the 'Fast Routine Facility'. Data recorded at Redu can be transferred to the Real Time Operating System (RTOS) at ESOC (Fig. 3) as it is being recorded at the station (real time) or after satellite operations have been interrupted (post pass). Such data will be used for satellite control and experiment data processing. Digital tapes carrying data recorded at Fairbanks will be mailed to ESOC for processing along with the Redu data.

Whilst Redu and Fairbanks are recording telemetry data, it will be necessary to produce 'quick-look' reports on selected housekeeping channels from which ESOC's controllers can monitor spacecraft performance. These reports will be produced by the main station computer (Honeywell 316) at regular intervals (e.g. every 3 h) and telexed to ESOC for analysis.

Spacecraft control will be effected via the existing Real Time Operating System at ESOC. The Schlumberger PCM equipment and IBM 1800/370 computers that have served past ESRO spacecraft missions, such as TD-1, HEOS-2, ESRO-IV and are currently serving the Dutch ANS satellite, will be used. Data received from the two ground stations will be processed by the RTOS, using specially developed software. Alphanumeric displays and strip-chart recordings of experiment and spacecraft parameters will be available to monitor and control operations. A graphic display of the experiment spark-chamber data will allow real-time analysis of the experiment's operation. Spacecraft commands can be initiated from the RTOS.

It is also possible to use the IBM 1800 system to directly control commands at Redu and to check the telemetry for command confirmation. This facility will be used for attitude manoeuvres and the immediate post-launch operations. Data stored temporarily on the IBM 1800 machine will be transferred at regular intervals to the IBM 370, where it will be put on file. Data from this file will be used for experiment data processing and detailed analysis of the housekeeping subsystems.

Special software is needed for attitude control and attitude determination, because of the need to know the pointing direction of the spacecraft's spin axis to within ± 0,5° half cone angle and to arrange operations so that there will be sufficient albedo sensor coverage of the Earth. Two programs have been developed for use by the experiment group to determine the optimum attitudes for the observation programme, including the most economic use of the available gas for attitude reorientations.

Le contrôle du satellite s'effectuera via le système d'exploitation en temps réel (RTOS) de l'ESOC, en faisant appel à l'équipement PCM Schlumberger et aux calculateurs IBM/1800/370 déjà utilisés pour les missions de précédents satellites du CERS tels que TD-1, HEOS-2 et ESRO-IV et qui le sont encore aujourd'hui pour le satellite hollandais ANS. Les données reçues des deux stations sol seront traitées par le RTOS à l'aide d'un logiciel spécialement mis au point. Des affichages alphanumériques et des enregistrements graphiques des paramètres des expériences et du véhicule spatial permettront de suivre et de contrôler les opérations. Un affichage graphique des données de la chambre à étincelles de l'expérience permettra d'analyser en temps réel le fonctionnement de cette dernière. Les ordres de télécommande à destination du satellite pourront être émis à partir du RTOS. Le système IBM 1800 pourra également servir à contrôler directement les ordres de télécommande à Redu et vérifier les télémesures pour confirmer l'exécution des ordres. Ce système sera utilisé pour les manoeuvres en attitude et les opérations suivant immédiatement le lancement. Les données stockées provisoirement dans l'IBM 1800 seront transférées à intervalles réguliers à l'IBM 370 où elles seront entrées en fichier. Les données de ce fichier seront utilisées pour le traitement des données des expériences et l'analyse détaillée des sous-systèmes de télémaintenance de bord.

Un logiciel spécial est nécessaire pour la commande et la détermination d'attitude, car il importe d'une part de connaître avec une précision de ± 0,5° de demi-angle au sommet du cône la direction de pointage de l'axe de rotation du satellite et d'autre part d'organiser les opérations de telle sorte que le capteur d'albedo assure une couverture suffisante de la Terre. A cette fin, deux programmes d'ordinateur ont été mis au point pour le Groupe chargé des expériences: ils visent à déterminer les attitudes optimales pour le programme d'observations, ainsi que l'utilisation la plus économique du gaz disponible pour les réorientations en attitude.

Les programmes de détermination orbitale utilisés pour COS-B sont, en principe, très proches de ceux d'HEOS-1 et HEOS-2,

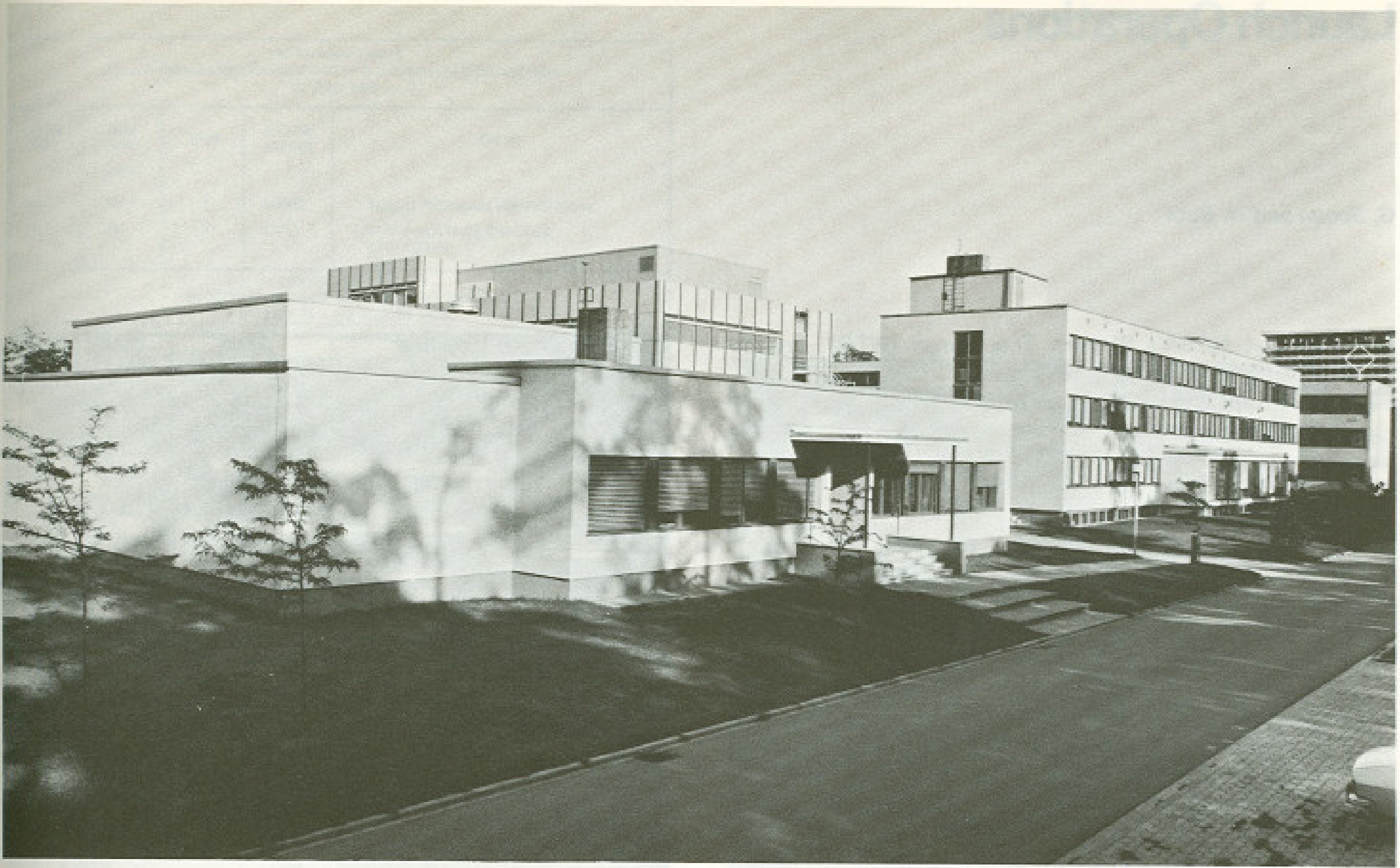


Figure 4 – Space Operations Centre (ESOC), Darmstadt.

The orbit-determination programs used for COS-B are, in principle, very similar to those used for HEOS-1 and HEOS-2; no major modifications have had to be made to the existing programs. Tracking data will also be forwarded to the CNES and NASA networks, mainly during the first month of spacecraft operations. By means of a differential correction program, orbital parameters will be derived representing minimum residuals between the spacecraft's predicted position and that derived from the tracking data. The different elements will then be used to produce the necessary pass predictions for the stations at Redu and Fairbanks and the refined position data for experiment data processing.

Experiment data processing for COS-B includes the production of experiment data tapes, with merged orbit and attitude information, and includes processing by the 'Fast Routine Facility'. As has already been pointed out, this FRF processing is to be used by the experimenters for on-the-spot analysis at ESOC of the scientific data soon after it is recorded at Redu. In order to ensure close harmony between the operations carried out at ESOC in support of the scientific mission and the direction of these operations for optimum scientific return, an experiment group will be located in ESOC to operate the FRF. The collaborating institutes have developed their own analysis programs for this, and ESOC has provided the basic system software with which to operate them. □

auxquels aucune modification majeure n'a dû être apportée. Les données de poursuite seront également transmises aux réseaux du CNES et de la NASA, notamment durant le premier mois des opérations du satellite. Un programme de correction différentielle permettra d'établir des paramètres orbitaux représentant le plus faible écart résiduel entre la position prévue du satellite et celle calculée à partir des données de poursuite. Ces différents éléments serviront alors à élaborer les prévisions de passage nécessaires pour les stations de Redu et de Fairbanks et à déterminer les données affinées de position pour le traitement des données des expériences.

Pour COS-B, ce traitement comporte la production de bandes de données d'expériences combinant des informations d'orbite et d'attitude et leur traitement par le système FRF. Comme il a déjà été indiqué, les expérimentateurs recourront à ce système pour analyser sur place à l'ESOC les données scientifiques peu après leur enregistrement à Redu. Afin d'assurer une étroite harmonie entre les opérations effectuées à l'ESOC en soutien de la mission scientifique et la conduite de ces opérations en vue d'en obtenir un bénéfice scientifique optimal, un groupe 'Expériences' sera installé à l'ESOC pour exploiter le système FRF. Les instituts coopérants ont élaboré à cette fin leurs propres programmes d'analyses et l'ESOC a fourni le logiciel systémique de base qui doit en permettre l'exploitation. □

Launch Operations

G. Scoon and H. Bath

Operations at NASA's Western Test Range (WTR), on the Californian coast, comprised two phases:
- the prototype compatibility phase, and
- the flight launch phase.

THE PROTOTYPE COMPATIBILITY PHASE

The prototype compatibility phase was completed successfully between 15 April and 2 May 1975. With the prototype spacecraft and ground-support equipment shipped from ESTEC, this phase was used to:
- install and check the electrical and mechanical ground-support equipment to be used during launch
- check spacecraft compatibility with the launch vehicle
- establish and verify all interfaces, whether hardware or procedural, between the satellite, ground-support equipment, and the WTR facilities
- check critical operations such as gas filling, servicing and gantry operations, in a realistic environment, and
- familiarise the team with WTR facilities and operational methods.

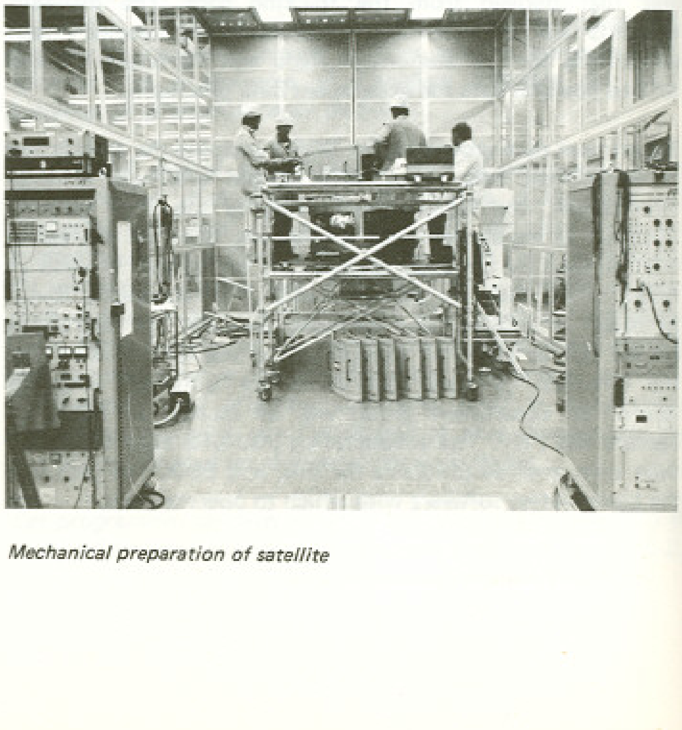
An important element of this phase was a full rehearsal of the countdown, lasting five hours. All sections of the Countdown Manual were rehearsed, with the exception of the Emergency Switch-Off procedure.

Moving of satellite to clean room for first check after arrival at WTR

THE FLIGHT LAUNCH PHASE

By 25 June 1975, the launch vehicle had been shipped by the manufacturer, McDonnell Douglas, to WTR and preparation of the vehicle started. Meanwhile, at ESTEC, acceptance testing of the COS-B flight model was being completed.
The COS-B Flight Readiness Review was held at ESTEC on 26 June and concluded with the Review Board recommending authorisation of the launch. This decision was accepted and promulgated by the ESA Directorate on 27 June.

The main launch operations tasks that had been completed prior to the Flight Readiness Review were:
- updating of the planned sequence of launch operation activities and their allocated durations, based on prototype phase experience, and on optimisation of the launch operations plan
- updating of the procedural contents of the countdown manual
- definition and implementation in terms of computer software, of the final go/no-go criteria to be applied to the



Mechanical preparation of satellite

LPD D31-078 COS-B
FLIGHT PROGRAMMER VERIFICATION & ORDNANCE CONNECTION
30 JULY 1975

LOCAL TIME	TASK TIME (MIN)	TASK	SLC-2W STATUS	EVENT
0400	750	1	AMBER	FLIGHT PROGRAM VERIFICATION
1630	360	2	CSP	STRAY VOLTAGE CHECKS & ORD CONN

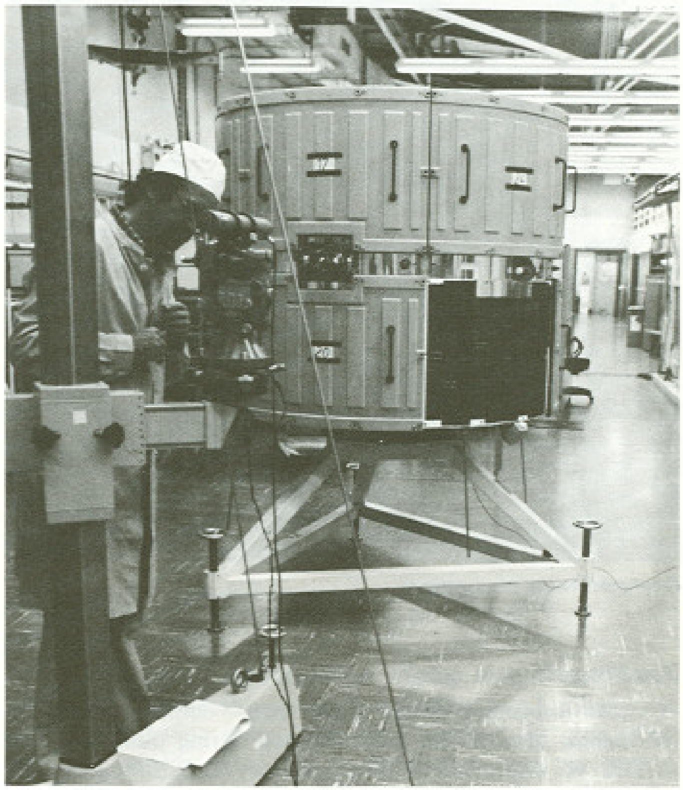
LPD D31-079 COS-B
SPACECRAFT-FAIRING-SOLID MOTOR FINALING
31 JULY 75 - 1-3 AUGUST 1975

(31 July 75)				
0630	690	1	AMBER	FIRST STAGE FUEL LOADING
1430 (1 Aug 75)	360	3	AMBER	SECOND STAGE FLW CNTL VALVE LK TEST
0800			AMBER	S/C PRESSURIZATION
(2 Aug 75)				
0630	90	2	AMBER	S/C FINAL PREP
0800 (3 Aug 75)	720	4		FAIRING INSTL & SHIMMING
0730	450		AMBER	S/C CHECKOUT
0730	450	5		SECOND STAGE PRPLT SERVICE PREPS
0730	240	6		FINAL PREPS FOR COUNTDOWN
0900	120	4		FAIRING SHIMMING
1500	360	7	CSP	FINAL CLOSURE & ORD INSTL

LPD D31-080 COS-B
COUNTDOWN
4-6 AUGUST 1975

LOCAL TIME	C/D CLOCK (MIN)	TASK	SLC-2W STATUS	EVENT
0730	T-2045	1	RED	SECOND STAGE PRPLT LOADING
1800	T-1415		AMBER	PLANNED HOLD 13 HRS 30 MIN
(5 Aug 75)				
0730	T-1415	2	CRP	GUID CHECKS & DISTRUCT CHECKS
0730	T-1415		AMBER	S/C CHECKOUT
1200	T-1145			FAIRING FINALING
1200	T-1145	3		INTERSTAGE FINALING
1200	T-1145	6		MST REMOVAL PREPS
2000	T-665			PLANNED HOLD 9 HRS
(6 Aug 75)				
0800	T-665	4	CRP	VEHICLE ARMING & 3RD STAGE ARMING
0800	T-485	6	AMBER	MST REMOVAL
1130	T-275	7	CRP	SINGLE POINT ARMING
1400	T-125		AMBER	PLANNED HOLD 1 HR 56 MIN 47 SEC
1556:47	T-125	8	RED	TERMINAL COUNTDOWN
				STATION READINESS CHECK
				HAZARD CORRIDOR CLEARANCE
	T-60			SSPU PRESSURIZATION
				PRELIM LOX LOADING
				AUTO SLEW TEST
1736:47	T-25			PLANNED HOLD (45 MIN)
1821:47	T-25			RESUME COUNTDOWN
				BEACON ON
				LOX LOAD TO 95%
1839:47	T-7			PLANNED HOLD (10 MIN)
1849:47	T-7			RESUME COUNTDOWN
				SPACECRAFT INTERNAL POWER
				LAUNCH ENABLED
1852:47	T-4			LAUNCH READINESS VERIFICATION
	T-240 SEC			BEGIN INTERNAL TRANSFER
	T-90 SEC			ALL STATIONS CLEAR TO LAUNCH
	T-60 SEC			VEHICLE READY TO LAUNCH
	T-45 SEC			SECOND STAGE HYDRAULICS ON
	T-30 SEC			LOX LOAD TO 100%
	T-15 SEC			CAMERAS ON
	T-10 SEC			COUNTDOWN
	T-2 SEC			ENGINE START
1856:47	T-0			LIFT-OFF
1932:41	T-0			LAST POSSIBLE LIFT-OFF

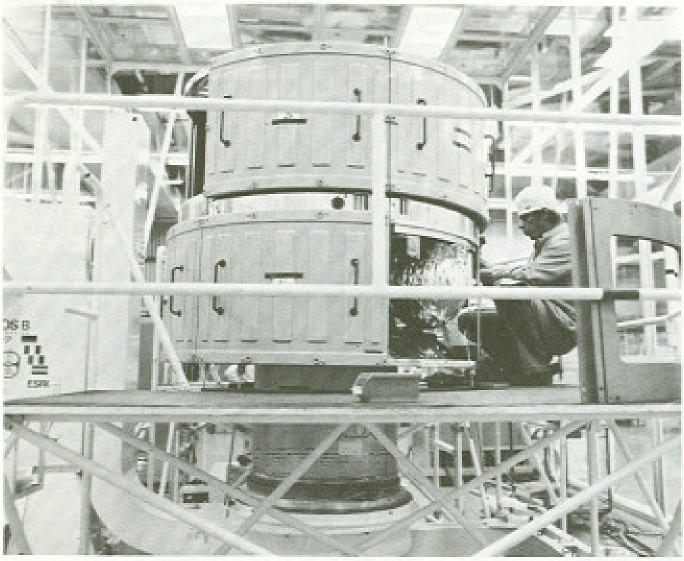
COS-B Project Manager's countdown card



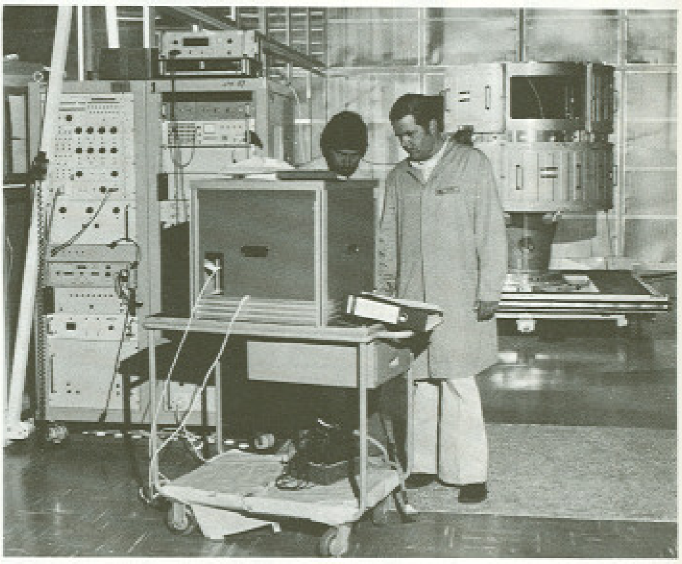
Alignment check of AMS sensor optics and ACS thrusters

satellite's functional performance parameters during countdown
- final arrangements for packing and transportation.

Packing of the hardware and software in preparation for transportation was completed on schedule and the two consignments were airfreighted from Rotterdam on 2 July. The main groups of the launch operations team were available at the range on Monday 7 July, where they proceeded with the parallel activities of unpacking equipment, accessories and documentation software. The mainstream activities were the establishment and organisation of facilities and a post-transport visual inspection of the satellite in preparation for its first functional check on the range. As one checkout station and the 50 Hz AC/AC converters had been left in a state of operational readiness, reactivation of these essential facilities required only a brief check. Installation and commissioning of the second Overall Checkout Equipment station was continued in parallel.



Final mechanical preparations



Antenna unit test

Test Phase

A visual inspection of the flight model confirmed that no mechanical damage had been suffered during transport from ESTEC to California. The preparatory activities and tests applied to the satellite during this phase constituted a logical sequence of preparation, checking and testing of all its functional performance parameters and its technological and scientific behaviour. The tests were applied in the following sequence:

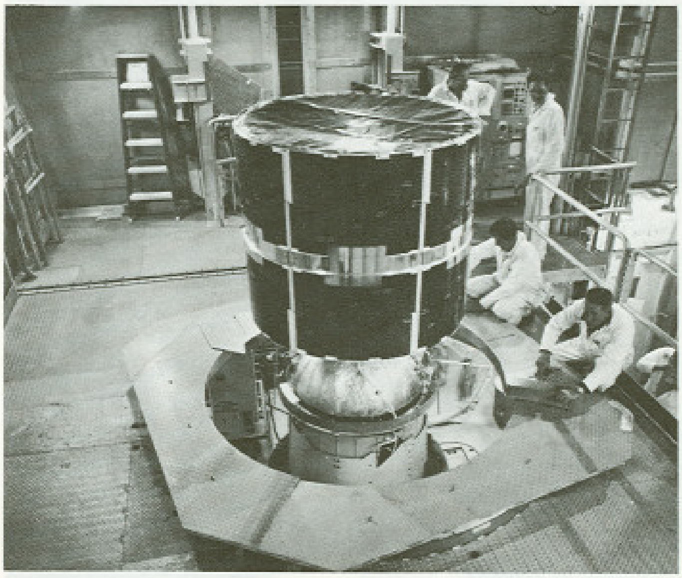
- Verification of correct satellite functional performance after transport — Integrated Satellite Checkout. An electromagnetic problem was detected in the pulsar synchroniser, which was subsequently exchanged for a second unit.
- Battery-conditioning and flight-battery-selection activities resulted in the selection and installation of the F6 battery for flight.
- Leak measurements, including preparatory activities for filling and gas sampling, were well within the system specifications.
- Solar-array performance tests conducted at panel level gave good results with no degradation. Flight solar panels were selected on the basis of these results.
- System-level supplementary tests verified specified performance of all satellite system elements.
- Alignment check, limited to attitude-measurement-system optics and attitude-control-system thrusters, showed good results.
- Visual inspection resulted in a minor repair to the lower superinsulation.
- Mechanical preparation included the final torquing of all units.
- Antenna unit test showed no degradation compared to reference and later measurements.
- Solar-array functional check was carried out, with correct results, with the satellite in its flight configuration.
- Battery selection and installation: the F6 battery fulfilled the specified performance criteria best and was therefore installed for flight.
- Closing of spacecraft and final visual inspection.
- Final integrated system test indicated correct performance with good results.
- Scientific data accumulation was extended beyond the 48 h requirement specified by the COS-B Scientific Collaboration. Quality data was obtained which verified expected scientific performance and resulted in declaration of a 'green status' by the Collaboration.

Gantry Operations Phase

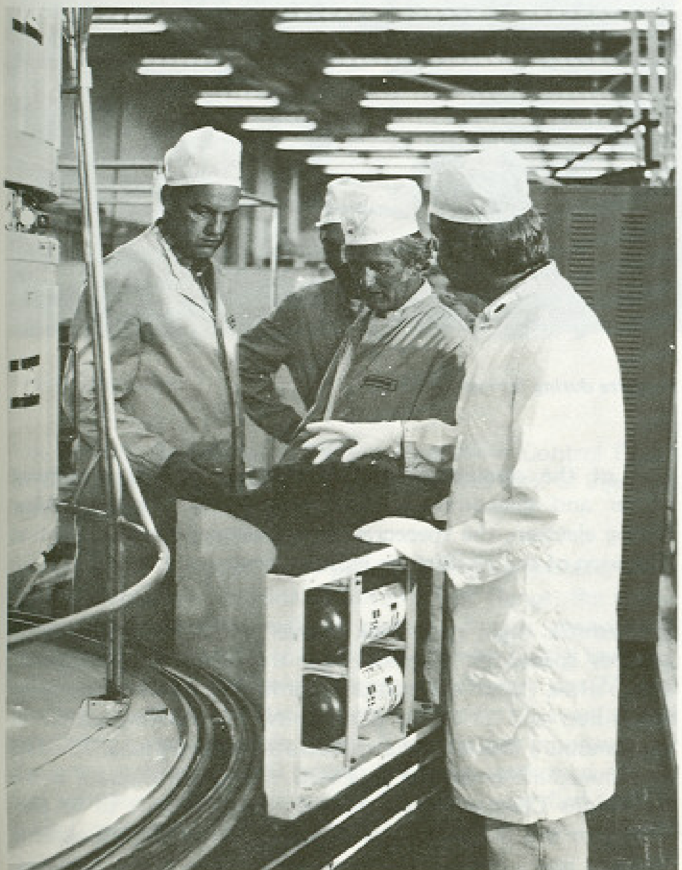
- Mating with the launcher was completed successfully on 29 July.
- Tests on launcher after mating:

  Telecommand uplink, telemetry downlink, stimuli and feedback links were successfully established.

Hoisting the satellite in container to gantry Level Six



Satellite after final preparation on gantry



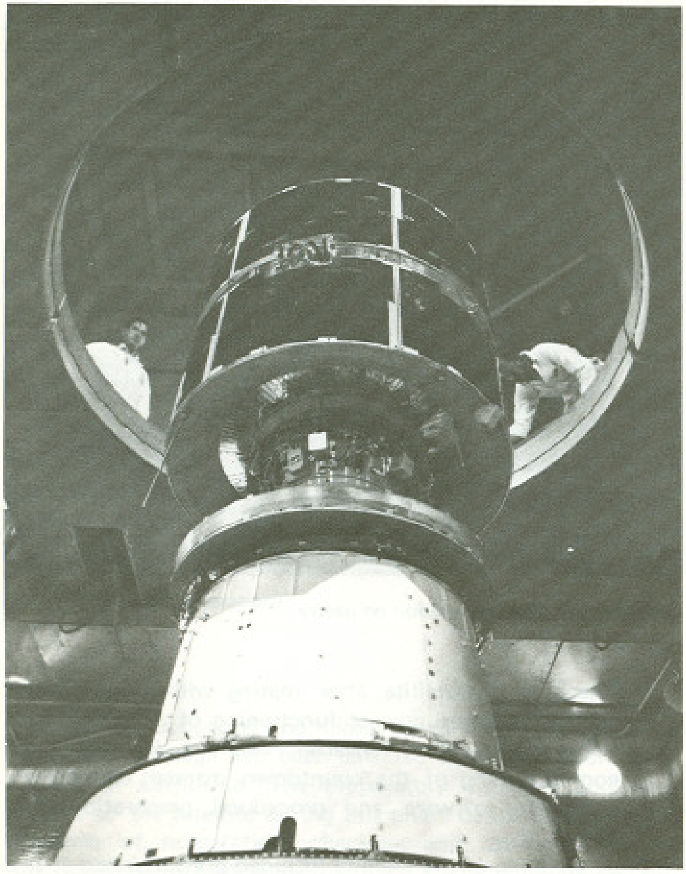
Team members discussing pneumatic activities

Checking of satellite after mating with Delta launch vehicle indicated correct functioning of all subsystems. Countdown dress rehearsal resulted in the final commissioning of the countdown manual, countdown computer software and procedural preparations for launch.

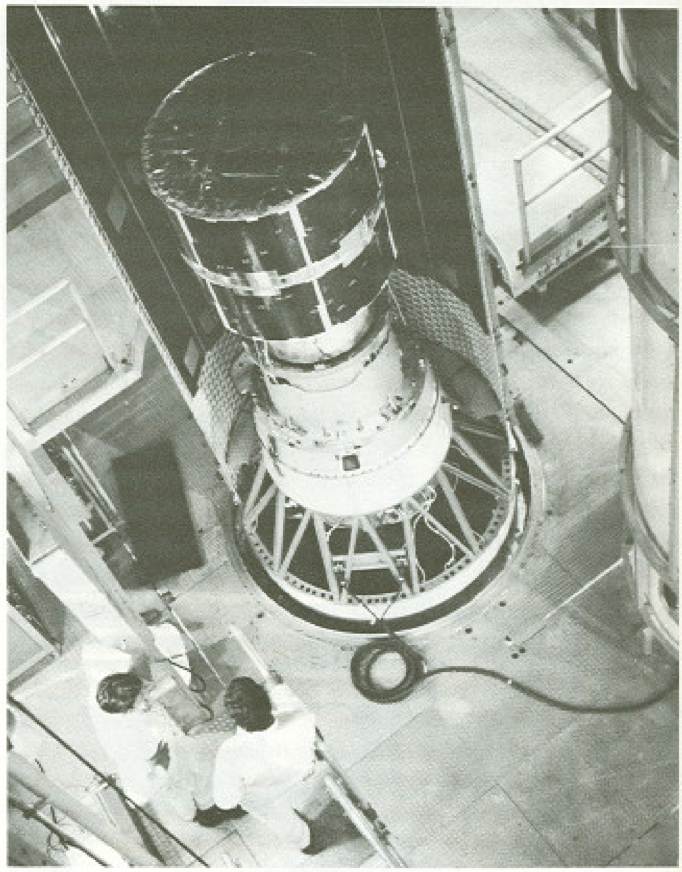
- Final servicing of the satellite included pressurisation of the attitude-control-system gas tanks to a nominal 250 bar, and the gas-flushing-system tanks to a nominal 33 bar. The spark-chamber vessel was 'topped-down' to a nominal 1.5 bar. Umbilical connections were checked and solar-array covers, attitude-measurement-system hoods, attitude-control-system thruster covers and connector dust caps were removed.

After completion of these activities by the ESA team on the gantry, the fairings were installed.

Launch had been set for 18.56 h on 6 August 1975. Countdown to this target proceeded satisfactorily until some 5h before launch when operations had to be aborted. Following closure of their tracking station at Tananarive, Madagascar, NASA were using an Advance Range Instrumental Aircraft (ARIA), operating from Johannesburg, to monitor the flight sequence from third-stage separation to separation of the spacecraft. In the early afternoon, news was received that this aircraft could not take off because of trouble with its hydrau-



Satellite mounted on top of third stage



Satellite during fairing installation

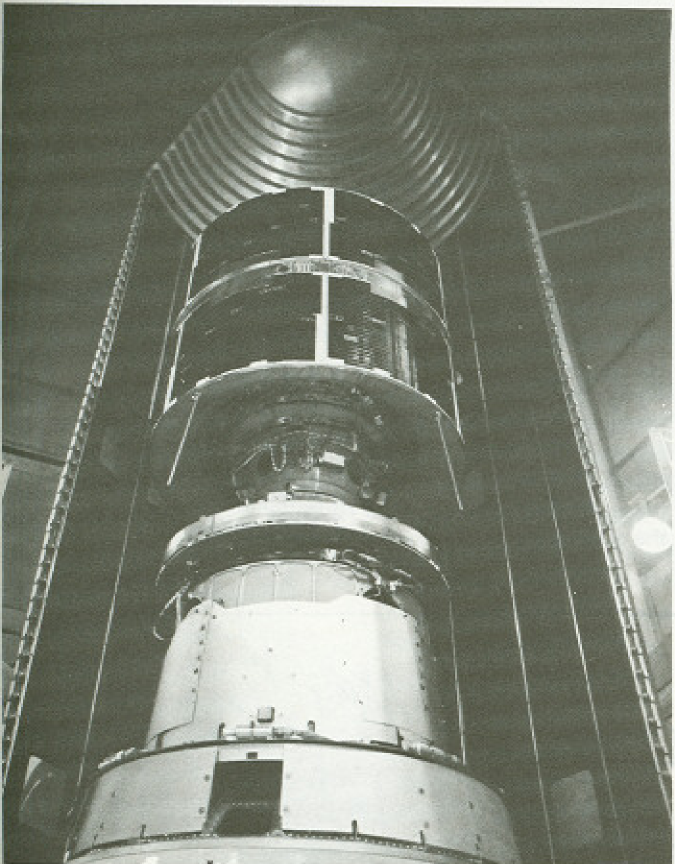
lics. This obliged NASA's Delta Office to postpone the launch for 48h, and it was re-scheduled for 18.48 h on 8 August, the opening of a 36 min launch window. Meanwhile, a second ARIA was prepared and flown from California to South Africa.

At 07.30 h on 8 August, the countdown was resumed and, after periods of further uncertainty about the arrival of the second aircraft on station (it was refuelled and airborne again within 2 h of landing at Johannesburg), the terminal countdown began on schedule at 15.48 h. Lift-off occurred 0.4 s before the scheduled time of 18.48 h.

Early Flight Data Assessment

Data from the launch (boosted) phase showed correct operation of the satellite in launch configuration with nominal power and telecommunication subsystems operation. After fairing ejection, the spacecraft data assessors observed the first powering of the satellite via its solar arrays.

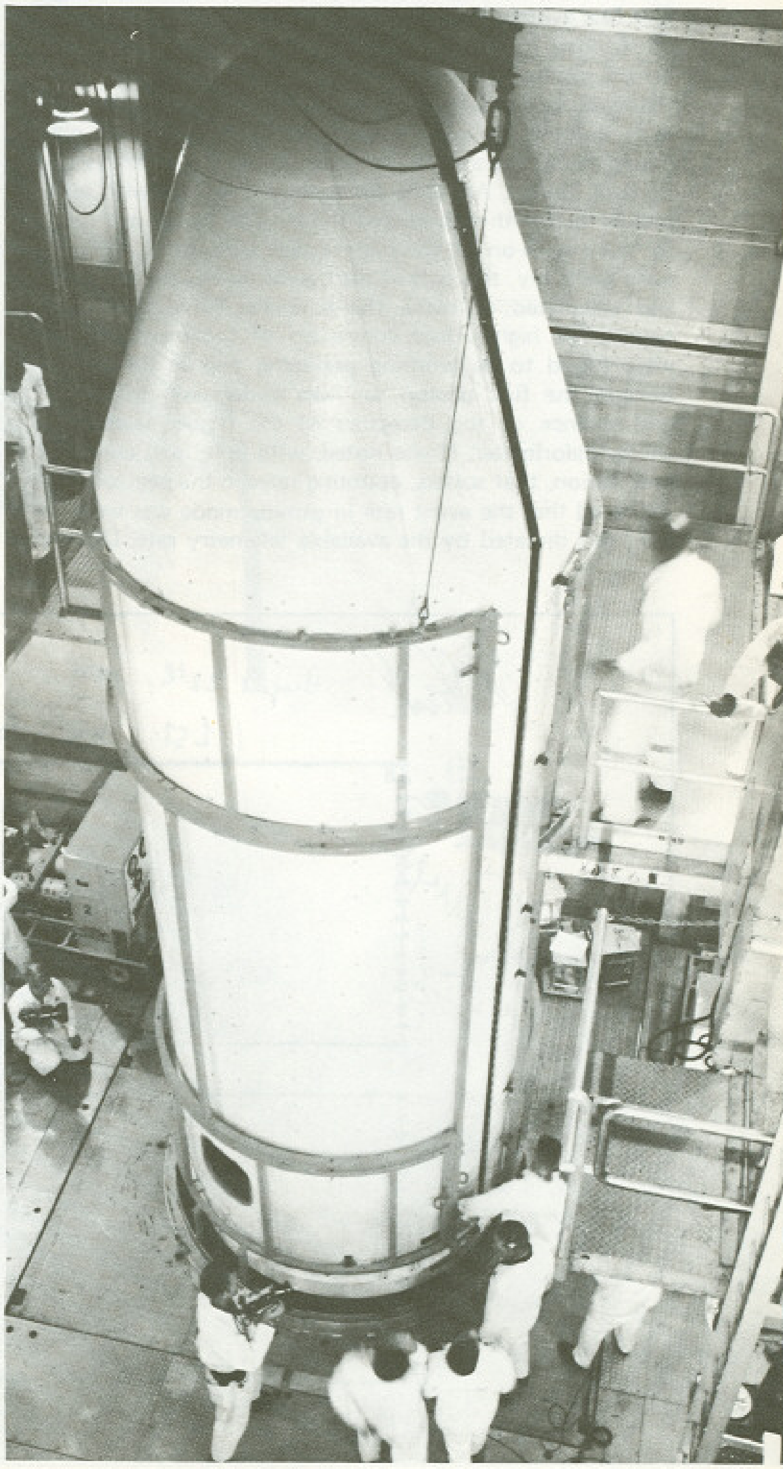
The vehicle flight path took it over the South Pole and on towards spacecraft injection over the island of Madagascar. The ARIA, now on station, confirmed vehicle telemetry requisition and at 19.36 pdt the NASA tracking station at Johannesburg acquired the spacecraft telemetry data. The data was immediately relayed to ESOC where the displays in the Operations Control Room showed the spacecraft to be connected to the third stage as expected. Although the satellite pass was just a few degrees above the horizon of the Johannesburg, station it was possible to retain contact with the spacecraft up to satellite injection. Some 15 s before Johannesburg



Fairing installation

lost contact, data displayed in the Operations Control Room at ESOC confirmed spacecraft injection. The time of injection was 19.41 pdt.

During the first pass at 1940 pdt on 8 August, monitored by the ESA checkout stations at Western Test Range, the spacecraft assessors witnessed a perfect despin manoeuvre, terminating in a nominal spin rate of 9.25 rpm (initial launcher spin rate 47 rpm). The solar attitude aspect angle was 77° and nutation less than 1°, all parameters and data observed at this time being nominal within limits. A second pass monitored by the range station at 1300 pdt on 9 August confirmed normal and satisfactory performance of COS-B on its first day of orbital operation. □



Fairing installed on Delta 2913

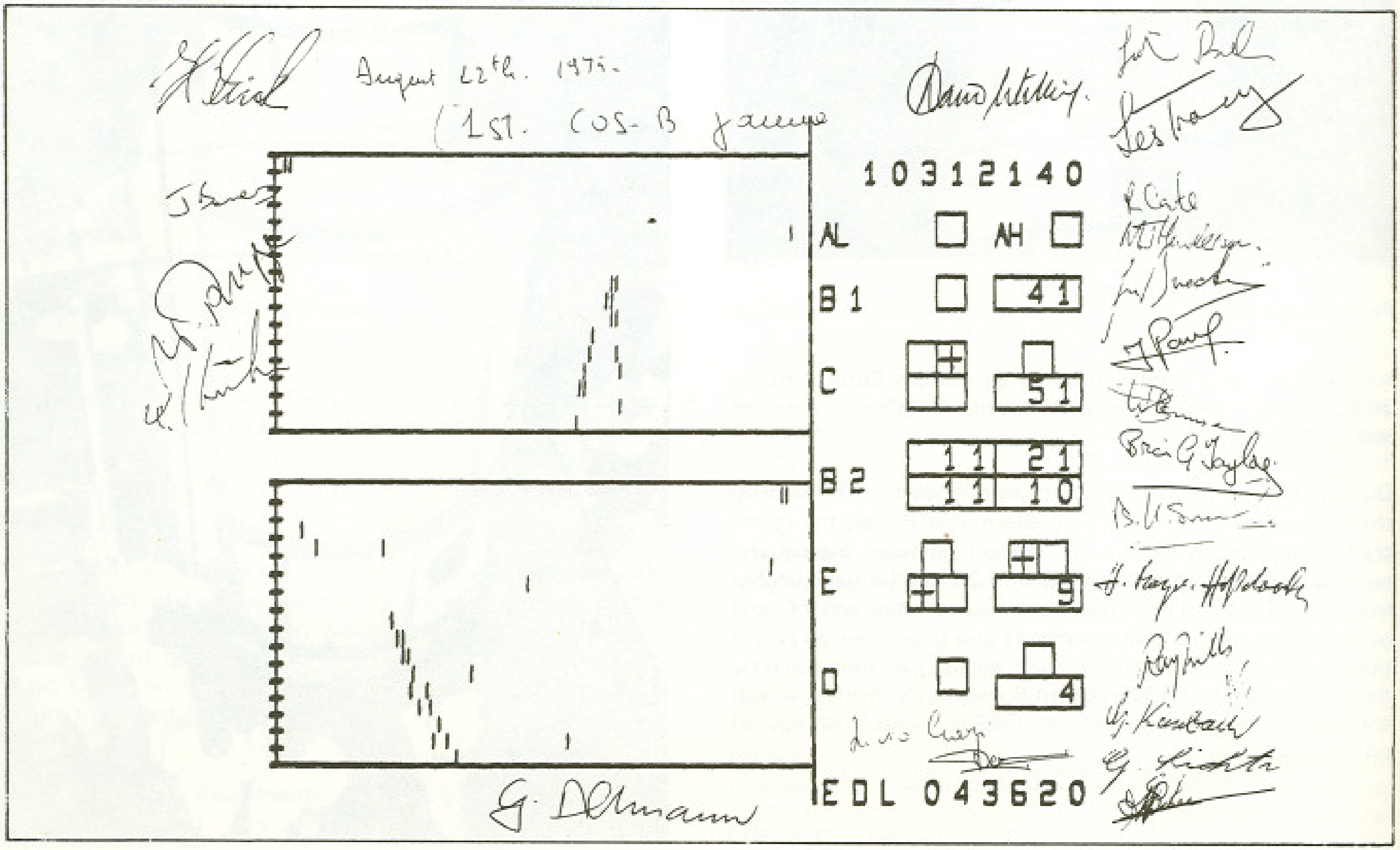
Experiment Switch-on and Evaluation

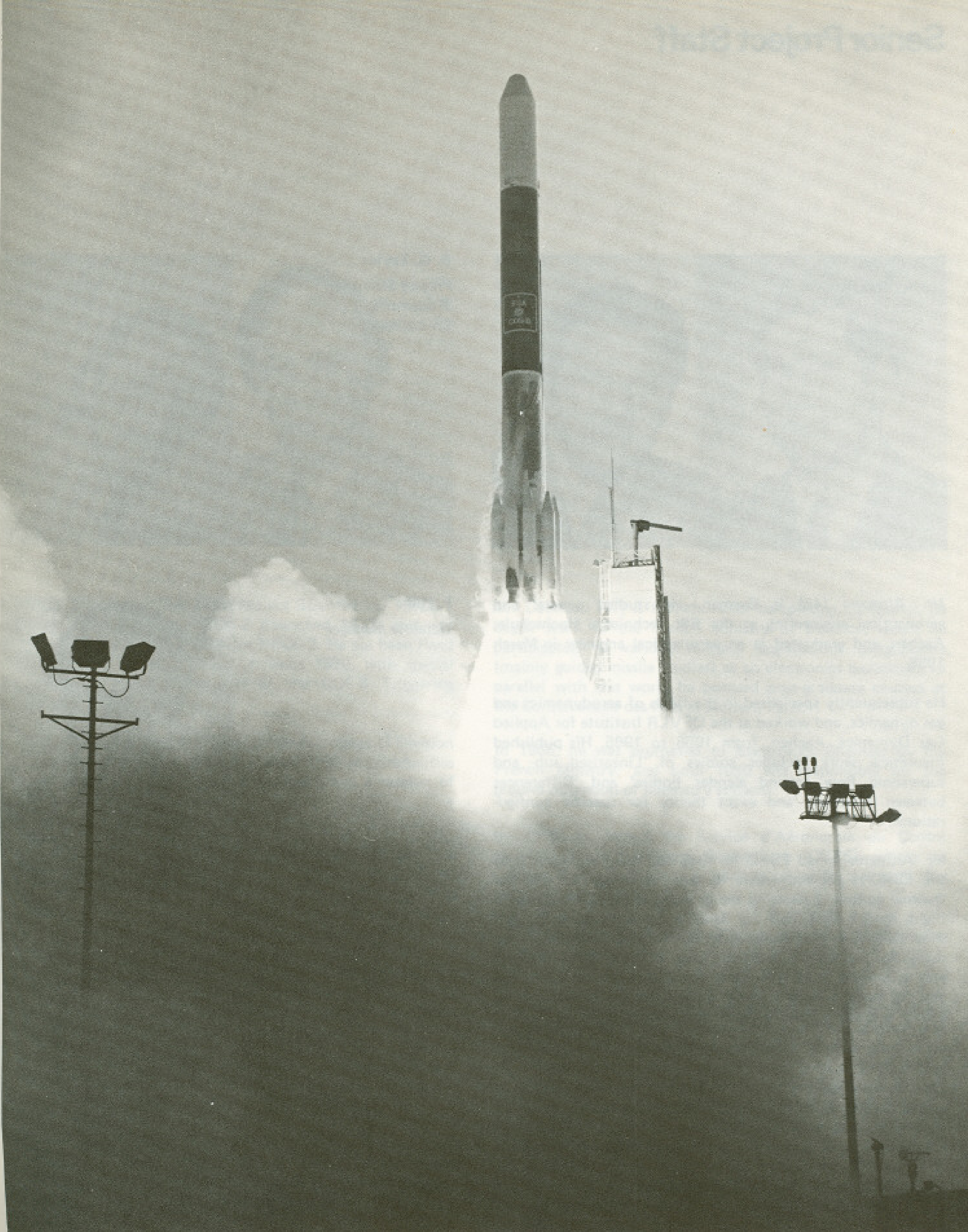
B.G. Taylor

The first switch-on of the experiments was started on schedule on Monday 11 August, when the satellite was close to apogee on its second orbit, some 57 h after lift-off. The strategy followed was to apply power to the low-voltage sections of each unit of the main experiment in turn and to observe housekeeping parameters on the quick-look displays in the Control Centre. All units functioned correctly with all parameters well within predicted limits. This phase was followed by the switch-on of the high-voltage sections of each unit in turn. Certainly, this part of the operation was the most critical and calculated to make the adrenalin flow! However, all twenty-five high-voltage converters of the main experiment were found to be working perfectly, and at 63 h into the mission the first proton run was undertaken to check the performance of the detectors of the trigger telescope and energy calorimeter. It was noted, with relief and considerable satisfaction, that scalers, counting rates in the payload, clearly indicated that the event rate in gamma mode was well within the limit dictated by the available telemetry rate. Operations on the payload in this orbit were completed by the running of the 'in-flight tests', in which the experiment units were tested by built-in stimuli units. The experiments were switched off at T + 67 h, prior to entering the radiation belts and loss of signal from the ground station.

The second switch-on was performed on Tuesday 12 August after the satellite had cleared the radiation belts at the start of its next orbit. A proton run was made, this time with the objective of checking the performance of the spark chamber. Correct performance was soon established with the observation of straight tracks on the quick-look displays. The pulsar synchroniser was then switched on and found to be working satisfactorily.

The experiment was then switched to gamma mode and the first gamma event with a clear signature in the spark chamber awaited with bated breath. The first gamma ray detected by COS-B is shown in the accompanying diagram, signed by all those present in the control room when the event came up on the quick-look display screen. □





Senior Project Staff

G. Altmann
Project Manager

Mr. Altmann (45) is German. He studied general and aeronautical engineering at the RW Technische Hochschule, Aachen, and graduated as an aeronautical engineer in March 1958.

He subsequently specialised in the fields of aerodynamics and gas dynamics, and worked at the DFVLR Institute for Applied Gas Dynamics, Aachen, from 1958 to 1965. His published theoretical work includes studies of 'Linearised sub- and supersonic flow around slender bodies' and 'Differences between linearised and exact theory for specific configurations'.

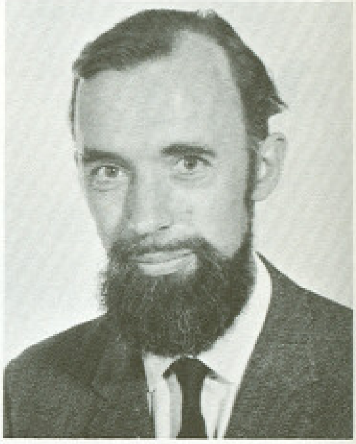
Mr. Altmann joined ESRO in 1965 and was assigned first to the ESRO-II project, where he was responsible for satellite thermal control. Following the decision to prepare the second flight model ESRO-IIB for launch, he was appointed test supervisor for the acceptance test programme. After the successful launch of ESRO-IIB from WTR in May 1968, he was appointed Study Manager for a future scientific mission, and following selection of the COS-B and GEOS missions by ESRO, was appointed COS-B Project Manager. □

Dr. Taylor (34) is British. He obtained his initial degree in physics (BSc Hons.) at Southampton University in 1962, before proceeding with his PhD thesis on 'Instrumentation and measurement for gamma-ray astronomy'. Whilst at Southampton, he was co-worker for a spark-chamber experiment, launched aboard NASA's OGO-5 satellite in 1968.

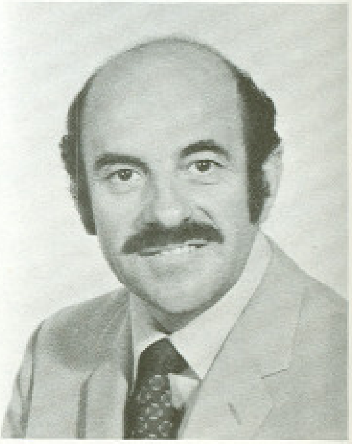
Since joining ESLAB, now Space Science Department, ESTEC,

B. G. Taylor
Project Scientist
& Scientific
Co-ordinator

P. Hill
Satellite Manager



P. Coufleau
Payload Manager

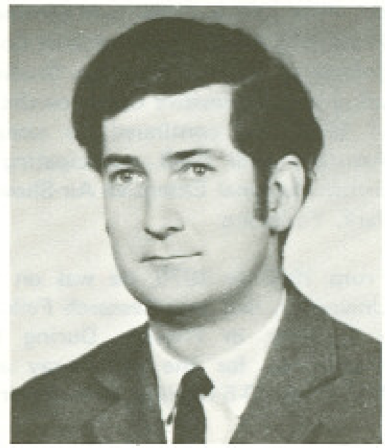


R. D. Wills

Deputy Project Scientist

H. Bath

Mission-Support Manager



in 1967, Dr. Taylor has been Project Scientist for HEOS-1 (launched in 1968) and HEOS-2 (launched 1972) and was co-worker on experiment S204 for HEOS-2. He has been Head of the COS-B Experiment Group since 1970, with special responsibility for the provision of the COS-B Triggering Telescope.

He is presently Head of the High-Energy Astrophysics Division of Space Science Department, where his responsibilities include the COS-B and EXOSAT payloads, and a number of laboratory research programmes. □

Mr. Hill (41) is British. After a period of service with the Royal Air Force, during which he taught the principles of radar equipment, he joined the aerospace industry (GEC) in Coventry, England, where he was concerned with a number of development projects involving highly reliable electronic and electromechanical equipment.

In the early 1960's, he began working on preliminary spacecraft equipment studies, which led later to his participation in the UK-3 satellite programme (launch May 1967).

His later work was concerned with on-board and test equipment for the Black Arrow X-3 satellite, and other studies for the X-4 and UK-5 spacecraft.

Mr. Hill joined ESRO in 1969, and since then he has been involved continuously with COS-B, as Satellite Manager, from the initial preparation of requirement specifications, through to launch and post- launch performance assessment. □

Mr. Coufleau (47) is French. After completing his studies, he began work in the French Ministry of Defence, where he participated in various military applications programmes (mainly guided-missile studies) as an electronics technician. In parallel with this work, he pursued post-graduate courses at the Conservatoire des Arts et Métiers, Paris.

In 1955, he was promoted to Electronics Engineer by the French Ministry, and until 1960 was responsible for the ground operation of telemetry stations.

In 1960, he joined the Service d'Aéronomie du Centre National de la Recherche Scientifique (CNRS), where he worked for two years on various scientific payloads for balloons and rockets.

In 1962, he participated in the Geophysical Year studies in the Kerguelen Islands.

For the next two years he was assigned to Goddard Space Flight Center as Project Manager for a scientific experiment to be flown on the OGO-3 and 4 spacecraft, returning to France in 1964 to head the Satellite Section of Service d'Aéronomie du CNRS. Here, he designed and developed various visible and ultraviolet photometers, which were later flown successfully on the American OGO-5 and 6 and OSO-5 satellites and on the French D-2A satellite.

In 1970, he was awarded the Centre National d'Etudes Spatiales (CNES) gold medal, and in the same year joined ESRO as Payload Manager for the COS-B satellite. □

Dr. Wills (39) is British and obtained his physics degree (BSc Hons. and ARCS) from Imperial College, London, in 1958. He completed his PhD thesis on 'Studies of extensive air showers using energy-sensitive Cerenkov detectors' at Imperial College in 1961, and continued his research there as a Research Assistant until 1963, participating in the setting up of the British National Extensive Air-Shower Experiment at Haverah Park, Yorkshire.

From 1963 to 1970, he was on the staff of Southampton University, first as a Research Fellow (until 1965) and later as a Lecturer in Physics. During this period, he was co-investigator for the gamma-ray astronomy experiment on NASA's OGO-5 satellite, launched in 1968.

During the mission-definition study for COS-B in 1969, he acted as a consultant to ESRO. In 1969/70 he represented Southampton University, as their Experiment Officer, in the 'Caravane Collaboration'.

After joining Space Science Department, ESTEC, in 1970, he continued his role as Experiment Officer for the Triggering Telescope subsystem of the COS-B experiment, serving also as Data Reduction Officer. He is presently Data Reduction Co-ordinator for the COS-B payload, Co-ordinator for the Fast-Routine Facility, and Deputy Project Scientist.

Dr. Wills' responsibilities within Space Science Department also include participation in the laboratory research programme of the High-Energy Astrophysics Division and in occasional Mission Definition Groups for future ESA scientific programmes.

After the launch of COS-B, he will take over as Project Scientist from Dr. Taylor. □

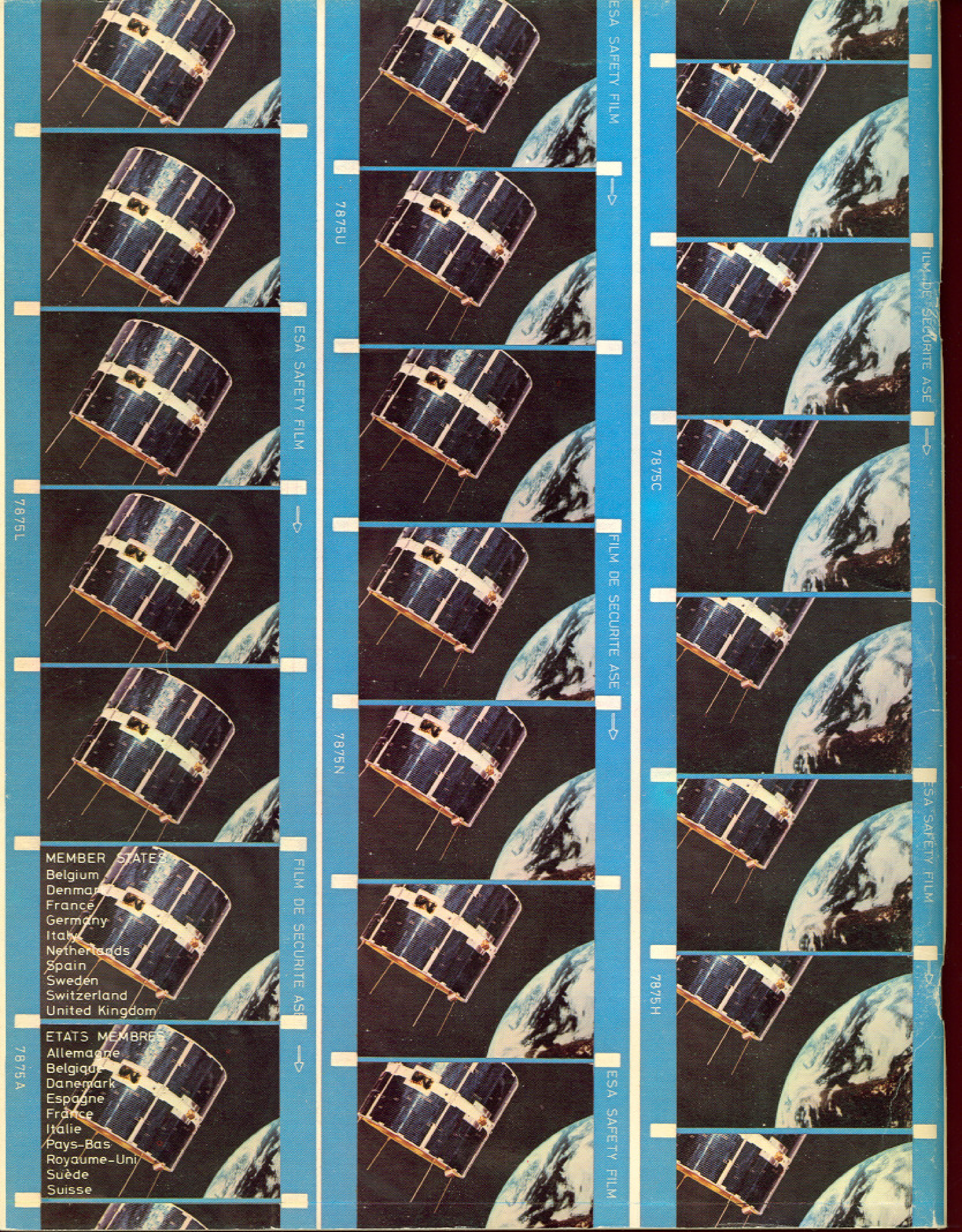
Mr. Bath (40) is British and studied Electrical Engineering at Wandsworth College of Advanced Technology from 1956 to 1961.

Prior to joining ESRO in January 1968, he was employed for six years in the Central Research Laboratory of Edwards High Vacuum Ltd., where he worked on automation and control processing of passive thin-film devices.

Before taking up duties in the ESOC Mission Management Group, he was responsible for the satellite systems operations of HEOS-1 until 1970. Since 1970, he has been co-ordinating the ESOC support for five different missions, covering the scientific and applications programmes. In 1974 he became responsible for the co-ordination of the COS-B mission-support activities at ESOC. □

ESA COS-B TEAM

Project Staff, Scientists and Contractors present at Western Test Range California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