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EUROPEAN SPACE AGENCY
AGENCE SPATIALE EUROPEENNE

8–10, rue Mario Nikis
75738 Paris Cedex 15, France

The European Space Agency was formed out of, and took over the rights and obligations of, the two earlier European Space Organisations: the European Space Research Organisation (ESRO) and the European Organisation for the Development and Construction of Space Vehicle Launchers (ELDO). The Member States are Belgium, Denmark, France, Germany, Italy, Netherlands, Spain, Sweden, Switzerland and the United Kingdom. Ireland has signed the ESA Convention and will become a Member State upon its ratification. Austria, Canada and Norway have been granted Observer status.

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 for operational space applications systems,

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

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

The 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.

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.

Chairman of the Council for 1976: Dr. W. Finke (Germany).

Director General: Mr. R. Gibson.

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

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

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

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

Le Directoire de l'Agence est composé du Directeur général, du Directeur des Programmes futurs et des Plans, du Directeur de l'Administration, du Directeur des Programmes de satellites scientifiques et météorologique, du Directeur des Programmes de satellites de communications, du Directeur du Programme Spacelab, de l'Inspecteur technique, du Directeur de l'ESTEC et du Directeur de l'ESOC.

Le SIEGE de l'ASE est à Paris.

Les principaux Etablissements de l'ASE sont:

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

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

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

Président du Conseil pour 1976: Dr. W. Finke (Allemagne).

Directeur général: M. R. Gibson.

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Introduction

J. Berghuis, Directeur de l'ESTEC

L'ESTEC (Centre européen de Recherche et de Technologie spatiale) a été créé en 1962 en tant qu'Etablissement technique du CERS (Organisation européenne de Recherches spatiales). D'abord implanté à Delft, dans des bâtiments en location, le Centre a été transféré en 1967 à Noordwijk, autre localité des Pays- Bas. Situé sur un terrain d'emprise de 38 ha, c'est le plus grand des Etablissements de l'Agence spatiale européenne, avec un effectif d'environ 1250 personnes dont 850 agents en titre, totalisant à lui seul près de 60% de l'ensemble des effectifs de l'ESA. Le personnel est recruté de préférence dans les 11 Etats membres de l'Agence, mais les scientifiques, ingénieurs, techniciens et agents administratifs qui le composent représentent en fait près de 20 nationalités différentes.

ORGANISATION DE L'ESTEC

La direction de l'ESTEC coiffait à l'origine toutes les activités liées à la réalisation et au lancement des fusées-sondes et satellites de l'Organisation, ainsi que les travaux de recherche appliquée. Lorsque l'ESA a succédé au CERS, en 1975, la responsabilité des différents programmes spatiaux de l'Agence a été confiée à des Directions de programmes, rattachées au Siège Central de Paris, la Direction de l'ESTEC restant chargée du soutien technologique spécialisé aux Directions de programmes, de l'exécution du Programme de recherche technologique de l'Agence, et de l'administration locale de l'Etablissement. Presque tous les bureaux de projet relevant des Directions de programmes restent néanmoins implantés à l'ESTEC et leur personnel est soumis à l'autorité du Directeur de l'Etablissement pour les questions intéressant la discipline.

Les missions aujourd'hui dévolues au Directeur de l'ESTEC sont donc de deux ordres. En premier lieu, c'est à lui qu'incombe l'entière responsabilité de la bonne marche des services de l'ESTEC figurant dans l'organigramme de la Figure 1. En second lieu, il est responsable du soutien logistique et de l'administration à l'échelon local des différents groupes suivants qui, bien qu'implantés à l'ESTEC, relèvent de Directions extérieures à l'Etablissement:

- *les équipes de projets* affectées au programme Spacelab, au programme de satellites de télécommunications (OTS/ECS, Marots et Aérosat) et au programme de satellites scientifiques (Geos, ISEE-B, IUE, Exosat et Télescope spatial);
- *le Département Science Spatiale*, rattaché à la Direction des programmes de satellites scientifiques et météorologiques;
- *une partie du Département des Finances, du Département des Contrats et du Département du Personnel*, relevant de la Direction de l'Administration installée au Siège de l'Agence;
- *une partie du Département Calcul* de l'Agence, placée sous l'autorité du Directeur de l'ESOC à Darmstadt (Allemagne);
- *le Service des Publications scientifiques et techniques de l'ESA* placé sour l'autorité du Chef du Service de Documentation spatiale de l'ESA à Frascati (Italie).

Ce regroupement au sein d'un même Etablissement de diverses fonctions rattachées à des Directions différentes illustre l'organisation matricielle qui régit, à l'intérieur de l'ESTEC, les relations entre les Directions responsables de la bonne exécution des programmes et les Directions chargées de fournir aux équipes de projet l'assistance technique et administrative dont elles ont besoin (Fig. 2).

ACTIVITES FONCTIONNELLES DE LA DIRECTION DE L'ESTEC

Les missions essentielles de la Direction de l'ESTEC sont les suivantes:

- *Maintien et promotion de la technologie spatiale* dans tous les secteurs nécessaires à l'exécution des programmes de l'ESA, dans les conditions requises de performance technique, de sécurité, de fonctionnement et d'économie. Cette responsabilité s'exerce dans les domaines ci-après:
  - soutien aux projets dans toutes leurs phases de préparation, d'exécution puis d'analyse et d'évaluation des résultats technologiques après lancement;
  - poursuite d'activités de recherche technologique avancée dans le cadre d'un programme d'ensemble préalablement défini;
  - assistance à la Direction concernée dans la sélection, la définition et le contrôle des études de programmes futurs.
- *Gestion des services du Centre* garantissant le fonctionnement adéquat et économique de tous les services locaux, administratifs et techniques, au profit de l'ensemble des personnels présents sur le Centre.

Pour exercer ses responsabilités, le Directeur de l'ESTEC s'appuie, comme cela a été indiqué plus haut, sur:

LE DEPARTEMENT DEVELOPPEMENT ET TECHNOLOGIE

Le Département est chargé de mener à bien les actions relevant de la recherche technologique (technologie générale et technologie rattachée aux projets) et du soutien aux Directions de programmes, soutien commun à l'ensemble des programmes et soutien spécialisé aux différentes Directions (par la mise à disposition des ingénieurs compétents); il a également pour tâche de favoriser et de développer l'harmonisation et la standardisation des techniques de projets. Les présentations de MM. Hawkes (Chef du Département), Toussaint et Slachmuylders (Chefs de Groupe) décrivent les principales fonctions assumées par le Département. Les articles qui suivent, consacrés à des aspects technologiques spécifiques, n'ont pas pour ambition de donner une vue exhaustive de nos activités mais permettent d'avoir une notion plus précise des tâches que nous sommes chargés de mener à bien.

LE DÉPARTEMENT DE L'ADMINISTRATION

Le Département exerce son autorité sur l'ensemble des aspects touchant au rôle de Centre d'activités de l'ESA: il s'agit des aspects tant externes (représentation officielle du Centre au titre de l'Accord régissant son établissement

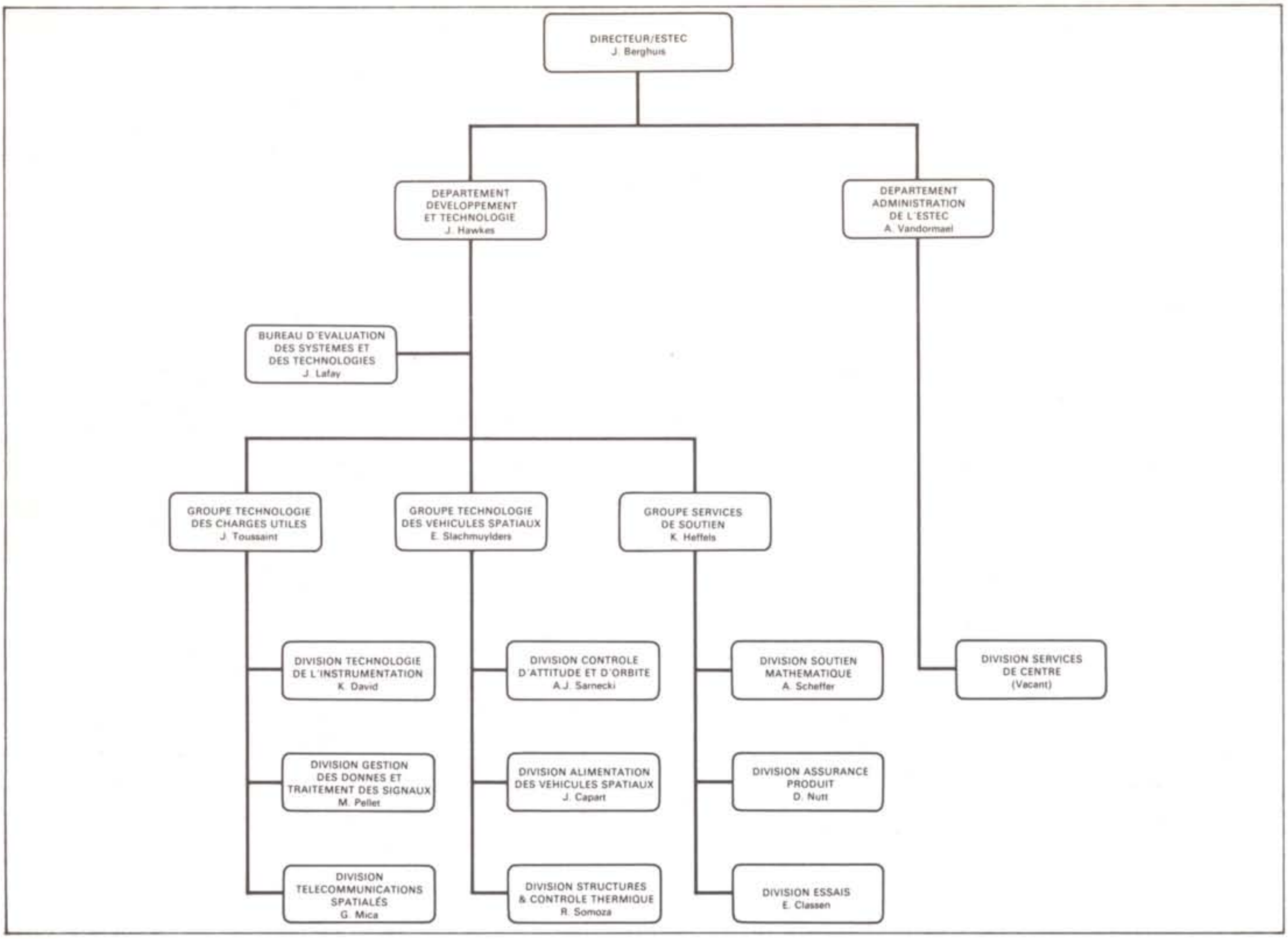


Figure 1 – Organigramme de l'ESTEC

aux Pays-Bas et autres relations extérieures) qu'internes (maintien de l'intégrité du Centre, services logistiques courants et services spécialisés, hygiène et sécurité). La contribution apportée par M. Vandormael, Chef de l'Administration locale, décrit ainsi les multiples facettes des services qu'il est nécessaire de fournir et de coordonner pour permettre à tout le personnel présent sur le Centre de travailler avec un maximum d'efficacité.

MOYENS D'ESSAIS DU CENTRE

Un satellite comporte des dizaines de milliers d'éléments, mécaniques mais surtout électroniques. Une fois l'engin en orbite, il n'est plus question de remédier à une imperfection éventuelle; or la défaillance d'un seul composant, relativement peu coûteux par lui-même, risque de compromettre l'ensemble de la mission, avec les conséquences financières que l'on imagine. D'où la nécessité pour les ingénieurs de l'ESTEC de faire en sorte qu'une telle défaillance ait aussi peu de chances que possible de se produire. A cette fin, les composants subissent toute une série d'essais destinés à vérifier leur qualité et leur bon fonctionnement. Chaque satellite, ainsi que tous les éléments qui le composent, doit pouvoir encaisser les niveaux considérables de vibration, d'accélération et de bruit engendrés par la fusée porteuse au cours du lancement. Une fois en orbite, il doit fonctionner dans le vide, en l'absence de pesanteur; sa partie éclairée par le Soleil va s'échauffer fortement, tandis que sa partie non éclairée deviendra très froide. En période d'éclipse, c'est-à-dire chaque fois que l'engin se trouvera dans l'ombre de la Terre, sa température extérieure descendra à des valeurs extrêmement basses.

L'ESTEC dispose de vastes installations d'essais pouvues de tout l'équipement nécessaire pour simuler les dures épreuves qui attendent un satellite dans les premières minutes du lancement et pour s'assurer que celui-ci est capable de fonctionner correctement dans l'espace extra-atmosphérique, où les conditions sont très différentes de celles régnant sur la Terre.

Le professeur J. Berghuis (52 ans) est néerlandais. Il est diplômé de l'Université d'Amsterdam, où il a obtenu son doctorat en mathématiques, physique, astronomie; il a également passé le doctorat en sciences techniques de l'Université Technique de Delft et effectué des études de biologie. Le professeur Berghuis a été conseiller scientifique de la société Bull – Nederland, et ingénieur-conseil de la Compagnie des Machines Bull, à Paris, de 1957 à 1964. A partir de 1964 il a travaillé pour la société Philips, aux Pays-Bas, où il fut, en 1968, responsable du groupe industriel des systèmes de traitement d'information; il était également, à partir de 1972, responsable de la programmation pour le compte de la société Unidata, une coopération de CII, Siemens et Philips. Parallèlement, il était professeur extraordinaire à l'Université Technique de Delft. Le professeur Berghuis a été nommé Directeur de l'ESTEC en octobre 1975.

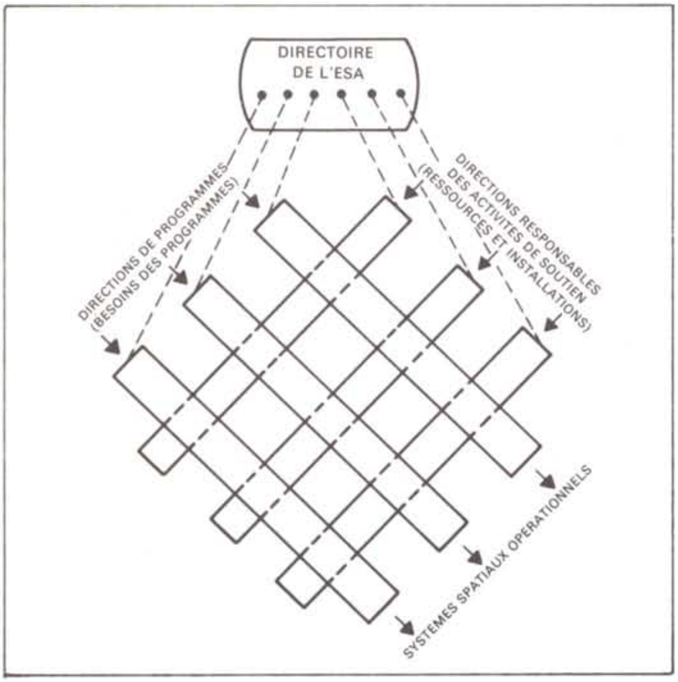


Figure 2 – Schéma d'organisation matricielle

C'est ainsi qu'à côté des tables vibrantes et des enceintes à vide thermique utilisées en liaison avec un ordinateur, l'ESTEC dispose de la plus grande chambre à vide d'Europe (10 m de diamètre, 15 m de hauteur), inaugurée en juin 1976. Dans une autre salle sont logées les machines pour la mesure des caractéristiques statiques telles que poids, moment d'inertie et centre de gravité. On trouve en outre des systèmes d'équilibrage, des centrifugeuses, une chambre d'essais acoustiques, des appareillages pour la détermination du diagramme de rayonnement des antennes et des installations d'essais magnétiques. Enfin, le Centre comprend de nombreux laboratoires spécialement équipés permettant l'expérimentation d'une large gamme de composants destinés aux usages spatiaux.

Les moyens d'essais du Centre sont donc particulièrement importants, parfois uniques en Europe, et représentent un investissement considérable. Les articles spécialisés qui suivent donnent une description détaillée de certain de ces moyens.

L'ESTEC, dans le cadre de la gestion de ces installations techniques, participe par ailleurs à la coordination des équipements de tests européens, afin d'assurer une réelle politique d'utilisation et de standardisation des moyens d'essais à l'échelle européenne.

En conclusion, l'ESTEC représente incontestablement une composante essentielle de l'Agence, qui rassemble en son sein, aux côtés du personnel rattaché à la Direction de l'Etablissement, diverses équipes appartenant à cinq des six autres Directions de l'ESA. En évoquant brièvement les différents groupes concernés et les liens qui les unissent, j'ai voulu mieux mettre en lumière l'objet du présent Bulletin, qui est de présenter un aperçu des compétences et des moyens que la Direction de l'ESTEC met au service du programme de l'Agence en matière de technologie spatiale, aussi bien pour les projets en cours que pour les systèmes spatiaux à venir. J'espère que les pages qui suivent contribueront à satisfaire la curiosité du lecteur.

□

ESTEC's Department of Development and Technology

J.C. Hawkes, Head of Department of Development & Technology, ESTEC

ESTEC's Department of Development and Technology represents the main source and reservoir of specialist technological support to the Agency's on-going development programme. As such, it has four main functions.

First, it provides specialist expertise to the various project management teams. When the degree of support required by a team is such as to occupy DDT staff full time, then they are detached from their parent Divisions and integrated into the project teams – returning to their parent Divisions after fulfilment of their roles; this is known as 'integrated support.' In other cases, the support to a project is provided somewhat in the manner of a consultancy by the DDT staff members from within their parent Divisions; this is known as 'functional support.'

The second and an equally important role of the Department is to organise and manage the Agency's portion of a co-ordinated European programme of technological research to ensure that Europe will be provided with the advanced technology appropriate to space projects of the future. Under the guidance of the Agency's Industrial Policy Group and Industrial Policy Department, by judicious placing of research contracts, the ESA research programme is also used as a vehicle to promote the rationalisation and competitiveness of Europe's space industries.

The Department's third function is to provide technical support to the development programmes in the shape of technical facilities for environmental testing, satellite checkout and so forth. The Department itself operates facilities representing an investment of over 30 MAU (roughly 40 million dollars), but also makes use of the national facilities existing in several Member States.

Fourthly, the Department provides a central product-assurance service to projects and takes the lead in the generation of PA procedures and specifications for European application. In space activities, product assurance of course assumes great importance because of the general impossibility of repair or maintenance of satellites in orbit.

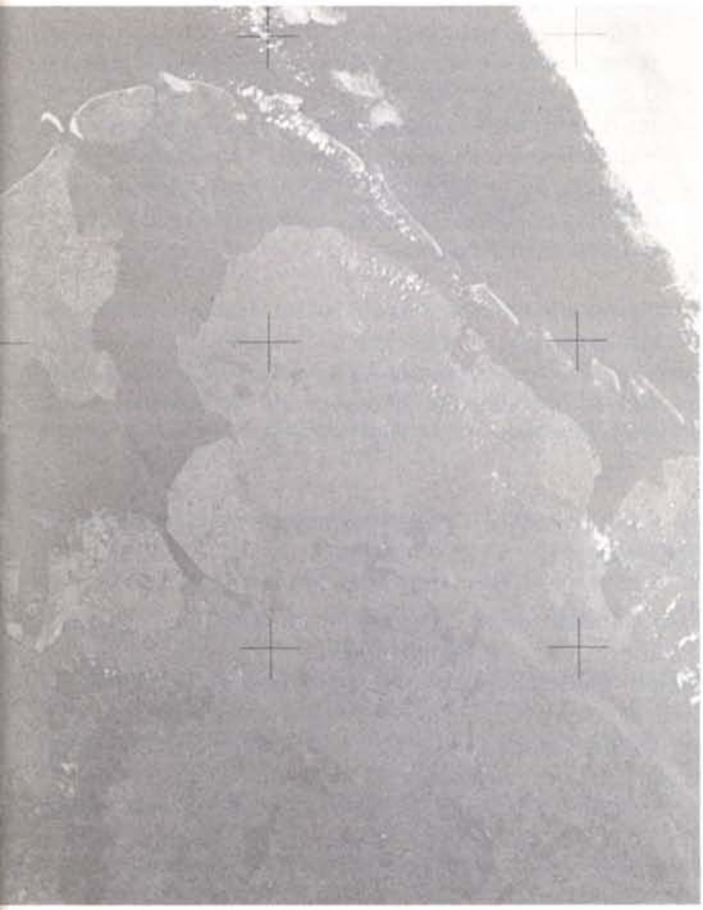
Within these functions, DDT staff at varying levels play their part in project development, qualification, and flight-readiness reviews, thus promoting both interproject co-ordination and interproject transmission of experience. In addition, the Department is constantly striving to promote closer co-operation between the Agency's Member States at the technological level and to provide greater support in the early feasibility and definition stages of a project, with less involvement in subsequent phases.

To carry out this work, the Department has a complement of 514 staff - the largest Department in the Executive. At the time of writing 488 are in post - 68 working as integrated support, 220 as functional support, 45 on technological research and 123 on the operation and maintenance of support.

An example of earth observation from space.

The Department is structured into nine Divisions, on the basis of technical specialisations, together with a small Office of Systems and Technological Assessment (OSTA). As shown in the organigramme in the previous article, the nine Divisions are collected into three main Groups - 'Spacecraft Technology', 'Payload Technology' and 'Support Services'. Each Division provides specialist support and also manages its own research programme. Divisional staff may be assigned solely to research or to support work, or they may divide their time between the two. The OSTA is charged with interfacing with all study work to identify gaps in technology; it also carries out a number of studies, primarily in the area of scientific missions.

Mr. J.C. Hawkes (55), OBE, graduated in Engineering at Birmingham University (UK). After the war, he joined the United Kingdom Scientific Civil Service in 1947. After diverse Headquarters and Establishment duties, in 1970 he was appointed Head of Research and Development in the British Government Communications Bureau, for which he had worked since 1957. Mr. Hawkes joined ESA on 1 April 1975, as Head of the Department of Development and Technology at ESTEC.



A Department with responsibilities such as these must constantly look to the future. With the coming of Spacelab, interest in material sciences in space is growing rapidly, and this is bringing with it new technological problems, the need for ovens able to operate at temperatures of 2000°C being a good example. The forthcoming earth-observation programme, with its expected high data outputs, requires studies in the areas of signal-processing and application of optical processing methods. A small nucleus of a new Division has already been formed to make a start in this sphere. As far as spacecraft structures are concerned, the development of larger satellites of advanced design will require a better understanding of the behaviour of such mechanical systems under space conditions. This is particularly true as regards testing, because the expense of building still larger test facilities becomes prohibitive if a reasonable return on capital investment is to be maintained. The problems encountered in achieving a satisfactory degree of product assurance and the use of standardisation must be continuously reviewed in pursuit of greater cost-effectiveness if European industry is to manufacture reliable satellites at competitive cost.

The expected increased complexity, sophistication and range of ESA's future activities, in combination with the continuing need for economic restraint, will demand the highest of skills and dedication of effort on the part of the staff of the Department of Development and Technology in the coming years. □

Le Soutien Spécialisé aux projets – Ses activités, ses méthodes, et son infrastructure

J. Toussaint, Groupe Technologie des Charges Utiles, ESTEC

En 1963, l'Organisation européenne de Recherches spatiales était fondée sur la base de deux grands départements techniques: le Département de Projets et le Département de Recherches appliquées. La théorie de l'époque voulait que l'Organisation commençât par faire ses preuves avec ses premiers projets, en mettant sur orbite deux ou trois satellites par an, et que ces succès devenant affaire de routine, sa renommée s'affirmerait par ses travaux de recherches dans les domaines les plus avancés de la technique.

Pendant quelques années, les deux départements ont coexisté, l'un faisant ses premières armes sur les projets ESRO-I, ESRO-II et TD, l'autre se consacrant à la formation de ses spécialistes. Toutefois, bien qu'elle ne fût nullement inscrite dans une charte quelconque, la collaboration entre ces deux départements s'imposait par la force des circonstances: les projets ne voulaient pas entrer dans leur phase de routine, le recours à des ingénieurs spécialisés s'imposait de plus en plus impérativement, et ces spécialistes eux-mêmes cherchaient dans la perspective des projets futurs leurs thèmes principaux de recherche. Finalement, toutes les divisions du Département de Recherches appliquées, rebaptisé 'Développement et Technologie' (DDT), furent invitées à collaborer activement à la gestion des projets en cours: pour sa part, l'Organisation venait de réinventer la notion de Soutien Spécialisé aux projets.

L'ORGANISATION MATRICIELLE DE L'ESTEC

Actuellement, l'Agence Spatiale Européenne a consacré la structure matricielle typique basée sur la dualité équipes projet – divisions spécialisées et reconnue comme la plus avantageuse pour gérer les activités discontinues que sont les projets de satellite.

Cette structure est illustrée sur le diagramme ci-joint. On y voit représentés d'une part les projets actuels de l'Agence et, d'autre part, les divisions spécialisées du DDT, organisées par 'sous-systèmes de satellite' ou définies à partir d'un 'service' fondamental tel que l'assurance produit, le soutien mathématique ou les essais d'ambiance. Chaque point d'intersection de ce diagramme correspond à un effort particulier, quantifié en termes de personnel nécessaire à cet effort, dans le cadre d'une division particulière collaborant à la gestion d'un projet.

On devine immédiatement l'intérêt d'une telle structure pour les activités de l'Agence; il découle essentiellement des deux considérations suivantes:

- au démarrage d'un projet, le DDT peut mobiliser des ingénieurs immédiatement utiles, car ils sont supposés avoir hérité de l'expérience des projets antérieurs, être conscients des méthodes et des traditions de l'Agence et connaître les infrastructures de base, telles que le réseau de télémesure ESA et les moyens d'essais disponibles;
- les divisions spécialisées jouent le rôle d'un réservoir d'ingénieurs spécialisés capable d'intégrer les fluctuations de la charge de travail correspondant aux différents projets, dans les conditions les plus économiques pour l'Agence.

En fait, pour les mêmes raisons, cette structure matricielle s'est imposée pour toutes les activités spatiales, aussi bien dans les Agences telles que la NASA ou l'ESA, que dans les firmes industrielles chargées de la réalisation du matériel.

LE ROLE DE L'INGENIEUR DE SOUTIEN SPECIALISE

Très généralement, l'ingénieur de Soutien Spécialisé collabore avec une équipe de projet. Il partage, dans son secteur particulier de compétence, les responsabilités de cette équipe chargée de définir les tâches des groupes industriels concernés et de veiller aux intérêts de la mission et de l'Agence tout au long de l'exécution du programme. Les interventions de cet ingénieur sont multiples, et on peut essayer de les classifier en parlant de trois niveaux d'activités.

Au *démarrage d'un projet*, les activités sont au *niveau conceptuel*. L'ingénieur spécialisé doit analyser le degré

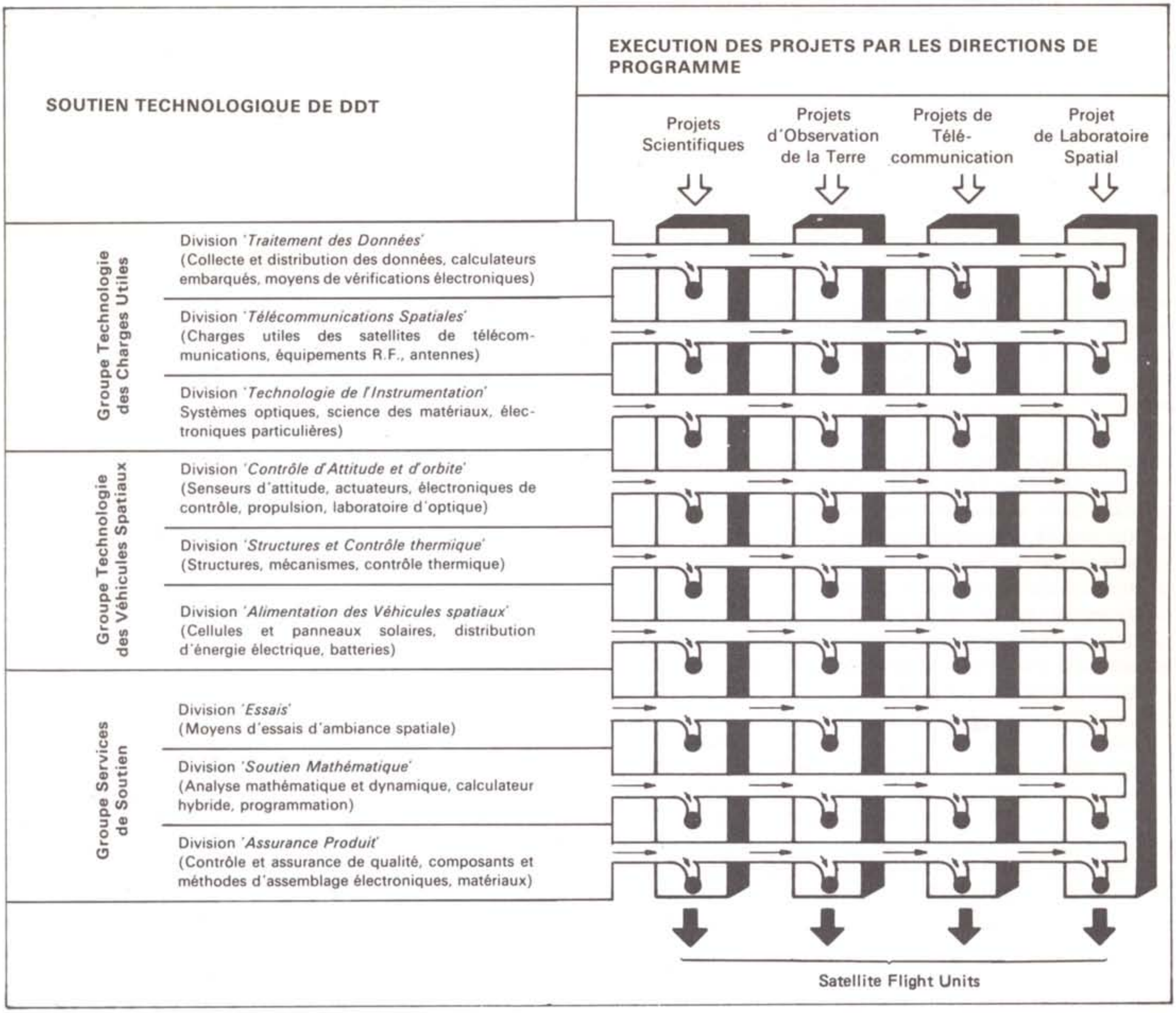


Figure 1 – Articulation des activités de soutien fonctionnel–Structure matricielle adoptée pour la définition et le suivi techniques des projets de l'ESA.

de performance exigé de son sous-système dans le contexte de la future mission, comparer ces exigences avec l'état d'avancement de la technique, et formuler une conclusion quant à la faisabilité de la mission. Cette activité, qui considère les aspects nouveaux de la mission, est essentielle, mais ne devrait pas éclipser un rôle plus obscur qui consiste à 'combler les vides'. En effet, tout n'est pas défini avec le même degré de précision au démarrage d'un projet. Au delà des performances essentielles du satellite, il reste à définir un certain nombre d'aspects du nouveau programme: débrouiller les points essentiels des spécifications, préciser les méthodes d'intégration, se soucier de la disponibilité des moyens d'essais, etc. C'est parfois dans ces tâches moins héroïques, que l'ingénieur de Soutien Spécialisé se rend le plus utile, car il a en principe l'avantage essentiel d'avoir déjà été confronté à ces problèmes à l'occasion d'un projet antérieur.

Au *cours du projet*, les activités tombent au *niveau de la routine;* il s'agit de surveiller l'état d'avancement d'un sous-système de satellite à travers l'appareil classique des revues de projets, de résoudre certains problèmes d'intégration ou d'interface entre sous-systèmes, de vérifier les résultats des essais, etc.

Mais le niveau le plus connu des activités de Soutien Spécialisé est celui qui, idéalement, ne devrait pas exister: c'est le *niveau d'urgence*. En effet, il est arrivé maintes fois qu'un problème imprévu, ou dont l'ampleur avait été nettement sous-estimée, nécessite une mobilisation immédiate de toutes les forces disponibles. Chaque division du DDT a à son actif certains hauts faits, où son intervention a été déterminante dans la poursuite d'un projet. On peut citer entre autres deux exemples significatifs:

- L'aventure des enregistreurs à bande magnétiques embarqués sur TD1. A un certain point du programme TD, cette machine paraissait ensorcelée, tant les pannes de différentes nature se succédaient les unes aux autres. Le Soutien Spécialisé s'est vu attribuer la responsabilité de cette partie du programme, tant pour ses compétences directes dans cette technique que pour éviter qu'elle n'absorbe exagérément les énergies du groupe projet, préoccupé de la conduite générale du programme. La suite de l'aventure a été peu glorieuse en ce qui concerne le programme TD, car elle a débouché sur une analyse des pannes survenues aux deux enregistreurs de bord. Par contre, la fin de l'aventure a été un succès complet: remanié sur la base de l'expérience chèrement acquise, l'enregistreur d'ESRO-IV ne s'est tu qu'après la désintégration finale du satellite, après avoir couvert l'intégralité de la mission.
- Dans un passé plus récent, les spécialistes de la section Batteries (Division de Conversion d'Energie) ont été appelés à procéder à la formation des batteries de deux satellites à partir de cellules Ag-Cd fournies par une firme américaine. A l'origine, cette tâche complexe et délicate devait être effectuée par l'industrie. La mise au point des nombreuses opérations requises se heurta cependant à de graves problèmes pratiques et il fut fait appel aux spécialistes de l'ESTEC à un stade avancé du projet. Cette opération d'urgence fut menée à bien grâce à l'expérience acquise depuis HEOS et l'équipement spécialisé du laboratoire d'essais de batteries.

L'INFRASTRUCTURE DU SOUTIEN SPECIALISE AUX PROJETS

Pour remplir son rôle efficacement, l'ingénieur spécialisé doit pouvoir compter sur le bagage technique accumulé par sa division. Cette dernière doit rester en contact avec la technologie avancée, ses difficultés et ses perspectives; elle doit se soucier de dégager l'enseignement du passé; elle doit enfin faire évoluer ses méthodes et mettre au point ses outils de travail essentiels. Certains exemples feront mieux comprendre ce que cela signifie pour certaines des divisions les plus engagées du DDT.

DIVISION GESTION DES DONNEES ET TRAITEMENT DES SIGNAUX

La grande préoccupation de cette division provient de ce que le sous-système de bord de 'traitement de l'information' non seulement a des ramifications dans tout le satellite, mais encore exige une compatibilité totale avec certaines grandes infrastructures de l'Agence: le réseau des stations au sol de télémesure et de télécommande, et l'instrumentation électronique nécessaire à l'intégration et aux essais des satellites. Le développement d'un tel sous-système, organisant à bord le trafic de centaines de canaux de télémesure et la distribution d'un nombre aussi élevé de messages de télécommande, serait une tâche impossible si les interfaces de ce sous-système n'étaient pas régis par des normes très précises. Ces normes sont d'une part les normes TTC (Tracking, Telemetry, Command) ESA/NASA, qui garantissent la compatibilité et assurent un niveau de performance dans les échanges d'informations avec les stations au sol, et d'autre part, les normes de traitement de l'information à bord des satellites, qui spécifient toutes les caractéristiques des signaux échangés à bord entre sous-systèmes. On conçoit que ces normes soient un outil de base de la division concernée, mais on ignore généralement tout ce que leur élaboration nécessite de recherches, d'études de points de détail, de travail d'optimalisation, de vérifications de faisabilité, de contacts avec les collègues de la NASA, etc. Et pourtant, un ingénieur de Soutien Spécialisé serait complètement démuni s'il devait s'attaquer à un projet de satellite sans disposer de ces normes, documentées et tenues à jour. (On trouvera par ailleurs, dans le présent Bulletin un compte rendu des activités conduites par cette division dans la gestion de l'instrumentation électronique nécessaire aux essais de satellites.)

DIVISION TELECOMMUNICATIONS SPATIALES

Cette division concentre l'expérience de l'ESA en matière d'équipements fonctionnant en fréquence radio: émetteurs, récepteurs, répondeurs, répéteurs de télécommunications, etc. Elle collabore avec la division mentionnée ci-dessus pour la rédaction des normes TTC, et assume en outre des responsabilités très concrètes en matière d'essais d'antennes. Elle gère les activités conduites sur le site d'essais d'antennes omnidirectionnelles de l'ESTEC, et a entrepris la planification des installations futures requises par les essais des antennes à gain élevé en hyperfréquences, basées sur l'utilisation des mesures du champ proche. Cette planification nécessite un éventail d'études très étendu, allant des études théoriques sur la méthode proprement dite aux études très concrètes sur les problèmes d'instrumentation. Enfin, sur un plan plus général, elle collabore aux activités du Siège visant à planifier, au niveau des instances internationales, les missions futures de télécommunication, en particulier pour ce qui concerne l'occupation du spectre des fréquences.

DIVISION STRUCTURES ET CONTROLE THERMIQUE
Cette division comprend des spécialistes dans les domaines des structures, de la régulation thermique et des mécanismes spatiaux. Au début de la conception d'un projet, les ingénieurs des structures et du thermique jouent un rôle de premier plan dans la définition du satellite dans son ensemble. Ils s'assurent de la meilleure utilisation possible de la masse et du volume disponible, compte tenu des contraintes de la charge utile, et étudient les problèmes liés aux conditions d'environnement. Leur participation active à la phase de développement assure la compatibilité des interfaces entre le module de service, la charge utile et le lanceur. Afin d'assurer à ces activités une certaine efficacité, une importante bibliothèque logicielle a été créée. Sa mise à jour constante en fait un outil de pointe pour les analyses thermiques et structurelles.

Les ingénieurs des mécanismes se sont spécialisés dans le développement de mécanismes à grande durée de vie et haute fiabilité. Ces mécanismes sont appelés à travailler dans des conditions sévères d'environnement, en particulier avec lubrification sous vide, et doivent satisfaire à des critères de grande propreté imposés par les systèmes optiques. Ils sont aussi responsables du développement d'un éventail de systèmes pyrotechniques fiables qui répondent aux mêmes critères de propreté.

Pour étudier les problèmes de lubrification sous vide, un Laboratoire Européen de Tribologie Spatiale (ESTL) a été créé. Il est installé dans les locaux de l'Atomic Energy Authority à Risley, Royaume-Uni. Ce laboratoire a permis de vérifier le comportement et la durée de vie de nombreux mécanismes critiques.

DIVISION CONTROLE D'ATTITUDE ET D'ORBITE
Cette division s'occupe de tous les aspects techniques du contrôle d'attitude et d'orbite des satellites, allant de la mesure à la commande de l'attitude au moyen de divers types d'organes de manoeuvre. Comme dans la plupart des cas, l'attitude du véhicule spatial est mesurée au moyen de détecteurs optiques d'attitude (qui utilisent le Soleil, l'albédo de la Terre ou de la Lune, les rayonnements infrarouges terrestres ou stellaires), la division dispose d'un laboratoire d'optique parfaitement équipé dans lequel les détecteurs d'attitude de nombreux satellites ont été vérifiés et étalonnés avant le lancement. Cette division s'occupe aussi, entre autres, de propulsion tant pour la mise en orbite que pour le contrôle d'attitude. Dans ce cas, pour des raisons de sécurité, les essais sur les sous-systèmes ne sont pas effectués à l'ESTEC, mais par des contractants possédant l'infrastructure spécialisée nécessaire.

DIVISION ALIMENTATION DES VEHICULES SPATIAUX
Le domaine d'activités de cette division comprend la génération de puissance par des réseaux solaires et son stockage par des batteries. Il s'étend aussi au conditionnement de cette puissance et à sa distribution aux utilisateurs ainsi qu'aux aspects compatibilité électromagnétique, et au câblage.

Outre le centre d'essais de batteries décrit par ailleurs dans ce Bulletin, la division utilise un laboratoire consacré aux essais de piles et de réseaux solaires. Equipé de simulateurs solaires et de simulateurs à éclats, sa tâche essentielle est l'étalonnage des piles solaires dans les conditions spatiales et la vérification des réseaux solaires à toutes les étapes du projet jusqu'au lancement. Enfin, la division possède une installation d'essai contrôlée par ordinateur servant à l'analyse des performances et de la stabilité de l'électronique de conditionnement et de distribution en présence des fluctuations de consommation rencontrées en vol.

DIVISION SOUTIEN MATHEMATIQUE
Cette division effectue le traitement mathématique et numérique de problèmes relatifs aux programmes spatiaux scientifiques et techniques de l'ESA. Un domaine particulier d'activité est l'analyse de systèmes par voie de simulation mathématique. Ceci englobe l'analyse, la

modélisation et la simulation du système considéré, y compris le choix de la méthode de simulation la plus appropriée. Un des moyens disponibles est le calculateur hybride, installé à l'ESTEC, et exploité par la division. Ce calculateur permet la simulation de systèmes qui, par nature incluent un mélange de phénomènes discrets et de phénomènes continus, lesquels sont modelés respectivement sur les sous-ensembles numériques et analogiques du calculateur. Ces deux parties sont reliées entre elles, et peuvent ainsi échanger des informations (contrôles et données). Cette installation est aussi utilisée pour les applications dans lesquelles un traitement de données mixtes (analogiques et digitales) est nécessaire. Un autre domaine d'activité se rattache au travail effectué sur le calculateur ICL de l'ESTEC. On fait ici référence non pas au travail de programmation effectué en support aux projets, mais aux tâches plus générales telles que la normalisation et la gestion du logiciel, la tenue de la bibliothèque des programmes, l'assistance aux utilisateurs de calculateurs au sujet de logiciels spécifiques relevant de tâches de recherche et de développement.

PERSPECTIVES D'AVENIR: LES MISSIONS PARTICULIERES DU SOUTIEN SPECIALISE

Les ingénieurs du Soutien Spécialisé continueront, comme par le passé, à prêter leur assistance aux chefs de projet chargés de préparer et de superviser les grands contrats industriels de l'ESA. Le Département Développement et Technologie souhaite que ces chefs de projet leur reconnaissent certaines missions particulières auxquelles leur appartenance à une division spécialisée les a particulièrement préparés. En effet, ces ingénieurs côtoient journellement leurs collègues consacrés à des travaux de recherches et au développement de l'infrastructure de l'ESA, et c'est cette situation qui fertilise leur travail, quels que soient les projets auxquels ils collaborent. Dans le contexte actuel de l'ESA, on peut mentionner deux missions essentielles.

PREPARATION DES PROGRAMMES FUTURS

On verra par ailleurs dans ce Bulletin (voir l'article sur 'Le Programme de Recherches Technologiques') que le DDT s'est efforcé par la publication de ses 'dossiers' de recherche, de faire la synthèse du potentiel industriel européen et de ses perspectives de développement dans tous les domaines de la technologie spatiale. Il faut aussi rappeler ici la récente publication par le Siège d'un modèle des missions de l'ESA à moyen terme. Tout cela devrait déboucher sur une meilleure préparation des projets futurs, dont on ne réalisera le bénéfice que si l'ingénieur spécialisé réussit à injecter les nouvelles acquisitions technologiques dans le projet auquel il collabore, de façon réaliste et réfléchie.

Il existe d'ailleurs déjà des exemples de continuité presque parfaite entre les recherches technologiques et les projets utilisateurs, par exemple celui du calculateur embarqué de l'ESA avec tout ce qu'il suppose d'infrastructure en logiciel et moyen d'essai, développé à titre de recherche technologique et qui a vu sa consécration dans les projets Ariane et Exosat. Ces exemples devraient devenir la règle pour le plus grand bien, d'une part, des projets dont on pourrait porter le rythme d'exécution des phases C/D au niveau de celui des programmes américains, d'autre part, des divisions spécialisées qui dissiperaient moins d'efforts dans des interventions d'urgence en cours de programme.

POURSUITE DE LA RENTABILITE

Il n'est pas question, sous ce titre, d'enlever aux groupes projets ce qu'ils considèrent comme une de leurs responsabilités essentielles. Toutefois, l'ingénieur spécialisé, dont la division recense en permanence les besoins de tous les projets au niveau d'un sous-système, est un excellent conseiller pour définir les options d'un nouveau programme, adapter ses exigences à des réalisations antérieures, et, au total, réduire les coûts en optant pour une seconde utilisation d'un équipement déjà développé.

Evidemment, cette politique de réutilisation ne peut être laissée au hasard. Sa réussite suppose que les divisions spécialisées prennent les devants en définissant des normes pour les équipements, en particulier électroniques, dont on prévoit une utilisation systématique dans les projets futurs. L'expérience a démontré, en particulier dans le domaine des équipements embarqués digitaux, que l'industrie était extrêmement intéressée à la publication de ces normes et voit, dans leur respect, un facteur non négligeable d'adaptation aux missions futures et de compétitivité industrielle. □

The Objectives and Methods of The Technological Research Programme

E. Slachmuylders, Head of Spacecraft Technology Group, ESTEC

The most important function of the Department of Development and Technology as a group of subsystem technology specialists is its twofold contribution to the early preparation of ESA's spacecraft projects. The first contribution, the involvement of specialist engineers in the early definition phases of projects, is described elsewhere in this Bulletin. The second and an equally important contribution is in the development of the technologies required to achieve the often initially ambitious objectives of planned future missions. For this, the Department runs a Technological Research Programme, the strength of which lies in its goals and achievements rather than in its size, as it represents only a few percent of the Agency's overall budget.

OBJECTIVES OF THE TECHNOLOGY PROGRAMME

The ultimate and overriding purpose of the technology programme is the timely development of the hardware required for future missions and activities are conducted with the following two complementary objectives:
- the timely development of technologies and hardware, essential for the feasibility of a project, i.e. mission-critical technologies,
- the continuous updating of space technology and the incorporation of progress made in other fields of technology and engineering to enhance overall mission performance, both technical and economic.

MISSION-CRITICAL TECHNOLOGY

The relative importance of the activities aimed at ensuring the timely availability of mission-critical technology is accentuated by the comparatively small number of spacecraft in the ESA programme. Indeed, in keeping up with the rapid developments in space technology, each spacecraft in the Agency's programme represents a considerable step forward in technical and/or scientific objectives. The very limited funds available for these advances which must be realised by the technology programme make their achievement a difficult task. The situation is further complicated by the demands of the Agency's scientific mission programme, within which a wide spectrum of possible and contending scientific missions are studied and only a very small fraction selected for implementation. The technological requirements are so vast as to swamp any technological programme budget, no matter how generous its funds. It is fortunate that the objectives and schedules of other programmes, such as those in telecommunications and earth observation, are more easily foreseen than those of the scientific programme.

One of the technology programme's major challenges is therefore to extract from the future mission model, in all its vagueness, those objectives that require long and intensive technological preparation to ensure their feasibility and to convert these general intentions into specific functional and technological objectives to be realised according to a time schedule compatible with the application of the new technology in the envisaged project.

The level of development required depends in general, of course, on the project as well as the technology. There is a basic difference in approach between the scientific and the applications projects. The latter require a significant provision for the development of specific hardware items under the so-called Supporting Technology Programme (STP). The scientific programme, however, contains no such provision, and in general technology developments for future scientific missions will be progressed by the Technological Research Programme to a much more advanced level than is the case for the applications programme.

The Technological Research Programme contains numerous examples of the successful development of technologies and/or specific hardware items essential to the execution of a mission, development of hydrazine monopropellant propulsion for spacecraft orbit and attitude control and of a versatile on-board data-handling subsystem being but two.

During the late 1960's, it was recognised that for both the scientific and applications satellites programmes of the 70's an advanced, auxiliary propulsion technology would have to be developed for efficient orbital control. From the various possible candidates, hydrazine monopropellant was selected for its ability to satisfy the wide range of requirements associated with the anticipated spin-stabilised and three-axis-stabilised scientific and applications satellites, while at the same time holding promise of sufficient evolutionary growth potential. Development of the basic elements of the hydrazine system was started in 1970 and successfully completed a few years later, by which time the attitude and orbit control requirements of the Agency's Geos satellite had become a major consideration. In parallel, the telecommunications programme, through its Supporting Technology Programme, had initiated the development of specific hardware items for the OTS telecommunications spacecraft, which is also to be launched this year.

In 1971, it was foreseen that the steady growth in data-handling requirements, and particularly those of the scientific missions, would require the presence of computer equipment on board future satellites. Only an on-board computer could perform the sophisticated data-compression operations needed to match the information rate with the capacity of the available telemetry channel, or ensure a sufficient degree of automation to make the satellite autonomous under certain critical conditions. At about this time, it became apparent that the progress in digital electronics was rendering obsolete the concept of separate telemetry encoder and telecommand decoder boxes surrounded by hundreds of wires and connections. A single signal bus communicating with 'remote' acquisition and distribution units and with a central controller was becoming the preferred approach, the on-board computer completing an on-board 'data-handling subsystem' with full data transfer and processing capabilities. The full system is now almost complete, with on-board computer bus, remote terminal unit, central terminal unit, software packages, etc., and it will be used for the first time on the Exosat scientific spacecraft to be launched in 1980.

These two examples serve to illustrate one of the major problems in developing technologies for space application, namely the considerable lead time required from the start of development to application, with development periods of more than five years not being unusual. It is this time lag in developing a technology to a sufficient level to allow its incorporation in the early design of a spacecraft that makes the early identification of the technological development needs of future missions all the more important. The matrix organisation of the Agency aids early recognition and identification of needs for new technological developments, with subsystem specialist engineers who provide specialist support to early mission studies or on-going projects working in the same Division as the technologists responsible for technological subsystem research. The resulting frequent contacts and exchanges of information also facilitate the injection into projects of new or updated technologies resulting from complementary development activities.

TECHNOLOGY UPDATING

As already mentioned, the aim here is to keep pace with the steady progress in all fields of technology and engineering and to adapt it to space applications to allow missions to be conducted more efficiently. The individual development targets and results associated with this second objective may not be as spectacular as for the development of mission-critical items, but it must be remembered that the steady improvement of technologies across all spacecraft subsystems has contributed substantially to the increased performance of the Agency's spacecraft.

It is likely that this aspect of the Technological Research Programme will grow in importance with the introduction of operational application satellite systems and the advent of a World market for telecommunications satellites. Such operational satellites must, above all, be economic and a major factor in this respect is the capacity of the payload. This capacity is a direct function of the inherent performance capability of the technology used, as well as of the mass and power available for the payload. Hence the interest in improving the mass and power characteristics of conventional spacecraft subsystems in addition to improving the payload technologies.

Other important factors such as reliability and cost of design and development plead for progress through evolution rather than revolution. In other words, the progress made between successive spacecraft of an operational system is to be achieved preferably by the injection of updated technologies requiring limited redesign/redevelopment at system level. This evolutionary process yields a gradual growth in payload capacity which in some instances is no longer sufficient, and new generations of advanced technology may become necessary.

Examples of gradual technology improvement can be found in all the fields covered by the Technological Research Programme. Perhaps one of the main problems faced when defining the precise content of the programme is to establish a correct balance between development effort devoted to gradual improvement and that devoted to new-generation technology.

MAJOR ELEMENTS OF THE TECHNOLOGICAL RESEARCH PROGRAMME

From the foregoing it will be evident that the scope of the Technological Research Programme is closely linked with the mission intentions of the Agency. In this context, ESA's space programme may be conveniently split up into four elements that have different degrees of definition and require different types of technological preparation: the telecommunications programme, the earth-observation programme, the scientific programme and the Spacelab utilisation programme.

The telecommunications programme is characterised in part by the setting up of an operational system for the coming decade with spacecraft derived, at least initially, from the Agency's Orbital Test Satellite (OTS). In parallel, developments for advanced telecommunication missions are being actively pursued (e.g. semi-direct TV distribution, mobile telecoms). Worthy of mention here are: RF technology developments (millimetre wave technology for increased capacity, multibeam antennas for improved coverage), power-supply developments (high-power systems, advanced batteries for eclipse operation), auxiliary propulsion (electric propulsion for efficient station keeping), active thermal control (heat-pipe radiators) to cope with high and fluctuating power dissipation levels, and of course developments aimed at improving lifetimes and reliabilities in all fields of space technology.

Like the telecommunications programme, the earth-observation programme has two distinct elements: a meteorology programme, which is expected to evolve into an operational system and a remote-sensing programme (observation of earth resources, pollution, etc.). All remote-sensing missions involve high-resolution imaging of some kind and the associated technology programme is therefore concerned both with the image detection systems technologies and with the enormous data handling and storage problems inherent in the production and temporary archiving of high-quality pictures.

The third element, the scientific programme, does not lend itself to a summary description because of its very varied nature. Although somewhat unusual descriptors in connection with science, the words 'bigger and better' are applicable in the sense that successive missions investigate more aspects of scientific phenomena in greater detail and for longer periods, requiring spacecraft of increased complexity, both in design and operation, and with increased data generation capacity.

This explains why the problems associated with handling payload data and with the flexible operation of complex multipurpose instruments are an important element of the Technological Research Programme. Equally important is the development of technologies enhancing the value of future scientific observations, such as the work on cryogenics, which should substantially enhance the detection capabilities of many scientific instruments.

The fourth element of the ESA programme, Spacelab utilisation, is fairly new and still rather ill-defined. It is to be expected, however, that Spacelab flights will be used to test advanced observation instruments prior to their flight on autonomous spacecraft, for scientific observations, as well as for space-laboratory (zero-gravity and vacuum) investigations in the fields of life and material sciences. All three types of application will have their impact on the Technology Research Programme.

DEFINITION AND HARMONISATION OF THE PROGRAMME

A technological research programme covering all the identified short and medium term needs of the Agency's space missions would require funds far exceeding those of ESA's technology programme, but not the overall European technology development effort sponsored by both ESA and national agencies. Bridging the gap between requirements and financial possibilities therefore requires careful selectivity in defining priorities as well as careful harmonisation of the ESA and nationally sponsored technology programmes. Timely transfer of a development activity to the appropriate Supporting Technology Programme (telecommunications, earth-observation etc.) to free capacity for new and longer-term activities is also an important factor.

The harmonisation effort is directed against unnecessary duplication of development effort by the Agency and its Member States, thereby minimising development gaps caused by lack of funds, but the strong national interests are difficult obstacles in the path of a streamlined European technology programme. The threat of unjustified duplication of development effort is and will always be present as a consequence of national interests whereby the national programmes tend to concentrate technological effort on those items that promise the highest commercial or political return. Although fair competition may have a healthy influence on costs, too much competition will have an adverse impact in the long run by creating an over-capacity for the European market and hence requiring artificial support to centres of expertise to span gaps in project assignments. On the other hand, reducing national funds for space activities will widen the gaps in technological development unless effective harmonisation of activities and programmes is achieved.

The visibility required for such harmonisation is fostered by adequate documentation of the technology programme. The complete field of space technology has been divided into a number (approximately 40) of technology lines. For each of these, a 'dossier' is published containing a review of the relevant technology requirements resulting from the mission model, a description of the state of the art in the field of interest (including a survey of relevant industrial competences), the required technological developments, and finally the technology programme proposed to achieve the targets identified. To date some 25 of the 40 dossiers required for complete space technology coverage have been published.

Following publication, the dossiers are discussed at round-table meetings by technology specialists. The dossier is then amended, where necessary, and submitted to the Agency's Industrial Policy Committee for endorsement of its technological programme, which typically covers a period of three to five years and describes a programme that represents the total European development effort considered necessary to prepare for the envisaged space projects. Only after this endorsement by the Industrial Policy Committee can really effective harmonisation with national programmes be accomplished. Unfortunately, it is still too early to be able to quote major results here, but initial contact with Member States gives hope of at least partial success, success that is essential if Europe is to maintain a technological readiness commensurate with the challenging objectives of future scientific and application missions, within its restricted budget.

IMPLEMENTATION OF THE PROGRAMME

In line with general ESA policy, the vast majority of the Agency's technology programme is carried out by industry under the supervision of the staff of ESTEC's Department of Development and Technology, an approach that ensures that the technology is developed where it will be required for later application to projects, namely at subsystem and/or unit-supplier industrial companies. To ensure that the development work is not too widely and too thinly spread over too many companies, which would seriously harm the effectiveness and efficiency of the technology funds, ESA is about to implement an appropriate industrial policy.

In total, approximately 40 man years of effort are devoted annually by the Department to the definition, initiation, monitoring and verification of the technological research programme. The matrix organisation mentioned earlier promotes a frequent exchange of information by which the technology research activities acquire a realistic flavour, and the specialists supporting projects are kept informed of progress in the state of the art. The benefits are not restricted to the exchange of information; the facilities required for the provision of specialist support or testing frequently find application in the testing and verification of the technology programme. □

L'Administration de l'ESTEC

A. Vandormael, Département Administration, ESTEC

L'installation sur le site actuel de Noordwijk du Centre européen de Recherche et de Technologie spatiale (ESTEC) – qui avait commencé à fonctionner en 1963 à Delft – est régie par un accord passé entre le Royaume des Pays-Bas et l'Organisation européenne de Recherches spatiales, accord signé à la Haye le 2 février 1967 et entré en vigueur le 31 juillet de la même année.

Les bâtiments du Centre recouvrent aujourd'hui une surface au sol de 24 800 m². Elevés, en leur partie centrale, sur 4 étages, ils offrent une surface totale de plancher de 46 850 m². Les bureaux y occupent une surface utile de 13 000 m²; les laboratoires, ateliers, halls d'intégration, salles d'essais, salles de calcul, salles de contrôle, magasins et bureaux de dessin une surface de 17 100 m²; les services d'utilité commune et d'intendance ainsi que les zones de service une surface de 16 750 m².

Actuellement, près de 1250 personnes travaillent sur le Centre, réparties comme suit:

- 70% bénéficiant du statut de membres du personnel de l'Agence;
- 10% d'agents sous statuts particuliers (boursiers, personnel surnuméraire, agents sous contrats de droit local, experts-conseils, ingénieurs de l'industrie ou étudiants en stage et agents de la NASA);
- 20% de personnels contractants venant de firmes de prestation de services.

Parmi le personnel relevant du statut de l'Agence, on ne compte pas moins de 18 nationalités différentes qui représentent l'ensemble des 11 Etats Membres, plus un faible pourcentage de spécialistes ressortissants de pays non membres.

A cette diversité humaine qui constitue un facteur original de l'Etablissement s'ajoute la diversité des formations universitaires et des expériences professionnelles: certains agents viennent de l'industrie privée tandis que d'autres de l'Administration traditionnelle. De plus, comme dans tout Centre de recherche, la gamme des fonctions et spécialités exercées est très variée, ce qui donne un 'cachet' particulier à chaque 'quartier' de l'Etablissement. Ici, c'est l'ambiance universitaire des laboratoires avec un fouillis apparemment inextricable; là le silence solennel des bureaux d'études et la propreté intimidante des vastes halls d'intégration; ailleurs, c'est l'animation bruyante des ateliers ou l'atmosphère feutrée des services financiers. Autre trait caractéristique: dans les secteurs techniques et scientifiques, on trouve une forte proportion de cadres (67,5%) tandis que dans l'Administration (9,5% de l'ensemble du personnel), la proportion est inversée (13% de cadres).

ORGANISATION DE L'ADMINISTRATION

Depuis la naissance de facto de l'Agence spatiale européenne et l'introduction de la nouvelle structure de direction fondée sur les programmes, les fonctions administratives classiques de l'Agence (personnel, finance, contrats) sont devenues centralisées et le personnel administratif des différents Etablissements (ESTEC, ESOC, ESRIN) relève désormais de la Direction de l'Administration, installée au Siège de l'Agence. Le Département de l'Administration de l'ESTEC est responsable, pour sa part, de l'administration de l'Etablissement proprement dit (c'est-à-dire du site et des installations) et de la gestion des moyens matériels et humains sur le plan local.

Effectif

L'effectif du Département de l'Administration, c'est-à-dire le nombre réel de personnes affectées à des tâches fixes et permanentes émargeant au sous-titre 'Dépenses de personnel' du Budget annuel est d'une centaine de personnes. Il se trouve actuellement, pour des raisons conjoncturelles, au-dessous de la ressource 'Main d'oeuvre' inscrite au Programme annuel. La structure d'emploi de cette ressource figure dans le Tableau ci-dessous:

Il ressort de ce Tableau que le Département de l'Administration de l'ESTEC est essentiellement un organe pourvoyeur de services – matériels dans la majorité des cas – au bénéfice d'ailleurs de la totalité de la population du Centre. Parmi les activités inventoriées dans le Tableau, certaines procèdent de la même nature de travail ou de spécialisation. C'est selon ce critère qu'ont été constituées les 'Unités fonctionnelles homogènes' toutes établies au niveau 'Section'. Ces différentes

Structure d'emploi de la Ressource 'Main d'Oeuvre'

– FONCTIONS D'AUTORITE PROPREMENT DITES*				3%
Secrétariat et tâches de bureau rattachés à ces fonctions				3%
– GESTION DU PATRIMOINE				11%
Sûreté, Inventaire, Maintenance et Entretien, Travaux nouveaux				
– SERVICES LIES AUX ACTIVITES PROFESSIONNELLES				76%
• *Intendance*			46,5%	
– Services généraux		20 %		
Services de Bureaux et divers	2%			
Courrier	4%			
Téléphone, téléfax, télex	10%			
Voitures de Service, Bureau de Voyages	4%			
– Bureau des Achats		10,5%		
– Magasins et Transports		16 %		
• *Soutien spécifique*			29,5%	
Imprimerie	15,25%			
Photo & Cinéma	2,75%			
Illustration graphique	2,75%			
Bibliothèque	6 %			
Documentation 'Projets'	1,5 %			
Traduction	1,25%			
– SERVICES LIES AUX PERSONNES				2,50%
Service médical				
Hygiène et sécurité du travail				
Discipline				
Restaurant				
– SERVICES LIES A LA VIE SOCIALE				2,50%
Assistance (Logement, Bus scolaires, etc.)				
Enseignement des langues				
– RELATIONS AVEC L'EXTERIEUR				2 %

* Fonctions de Chef ayant autorité sur plusieurs 'Unités fonctionnelles homogènes'; on verra plus loin qu'elles ne consistent qu'en 3 postes: un chef de Département et son Assistant et un Chef de Division.

Sections figurent dans l'organigramme qui suit, avec indication des activités respectivement couvertes par chacune d'elles. Pour six de ces Sections, les fonctions assumées avaient, à des degrés divers, un caractère technique tel qu'il y fallait la supervision et la coordination d'un 'Chef de Division' polyvalent s'interposant entre elles et le Chef de l'Administration. On pourrait concevoir une situation symétrique à l'égard des cinq autres Sections en les plaçant sous l'autorité d'un Administrateur – Chef de Division. Cette fonction étant toutefois jugée moins nécessaire, il a été décidé d'en faire l'économie.

GESTION DU PATRIMOINE

Sûreté et Inventaire
Il s'agit là, en premier lieu, de veiller, par un service de gardiennage, à l'intégrité du Site et de ses biens contre tous dommages ou aliénations et, d'autre part, de tenir registre de tous les articles, depuis le plus modeste jusqu'aux plus nobles et coûteux, soit une liste d'environ 27 000 articles (dont 17 000 de nature technique et 10 000 d'équipements de bureaux).

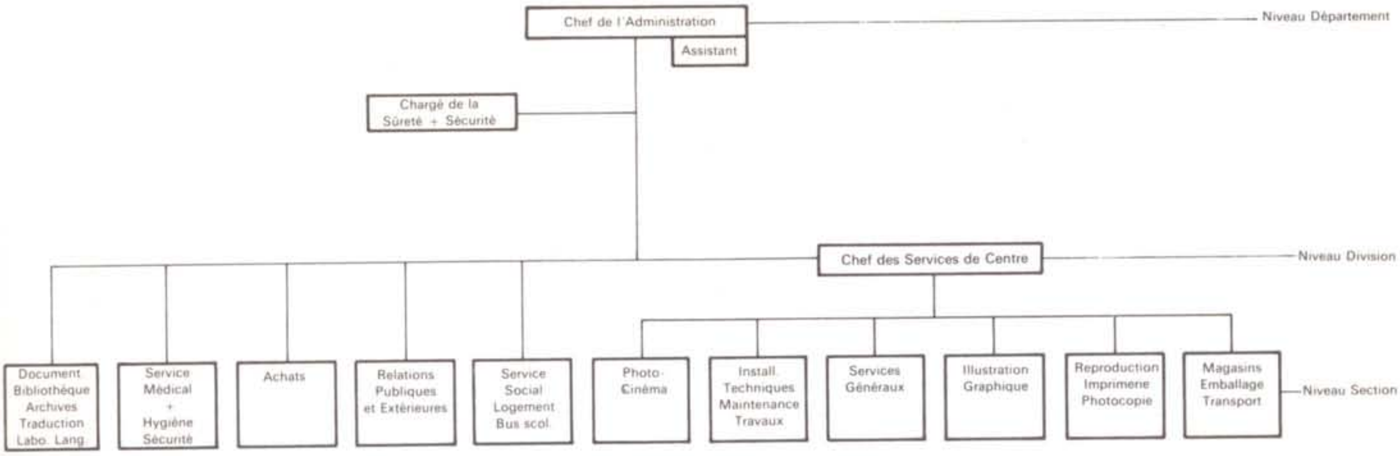
Maintenance et entretien – Travaux nouveaux
Il s'agit, en second lieu, d'assurer la maintenance et l'entretien des installations d'un Centre dont la surface est consacrée pour plus de la moitié à des activités autres que les tâches de bureau, nécessitant une puissance électrique installée de 10 000 kVA. Enfin, comme dans tout Etablissement technique de cette dimension, c'est à longueur d'année qu'il faut procéder à des modifications ou extensions, soit pour améliorer les installations existantes, soit pour loger de nouveaux services. Le nombre moyen de tels 'chantiers' à l'ESTEC s'élève bon an mal an à 800.

INTENDANCE

Ces activités sont de même nature que celles trouvées dans d'autres Etablissements analogues. Elles revêtent toutefois, dans notre Centre, une particulière intensité, inhérente à la nature des missions de l'Agence.

Bureaux
Du fait de la diversité et de la rapidité d'évolution des programmes de l'ESA, la distribution et la configuration des bureaux de l'ESTEC subissent de fréquents change-

Organigramme du DEPARTEMENT DE L'ADMINISTRATION DE L'ESTEC



ments et réaménagements. Nous n'en avons pas pour autant adopté à grande échelle le parti du bureau sur plan libre qui, dans la majorité des cas, ne satisfait pas aux conditions requises de travail. Nous avons simplement généralisé, pour les cloisonnements transversaux, l'emploi de cloisons préfabriquées et normalisées aisément déplaçables.

Courrier, Téléphone, Télex et Téléfax
La collecte et la distribution du courrier ainsi que l'utilisation de moyens de communication instantanée (téléphone, télex, téléfax) connaissent à l'ESTEC une intensité qui reflète la complexité des tâches de coordination et de liaison qu'implique la mission de l'Agence. Quotidiennement et en moyenne, 10 250 colis, lettres et documents sont manipulés au Bureau du Courrier, distribués ou collectés en 65 points de service; 450 appels téléphoniques sont passés sur l'étranger tandis que quatre unités télex fonctionnent en permanence produisant en émission et réception 55 m de messages et que quatre postes téléfax opèrent, dont deux en service continu, traitant au total 165 messages.

Services de Voyages
Les missions, soumises à un strict contrôle, demeurent nombreuses (environ 10 000 en 1976) et requièrent le soutien actif des services d'intendance (Bureau des voyages, voitures de service).

Bureau d'Achats
Les approvisionnements, à la fois variés et intenses, sont assurés par 'ordres d'achats' plutôt que par voie contractuelle, dans la mesure où l'article recherché est immédiatement disponible sur le marché. C'est alors l'affaire de l'Administration de l'ESTEC (alors que l'activité 'contrats' proprement dite relève, dans la structure actuelle de l'Agence, de la Direction de l'Administration centrale). Le principe est bien entendu celui de l'appel à la concurrence des offres. Une trentaine de commandes sont passées par jour, représentant une valeur moyenne de 1000 unités de compte par commande, pour des fournitures les plus diverses.

Magasins et Transports
Le catalogue comprend environ 8500 articles, depuis le plus minuscule des composants électroniques jusqu'à, par exemple, des disques de magnésium brut de plusieurs centaines de kilos. A cela, s'ajoutent 500 articles non catalogués et 350 conteneurs. Le nombre des transactions est d'environ 200 par jour, le tout géré par ordinateur. La surface développée de rangement de ces articles et d'entreposage des équipements remis en garde est de 735 m^2, au sein d'un bâtiment de 2055 m^2 de surface au sol. C'est aussi dans ce bâtiment que s'effectuent les opérations d'emballage/déballage des colis et de chargement/déchargement des camions. Le volume de matériel manipulé s'élève à 90 tonnes par mois, représentant 1200 opérations dont 250 justiciables de formalités douanières à raison d'un tiers en exportation et deux tiers en importation.

SOUTIEN SPECIFIQUE
Il s'agit ici d'activités qui normalement seraient mises au compte d'Unités de production dans une entreprise industrielle.

Imprimerie
Une des obligations imposées à l'Agence découle de l'article III de la Convention et concerne la publication des renseignements et résultats scientifiques et techniques. Cette 'obligation de publication' porte non seulement sur la documentation traditionnelle telle que les études effectuées sous contrats extérieurs, mais également sur la production intellectuelle propre de l'Agence (résultats

d'expériences scientifiques, brevets et inventions). Cette fonction est assumée par le 'Service de Documentation spatiale' (SDS) institué à l'échelon central et doté d'un réseau documentaire reliant la plupart des Etats membres. Mais 'l'unité de production' de ces publications est le Service des Publications scientifiques et techniques de l'ESA qui opère avec le soutien logistique de l'Atelier d'imprimerie de l'ESTEC. Environ 50% du plan de charge de l'Atelier sont représentés par les rapports et documents scientifiques et techniques ainsi que les périodiques de l'ASE (y compris le Bulletin que vous avez entre les mains); le reste, mise à part une fraction de 5% au profit des services du Siège, consiste en une production de routine (documents de travail internes à l'usage des différentes Divisions du Centre). S'étendant sur une surface de 600 m^2 et doté de tout l'équipement nécessaire, l'Atelier d'imprimerie est presque une entreprise en soi (5000 ordres de travaux sont exécutés par an, représentant 10 millions de pages imprimées en offset ordinaire, 5 millions de pages en impression de qualité professionnelle et 120 tonnes de papier).

Photo et Cinéma
La photographie et le cinéma industriels, en particulier le cinéma à prise de vue ultra-rapide, s'avèrent être des moyens de premier ordre et parfois irremplaçables pour l'analyse des résultats des essais pratiqués par la Division 'Essais'. Cette activité représente les 2/3 du plan de charge de la Section, l'autre tiers étant consacré à l'illustration documentaire au profit surtout du Service des Relations Publiques de l'Agence. Voici quelques chiffres de production par an:

Photos: 8000 clichés donnant lieu à 19 150 tirages à nombre à peu près égal entre noir et blanc, couleurs et diapositives couleurs.
Cinéma traditionnel: 2500 mètres de film.
Cinéma ultra-rapide: 35 interventions, la plupart nécessitant plusieurs caméras (jusqu'à 12 opérant simultanément).

Illustration graphique
Le dessin illustratif (vue éclatée, graphique, etc.) est souvent nécessaire pour expliciter un texte. Une petite Section existe pour cela qui satisfait environ 500 demandes de travaux par an.

Bibliothèque
La Bibliothèque occupe 625 m^2 et comprend 18 600 volumes, 713 journaux et périodiques et près de 437 000 rapports et normes (sur microfiches). Le Service de la Bibliothèque consiste non seulement à assister le personnel dans la recherche bibliographique mais encore, allant au devant de la demande, à diffuser de façon sélective l'information pressentie comme intéressante. Au total, le nombre des prestations est évalué à 17 000 par an, ce qui, rapporté au nombre d'agents ayant besoin d'une base bibliographique pour leur travail, représente une moyenne de 40 prestations par agent. Par définition, ce nombre ne comprend pas les démarches 'self-service' (consultations directes d'ouvrages, photocopies d'extraits, etc.) qui sont également considérables.

D'autre part, c'est naturellement la Bibliothèque qui gère le terminal du Système Recon installé au Centre. (Rappelons que le Recon est un système informatique de hautes performances permettant, par dialogue en mode conversationnel et en temps réel, la recherche automatisée de citations bibliographiques sur 12 fichiers – dont celui de la NASA – lesquels constituent l'une des plus importantes collections mondiales d'informations scientifiques et techniques simultanément disponibles, soit près de 7 millions de citations).

Documentation Projets
La réalisation d'un projet requiert une documentation souvent considérable (pouvant occuper jusqu'à 25 m^3). Une fois le projet terminé, il faut sélectionner et mettre en ordre ce qui, de cette masse documentaire, doit être conservé en archives par les soins de l'Administration.

Traduction
De nombreux documents scientifiques et techniques de l'Agence devant être établis à la fois en anglais et en français, leur traduction est assurée par un service spécialisé qui traite ainsi près de 2000 pages par an.

Service médical
L'examen médical annuel de routine est doublé d'un examen cardiographique, pratiqué à l'aide d'un appareillage des plus modernes et complété par un traitement sur ordinateur des questionnaires médicaux et des résultats d'analyses biologiques.

M. A.L. Vandormael (52 ans) est belge. Il a suivi les cours de l'Institut Supérieur des Sciences Administratives et Commerciales de Bruxelles. Il fut ensuite, de 1945 à 1966, fonctionnaire au Ministère de la Justice belge, d'abord au Département du Budget et des Finances, puis comme Chef de la Division du Personnel. Il travaille à l'ESTEC depuis janvier 1966, où après avoir été adjoint au Chef du Budget, puis Chef du Budget, et Chef des Finances en 1969, il occupe le poste de Chef du Département de l'Administration de l'ESTEC depuis le 1er mars 1972.

Hygiène et Sécurité du Travail
Pour faire face aux nuisances diverses et aux risques d'accident dans les ateliers, laboratoires et halls d'essai, ce sont les Chefs de Division qui sont tenus d'appliquer les directives générales (ou instructions spécifiques pour certains domaines) émises par le Directeur en matière d'hygiène et de sécurité du travail.

Restaurant
La participation active du personnel à l'affaire mérite d'être soulignée. L'Administration met à disposition l'infrastructure de fonctionnement nécessaire et prend en charge une part des coûts de main-d'oeuvre; les Agents pourvoient au reste, de leurs propres deniers. C'est en conséquence au personnel qu'est laissée, pour une grande part, la responsabilité de la gestion de l'affaire, la sauvegarde des intérêts de l'Administration et du personnel étant assurée par un Comité mixte.

VIE SOCIALE

Parmi les problèmes que pose l'installation des personnes dans un pays étranger, les plus immédiats sont, d'une part, le logement (avec tout ce que cela comporte de formalités administratives), et, d'autre part, l'éducation des enfants. Vu la barrière des langues, l'expatriation se double, pour la plupart des non-Néerlandais, d'un dépaysement complet.

Logement
Au regard du premier problème, l'assistance la plus diligente est assurée non seulement sous forme de renseignements et de démarches, mais aussi par l'offre de logements dont l'Administration dispose par accord avec certains organismes propriétaires (au total 500 maisons et appartements). Sur une année, 4000 services de diverses natures sont rendus, soit plus du triple du nombre de personnes travaillant dans le Centre.

Education
En ce qui concerne l'éducation des enfants, l'Administration de l'ESTEC apporte une contribution importante, d'une part en apportant une aide aux quatre écoles étrangères (allemande, anglaise, française et américaine), d'autre part, en organisant un service de ramassage scolaire dont bénéficient environ 550 enfants. Ce réseau de bus, réparti sur 35 points de ramassage, couvre près de 1600 km de lignes. Comme pour le Restaurant, ce service est géré avec la participation du personnel.

Enseignement des Langues
Afin d'aider le personnel à se sentir à l'aise dans la communauté polyglotte de l'ESTEC et à mieux s'intégrer dans la vie locale, des cours audiovisuels de langues (surtout en anglais, en français et en néerlandais) sont donnés tout au long de l'année. Il existe par ailleurs un laboratoire de langues qui dispose d'un équipement moderne et d'une collection de bandes et cassettes en différentes langues européennes.

RELATIONS AVEC L'EXTERIEUR

Par la nature même de ses activités, l'Etablissement est en prise permanente sur le monde extérieur: mille visiteurs venant de tous horizons et des milieux les plus divers sont accueillis par le Service des Relations publiques, tandis que l'image de l'Agence est mise en valeur auprès du grand public par des contacts avec des moyens d'information locaux et par une participation active aux manifestations spécialisées. □

The ESA Centralised Management System for Satellite Electronic Test and Checkout Instrumentation

J.B. Rowles et al., Data Handling and Signal Processing Division, ESTEC

The European Space Research Organisation, and later the European Space Agency, has progressively developed a centralised management system covering the major elements of the electronic instrumentation required for satellite integration and testing. The essential role of this centralised system has been to accumulate experience over the years and to organise the ground segment used for satellite integration and testing, comprising standards, procedures, software, equipment and logistic support. It has provided a sound basis for mission planning and has rationalised all these fields to ensure their readiness at the start of new missions. This has been possible because of the continuity of involvement of ESTEC's engineers and because of their close links with other Agency activities such as the elaboration of on-board data-handling, tracking, telemetry and command standards, and the development of the ESA ground-station network.

The major elements of the electronic instrumentation used for satellite integration and testing, and its supporting software, now constitute an important part of the ESA infrastructure. Past investments have brought the instrumentation available to the level required for five simultaneous satellite programmes, presently Geos, ISEE, Meteosat, OTS and Marots, with a total of 31 stations maintained in operation in England, France, Germany, Holland, Italy, Sweden and also in the USA for the launches.

Today, the experience gained in checkout management, the development of high-level language software and the modularisation and standardisation of equipment is such that European satellite projects external to the Agency programme have found a technical and commercial advantage in seeking the support of ESA's centralised system for their test and checkout activities.

THE PHILOSOPHY OF INTEGRATION AND TESTING

A satellite is a complex arrangement of electronic packages, all of which have to co-exist in a confined space and communicate with, and be controlled from, the ground through a common communications facility. The integration and testing of these electronic packages follow the same basic pattern as the commissioning of any complex assembly; the various functional elements are designed, built and tested separately by the relevant specialists and then progressively assembled and tested in their working environment until the complete satellite system is ready to perform its operational role. The only fundamental difference here is that both the functional elements and the satellite as a whole have to be tested more rigorously because they are to be exposed to very severe environmental conditions and because it will not be possible once they are in space to correct any latent design error.

To understand the nature and to appraise the types and complexity of the electronic instrumentation required for satellite integration and testing, it is necessary to be familiar with four of the 'key' concepts governing these operations. These are: (i) the concepts of 'unit', 'subsystem' and 'satellite system', (ii) the central role of the on-board data-handling subsystem in interfacing space segment and ground segment, (iii) the concept of telemetry, tracking, command and data-handling standards, and (iv) the concept of different levels of testing.

UNIT, SUBSYSTEM AND SATELLITE SYSTEM

In the context of satellite hardware:

- a 'unit' is a piece of hardware developed separately, for instance by one satellite subcontractor. This division accommodates the various specialisations of the industrial designers and manufacturers, and aims at minimising the interfaces between these units (telemetry transmitters, sun sensors, travelling wave tubes, etc.)
- a 'subsystem' is a group of electronic units which performs one of the major functions of the satellite. It can be the payload of the mission, such as a scientific experiment or a telecommunications repeater, or a supporting subsystem for attitude measurement and

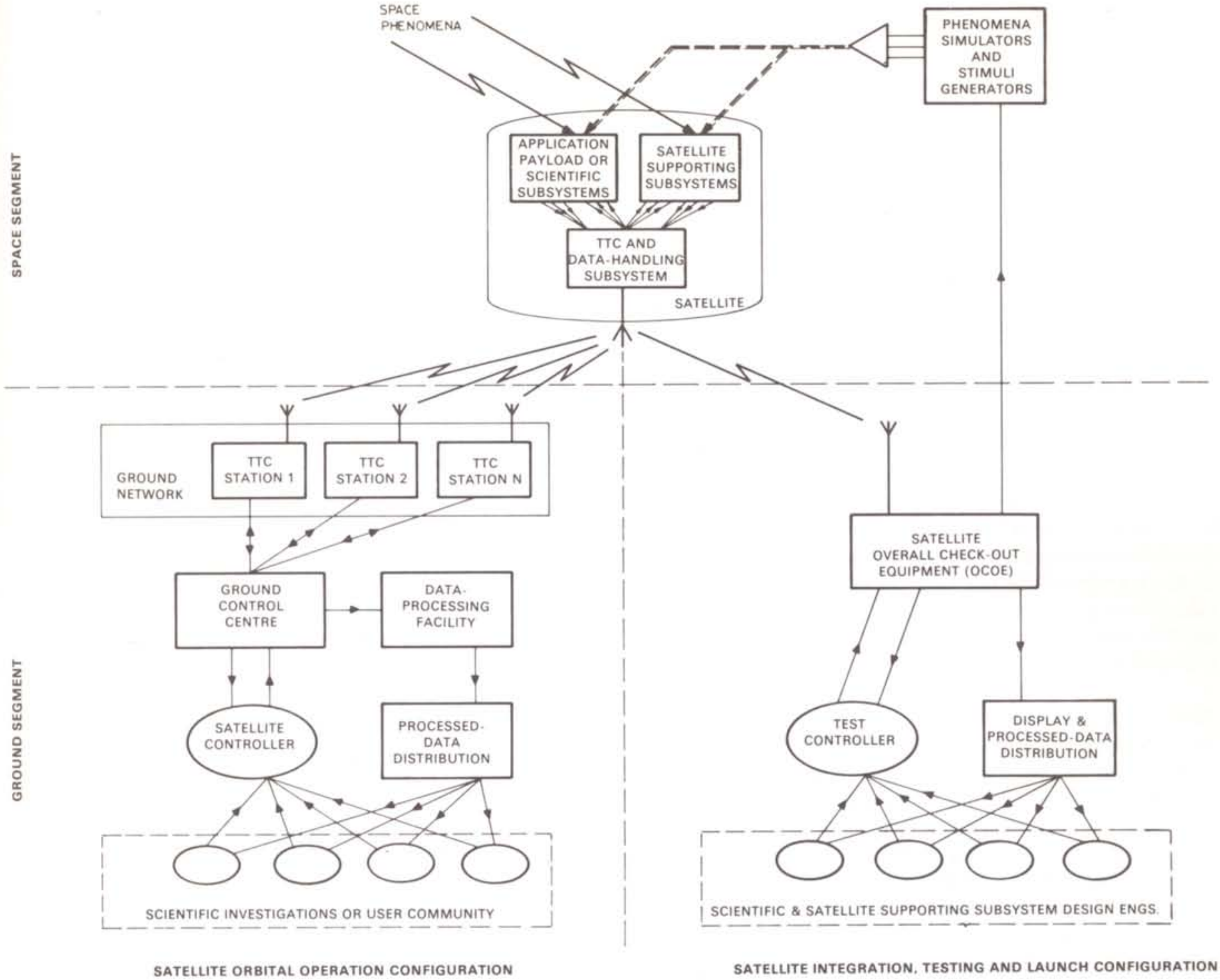


Figure 1 – Satellite control and monitoring interfaces for orbital operations and ground testing phases.

control, power generation and distribution, etc.
- the 'satellite system', or 'satellite', is the complete assembly of integrated subsystems.

CENTRAL ROLE OF DATA-HANDLING SUBSYSTEM

When a satellite is in orbit, communication between the spaceborne systems and the ground is via the on-board data-handling subsystem, which functions as a switchboard for information: collecting, multiplexing and processing data from various subsystems and demodulating and distributing the commands sent from the ground to change the satellite's mode of operation.

During satellite integration and testing, the on-board data-handling subsystem plays the same central role as for the operational phase. In fact, the satellite is controlled and monitored through the same radio-frequency links as when in orbit. This method provides the best simulation of orbital operations from the control point of view. The launch of a satellite is marked by the insertion of the TTC ground network (acquisition, command and tracking stations) between the satellite and the community of engineers and scientists interested in its performance, in place of the ground checkout station (Fig. 1). It also resolves in the best possible way the problem of accessing the on-board subsystems once integrated into the satellite, whether to monitor their performance or to change their mode of operation.

THE NEED FOR STANDARDS

The on-board data-handling subsystem typically deals with hundreds of communication channels in both directions and because of its central role, development of the satellite would be an impossible task if its interfaces, with the ground on the one side and with the payload and supporting subsystems on the other, were not governed by definite standards. In practice, the interfaces with the ground are governed by established ESA/NASA Tracking, Telemetry and Command (TTC) Standards, which ensure compatibility between the satellite and the major World networks, and guarantee the performance of the communication links. The interfaces within the satellite itself, between the on-board data-handling and all other subsystems to be controlled and monitored, are governed by ESA Data-Handling Standards, which specify the methods of transfer, processing, coding, formatting, etc. of the signals inside the satellite. These standards are a mandatory feature without which the parallel activities of all the designers of on-board equipment could not proceed in a timely and efficient manner.

TEST LEVELS AND TYPES

Tests are performed at unit and subsystem level prior to satellite integration and they require simulation of all other equipment with which the on-board units or subsystems interface. The goal is not just to verify that the subsystem or unit is working normally under nominal conditions, but also to assess at what level of degradation of some important parameter (quality of input signal, power-supply voltage, etc.) the device ceases to operate correctly. This is referred to as a *'performance test'*.

When the performance tests have been completed and the subsystems have been integrated with each other in the satellite, their real outputs must be compared with the expected ones for all possible configurations to be encountered in real operations. Each subsystem has to be stimulated and its measured responses compared with the predicted ones generated from a model of the whole satellite system. The basic logic of this operation is illustrated in Figure 2. All parameters are continually checked to verify that they remain within allowable safety margins and predictions for the parameters subject to calibration changes are updated with the environmental conditions. Statistics are produced on any drifts due to ageing. Tests of this type conducted at satellite level are referred to as *'functional tests'*.

Functional tests are performed:
- when the subsystems are being progressively integrated together, to assess the results of each step of the integration sequence
- when the satellite is fully integrated and submitted to various simulated environmental conditions (thermal vacuum, mechanical vibration, acoustic, magnetic, EMC, etc.) for final qualification
- at any time after qualification when routine checkout of the satellite is needed, such as on the launch vehicle.

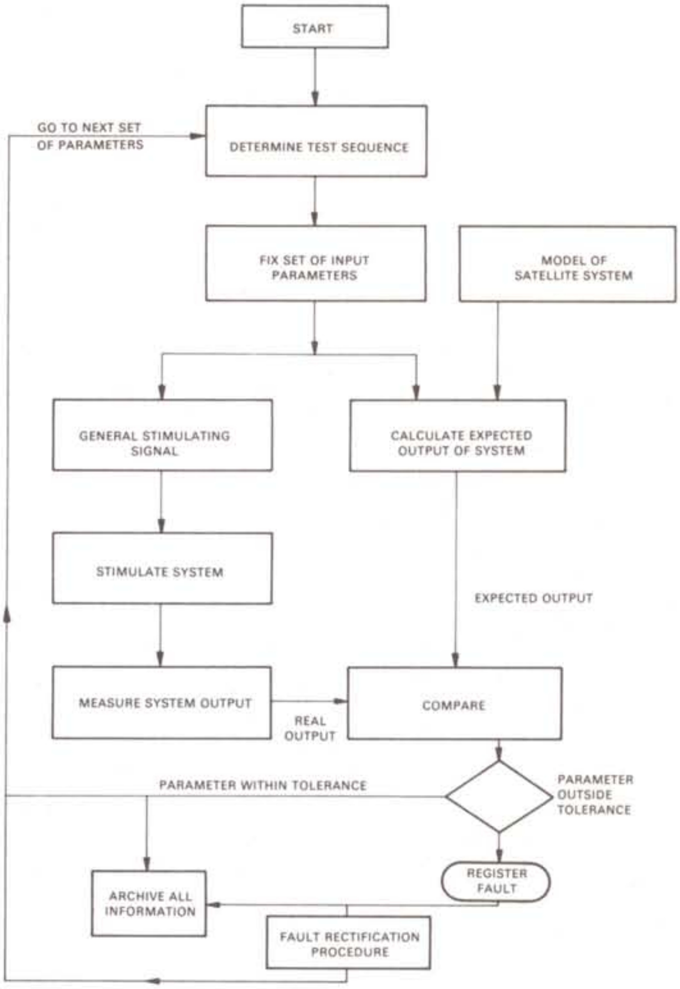


Figure 2 – Functional representation of a test-sequence step.

SUPPORTING EQUIPMENT

The basic tool used for performance testing is the test set, one of which is required for each subsystem. In many cases the subsystem is specific to the mission, as for a communications payload, or varies widely in essential features from mission to mission, as for an attitude-control or a power supply subsystem. Such subsystems require test sets specifically designed for a particular project.

Just as the on-board data-handling subsystem has a special role to play in satellite integration and testing, the data-handling test sets form a special category of

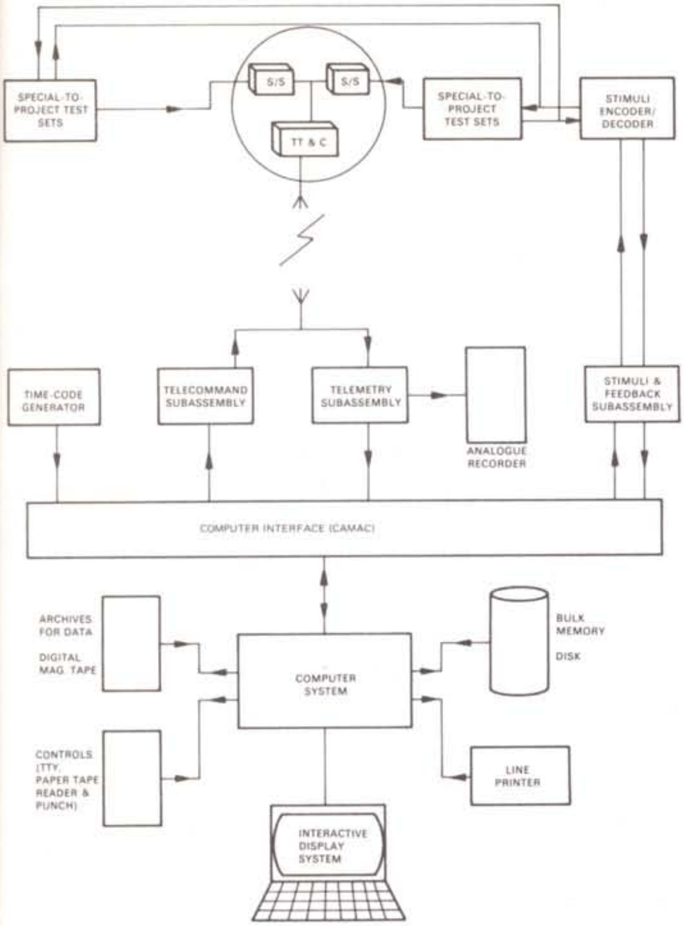


Figure 3 – Configuration of satellite and OCOE station during satellite integration and testing.

subsystem test set and are defined according to precise data-handling and TTC standards, which allows their re-utilisation for further missions, assuming that the same standards are retained. They are very complex in nature and reach a degree of sophistication justified by the absolute necessity to thoroughly assess the integrity of the on-board data-handling package throughout all stages of satellite development.

The basic tool used at satellite level for functional testing during the various stages of integration and environmental testing is the 'Overall Check-Out Equipment' (OCOE). It is essentially a data-processing facility equipped with TTC peripherals to communicate with the satellite for overall control and monitoring. As might be expected, the OCOE station is the most sophisticated electronic facility used for satellite development. Even so, this too can be re-used from project to project because its central processing system can be easily reprogrammed for other applications and because its essential TTC peripherals are designed according to TTC and data-handling standards.

GENERAL-PURPOSE CHECKOUT EQUIPMENT

The ESA centralised management system for electronic test and checkout equipment is concerned only with the stations and test sets that can be claimed to be 'general purpose' in the sense that they rely on TTC and data-handling standards and can be re-used in subsequent programmes. Accordingly, general-purpose checkout equipment infrastructure includes all the hardware, software and logistic organisation necessary to support the integration of a satellite and the performance testing of the standard on-board data-handling system.

The degree of sophistication of the general-purpose facilities must be the result of an optimisation process that takes into account both the investment required and the cost of the satellite integration and testing and the effort required to mobilise all the various contractors involved in the design of the satellite subsystems and specification of qualification procedures.

ESA's facilities go significantly beyond the lowest degree of sophistication needed for the mere display, by some automatic means, of the data produced by the satellite. They have been designed to prevent certain situations that can arise during testing and integration, the criticality of which has been amply demonstrated in the earlier programmes. Typical examples would be late discovery of cross-talk and spurious outputs causing a satellite integration sequence to be interrupted for an indefinite time, wrong suspicion cast on a subsystem by some unidentified intermittent failures leading to the disqualification of a subsystem, late discovery of a shortage of processing capacity leading to the revision and lengthening of a full test programme.

The OCOE stations

This equipment (Fig. 3) is used to control and test the overall satellite during its integration, qualification and launch phases. It is remotely connected (in a similar way to the ground-network stations when the satellite is in orbit) through the telecommand and telemetry radio links, so that the satellite can be controlled and monitored while situated in clean rooms, in test chambers, or on the launch vehicle.

Auxiliary ground telemetry and telecommand links are provided to control equipment which stimulates such items as sun sensors, earth sensors, experiments, etc. and to control the satellite's simulated power supply. The OCOE computer is therefore the master controller of the satellite and ground equipment and not just an 'off-line monitor' used from time to time like an oscilloscope. If the OCOE fails, satellite integration and testing comes to a halt. It is also important to note that the OCOE is not just an 'off-the-shelf' computer. In fact, the computer and its standard peripherals only account for approximately one third of the OCOE hardware. The specialist telecommand and telemetry subassemblies required for coding and decoding the satellite signals and the equipment for controlling the stimuli systems are the most important assemblies.

The key features that characterise the OCOE system can be summarised as follows:

- It has to have global control of the satellite and testing configuration because its output statements form part of the quality-control file. As such it has to perform many closed-loop operations in the setting-up and verifying procedure which involves all supporting stimuli systems as well as all on-board subsystems.
- It has to analyse all incoming data in real time in order to guarantee the safety of the satellite and reduce integration and testing time. An important aspect of this feature is the need to detect and document all transient phenomena and specify the situation under which such phenomena occurred.
- The OCOE computer has to process all the data acquired by the various on-board payload and supporting subsystem sensors so that it can be distributed in an intelligible form to all the experts concerned with the qualification of the satellite.

The Data Handling Test Sets

These sets are designed to make detailed performance tests on the on-board units and subsystems. In contrast to the OCOE, they are intimately connected through hundreds of wires to the on-board units (Fig. 4). The key features that characterise them are the ability to:

- verify that all the signals used to communicate with the payload and supporting subsystems conform to the ESA Data Handling Standards in terms of level, rise time, phasing, etc.

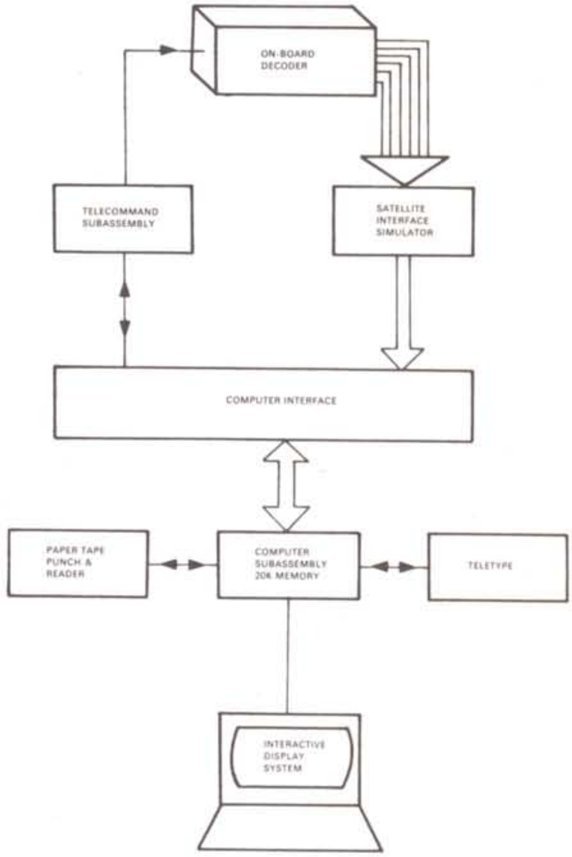


Figure 4 – On-board telecommand decoder test configuration.

- activate all inputs and simultaneously monitor all outputs to check for spurious as well as genuine responses
- establish that all parameters are according to specification for the various environmental conditions and moreover that the absolute performance is consistent with the actual design and eventual ageing of the system
- perform the above tests rapidly and efficiently because integration and testing of the overall satellite cannot start until the on-board data-handling subsystem is available and its integrity guaranteed in the light of the role it has to perform.

THE SOFTWARE INFRASTRUCTURE

The one element of the OCOE software that forms part of the general-purpose checkout infrastructure is the high-level users' language, which is independent of precise project requirements, but incorporates the universal testing principles which have been found desirable. This basic software provides the necessary tools to enable project engineers without substantial programming experience to write their own software with only limited specialised software support. It includes a 'Monitor' program to allow the test engineer to define the parameters of a subsystem or experiment and to give the corresponding upper and lower limits as a function of satellite status, and a 'Test Sequence' program, which permits him to specify a sequence of operations on the satellite, such as the sending of telecommands, stimuli commands, and the reading of data values. These can be compared with desired values and the program can take action in the light of the success or failure of a particular test.

The organisation of the 'Test Sequence' program is such that the simple sequences used in the early phases of integration can later be combined into long and complex chains built up from the tested elements. All operations are logged automatically to provide a permanent record of the tests carried out without further clerical effort.

THE LOGISTICS ORGANISATION

ESA delivers to the projects fully commissioned OCOE stations and data-handling test sets together with the basic software (executive, high-level 'users' language', diagnostics, etc.) and full operations and maintenance support.

Having been introduced to the systems, one can readily visualise the essential features required for this support, but there are certain important points which are not immediately evident. These are the need to:

- operate the stations at various contractors' premises throughout Europe and in the USA (Fig. 6)
- move the stations from one test location to another, which can mean up to 25 moves per year

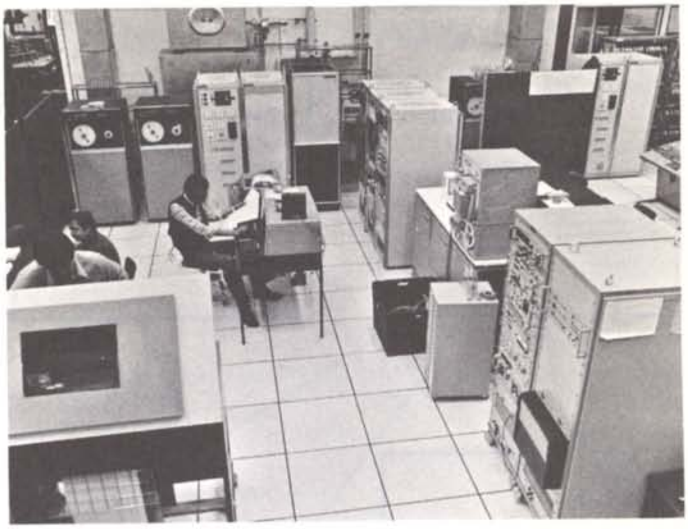


Figure 5 – Satellite OCOE station.

- guarantee that the systems will be fully operational, for at least 90% of the time they are required
- cope with peaks of activity associated with round-the-clock working
- be able to localise a fault quickly so that the appropriate expert (satellite designer, OCOE computer engineer, etc.) can be called in.

These problems and other particular requirements have been taken into account in establishing a streamlined supporting infrastructure based upon:

- rationalisation of hardware into standard assemblies and modules with simple, clearly defined interfaces
- use of standard equipment layouts on a deliverable false floor in which all interconnecting cables, power supplies, grounding, etc. are installed
- use of standard packing cases with built-in ramps to accept the racks of equipment, which are mounted on castors
- establishment of procedures and logical deployment of spares so that the operators can conduct first-line maintenance in the field, supported by a core of experienced engineers on call at ESTEC in case of emergency
- use of real-time verification aids, within the general-purpose checkout equipment, to demonstrate correct operation of the test equipment when anomalies arise in the overall test configuration.

The standardisation of the equipment, its layout, operating procedures, etc. reduces to a minimum the need for operator and maintenance-personnel training, spares holding, documentation, etc., and allows maximum flexibility in the transfer of personnel from one project to another to cover peaks of activity.

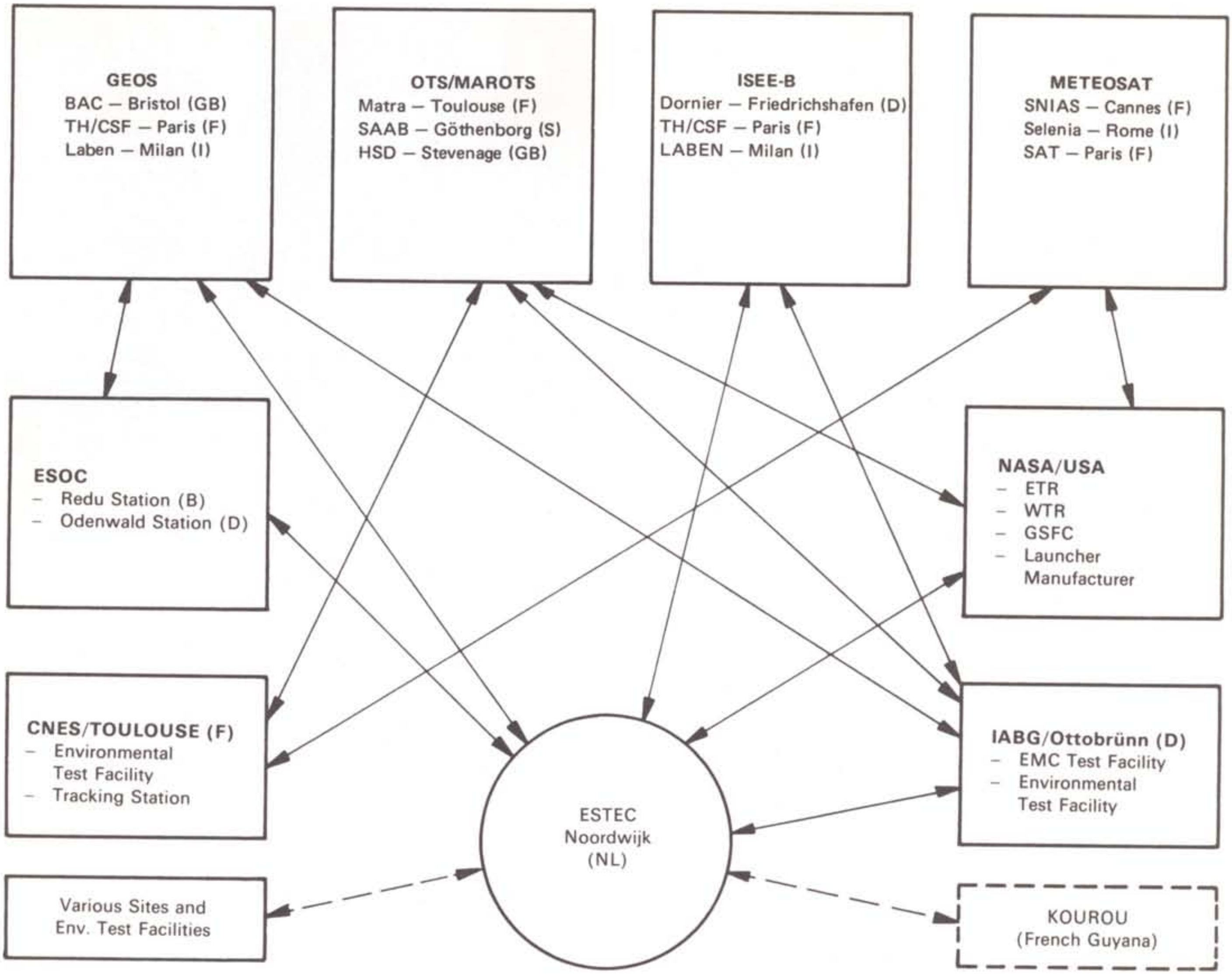


Figure 6 – An outline of the locations and movements of the general-purpose checkout equipment instrumentation.

CONCLUSION

The ESA centralised management system was instituted when it became apparent that the volume of the Agency's project activities would be sufficient to benefit from standardisation. The major considerations were the needs to accurately predict the system performances, to ensure correct matching of the hardware and software constituents of each system, and to use a common logistic support organisation encompassing documentation, procedures, maintenance and operations. As a result, it has been possible:

- to define the instrumentation required at a very early stage in a project and to initiate procurement action for a well-proven system, thus reducing the risks involved in the development of the spacecraft
- to achieve significant savings in capital investment, stemming from the possibility to re-utilise equipment for a second and sometimes a third project
- to achieve a substantial reduction in the time needed for satellite integration and testing by using well proven testing methods and procedures
- to readily accommodate the requirements of space missions of increasing complexity at low cost and low risk by way of simple additions or modifications to existing equipment and procedures.

The success of ESA's satellite test and checkout activities has been helped in no small part by their centralisation at ESTEC. This has provided the means both to accumulate experience continuously and to promote this knowledge within European space industry, with the aim of harmonising the integration and testing procedures used for the different satellite projects at a European level. □

Technology Developments to meet Tomorrow's Need for Higher Satellite Frequencies

G. Mica, Space Communications Division, ESTEC

The payload of ESA's OTS satellite is designed to work at frequencies above 10 GHz and technology pre-development is already being directed towards even higher frequencies. Surprisingly enough, the basic research on millimetre waves is more than twenty years old, in that the first steps were taken at the time transistors were being developed and the first satellites launched. However, the system designer was not able, at that time, to achieve reliable and reproducible performance with the building blocks available to him (magnetrons and klystrons, silicon diode mixers, bulky ferrite circulators) and the real progress of recent years has only been made possible by the development of reliable tubes, improvements in silicon and gallium-arsenide technology, the invention of new devices, and rapidly evolving integration techniques.

From the early applications in compact airborne radars to the broad band circular waveguide communications links now coming into service and the successful Nimbus radiometers, the viability of millimetre wave systems has been repeatedly demonstrated. Once the need for the very large bandwidths and narrow antenna beams that typify millimetre wave system performance becomes felt for space missions, the use of higher frequencies can be introduced without insurmountable problems provided an adequate pre-development programme is undertaken.

MISSION OBJECTIVES

When the European Communication Satellites (ECS) Programme began to take shape in 1970, the newly allocated 11–14 GHz frequency band was chosen to minimise problems of interference with ground links and existing satellite systems. OTS, the Agency's first experimental communications satellite using these frequencies, is to be launched this year, and the operational ECS system that will follow it is currently being approved. Why then should we need to move to still higher frequencies for communications satellites? The answer is that substantial increases in capacity will be needed, particularly if systems that are economically competitive with ground links can be offered. Moreover, the limited centimetre-wave frequency allocations may soon be saturated, in spite of the possible capacity improvements offered by such new developments as high-gain multibeam antennas and on-board switching, if the communication systems are to be designed around a single satellite of reasonable size and complexity.

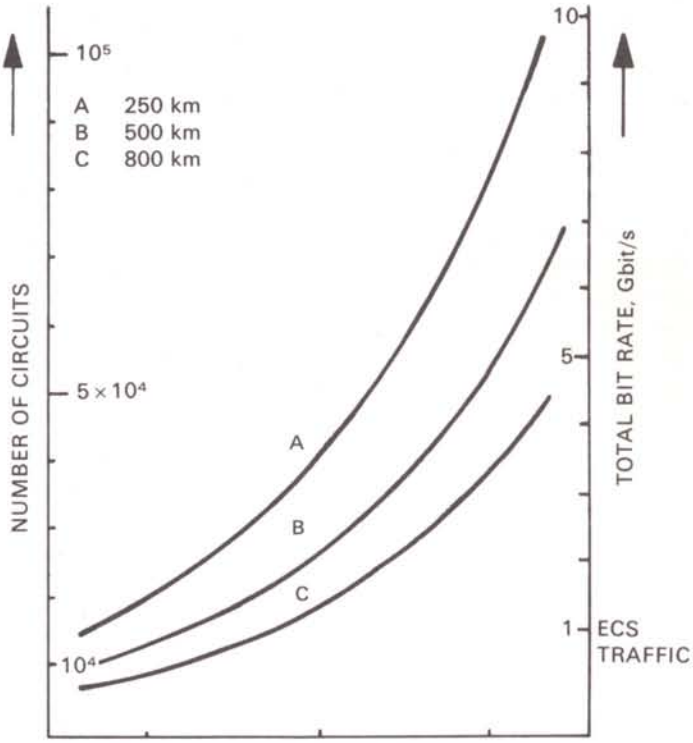


Figure 1 – Forecast European international traffic between 22 centres selected as ECS ground stations, as a function of the minimum interconnecting distance.

The development of telecommunications networks is a very interactive process in that the requirement for new capacity depends very much on the existing communications structures. In Europe, and in the industrialised

World as a whole, highly developed local networks for telephony, cable television, data links and facsimile already exist. These are a prequisite for quickly expanding interconnecting networks over distances of hundreds of kilometres, which can be implemented with satellite services. European international telephony traffic, for example, is expanding rapidly (Fig. 1); a conservatively estimated expansion rate of 15% per annum leads to a fourfold increase in traffic during the expected ten-year lifetime of a single generation of communications satellites. Further expansion could result from extension of the satellite interconnecting network to cover shorter distances and from the introduction of data-transmission, remote-printing, teleconference, videophone and electronic mail services.

Anyway, it is clear that by the end of the next decade capacity for long-distance communications will need to be at least one order of magnitude greater than can be provided by, for instance, the present ECS configuration.

Although larger satellites and use of advanced technologies could provide systems in the 11 to 14 GHz band capable of carrying a reasonable share of the extra traffic, the next generation of communications satellites must make use of higher frequencies to remain competitive with ground systems. Competitiveness will be required not only in capacity, but also and particularly in economy, which means inter alia inexpensive and reliable hardware.

PROPAGATION EFFECTS

The design of communications systems is further complicated by the increasing attenuation at frequencies above 10 GHz, due to absorption and scatter in the atmosphere. Even though a satellite link has only two 'legs', each of which spends but a few kilometres in the troposphere, 'clear-weather' absorption can already cause losses of a few decibels in the two next higher frequency ranges allocated to fixed communications (27.5-31 GHz uplink, and 17.7-21.2 GHz downlink) and prohibitive attenuations of tens of decibels above 60 GHz. Much heavier losses still are caused by absorption and scatter through clouds and precipitation.

Attenuation can be reduced to acceptable levels by using

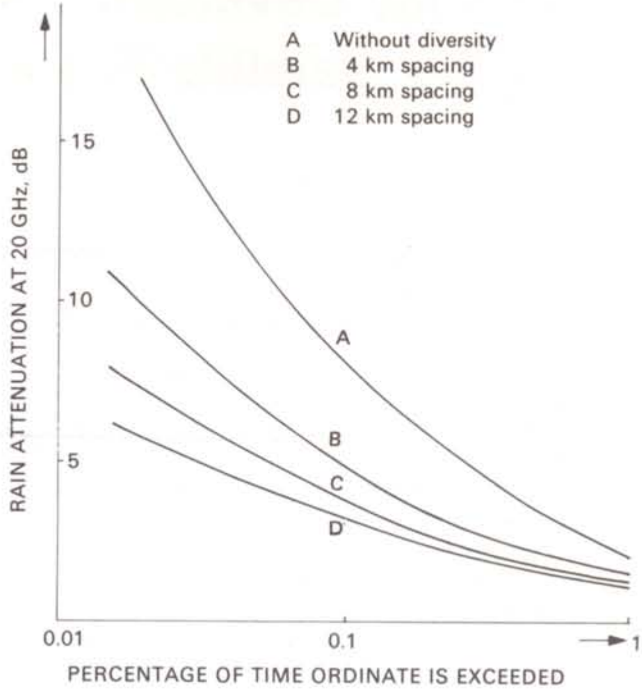


Figure 2 – Effect on reception of using stations in 'space diversity'.

two ground stations sufficiently widely separated to minimise correlation between local precipitations (Fig. 2).

However, overall propagation phenomena are not well understood and simple extrapolation from measurements at lower frequencies is not easy. Indeed, the first step in the planning of new systems working at millimetre wavelengths must be the setting up of a propagation research programme, a task that has been given priority in the Agency's planning, in order to provide systematic and extensive coverage, to assure valid statistical information on propagation characteristics with respect to both time and location. Ground radio link measurements and radiometric measurements of the sky and Sun temperature can provide the first extensive data base on absorption and correlation with meteorological phenomena can provide prediction methods. The latter is one of the objectives of an EEC project (COST 24/4) with which ESA is associated. Satellite beacons will, however, be required for measurement of scatter, scintillation, refraction, depolarisation and deep fades, and the help of well separated ground stations with large antennas will be needed to evaluate diversity improvement and the effects of scatter and refraction on wavefront coherence.

The first experiments have already been conducted in Europe under ESA supervision, using the 20-30 GHz beacons on the American ATS-6 satellite, and experiments at 12 and 18 GHz with the Italian Sirio satellite will provide further information during the next two years.

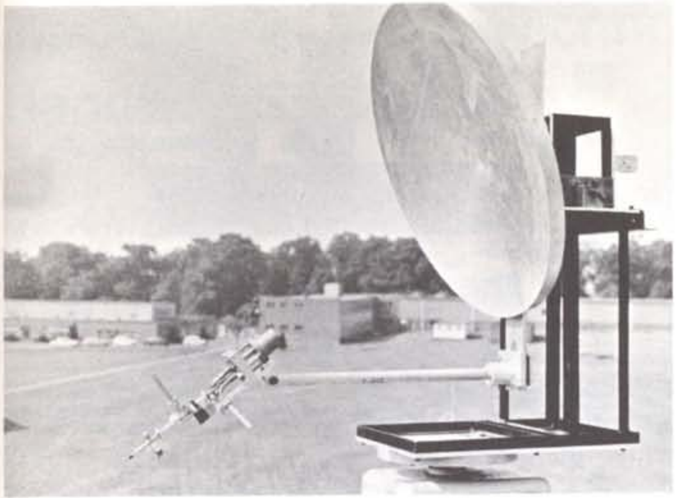


Figure 3 – 30 GHz multibeam antenna. The antenna model was developed at ERA (UK) and provides three beams with 44 dB gain.

SYSTEM-DESIGN CONSIDERATIONS

This concern about propagation problems should not be taken to mean that a high-performance satellite communications system operating at millimetre wavelengths is out of reach with the technology that can be developed in the coming years. On the contrary, extrapolation of today's technologies could provide a satellite payload with a communications capacity of the order of 5 Gbit/s using 30-20 GHz transponders and multi-spot-beam antennas.

Ground stations with 5 to 6 m antennas would be used but space diversity would only be required for high-availability links (99.9% of the time). Including the cost of an interconnecting ground link of some 12 km, typically across the town area where the traffic originates, the system would already be financially competitive with today's ground links over trajects of more than 500 km. The satellite payload would use 2 m antennas and spot beams with 0.5° coverage. The capacity and bandwidth of each transponder would be exactly six times those of the present Intelsat module and three times those of ECS, thus maintaining the possibility of easy system interconnection.

With larger satellites and the frequency reuse easily permitted by the narrow millimetre-wave spot beams, capacity could be increased three to four times when new types of communication, like videophones and teleconferencing, boost traffic requirements. Moreover, multi-satellite systems with intersatellite links at 54 GHz could increase flexibility and remove possible limitations imposed by spacecraft size and complexity.

Certainly, the large bandwidths (3.5 GHz at 20-30 GHz) available, the narrow antenna beams achievable, and the freedom in system parameter selection will allow us to design systems which will not be capacity-limited for a long time to come and which will be economically competitive.

Further system-design considerations can be expected to evolve with the development of European earth-observation satellites, which will need high-capacity downlinks to carry the voluminous data flow from their high-resolution radar and other sensing systems operating at millimetre wavelengths.

TECHNOLOGY DEVELOPMENT FOR MILLIMETRE WAVES

The first step towards technology development is to obtain a clear picture of the present state of the art for each element of the system and of possible developments in the time scale matching the forecast system evolution. Europe already has the knowhow to manufacture the satellite and ground antennas needed for the millimetre wave system. Verification and maintenance of dimensional accuracies of fractions of a millimetre in the exacting environment of space are, however, the crucial difficulties for these antennas. Their electrical design requires a scaling down of concepts developed for lower frequency ranges: ESA has already been working on antenna-pattern prediction methods and testing techniques for several years (Fig. 3), but further work is still required on multiple reflector configurations that provide an array of narrow adjacent beams covering a designated region on Earth, and on advanced designs such as lens antennas, array-fed reflectors etc.

The need for high transmitter powers in combination with large bandwidths points to the Travelling Wave Tube (TWT) as the high-power amplifier that will be used for many years to come for satellite systems operating at frequencies above 10 GHz. Within national programmes, developments are on the way for ground-station tubes with powers up to 1 kW, and for satellite tubes giving up to 30 W at 20 GHz and 10 W at 60 GHz. It is feasible and would obviously be desirable to raise satellite powers further, but technological continuity with the 11 GHz ECS/OTS amplifiers is mandatory both to minimise development risk and cost and to benefit from earlier satellite experience.

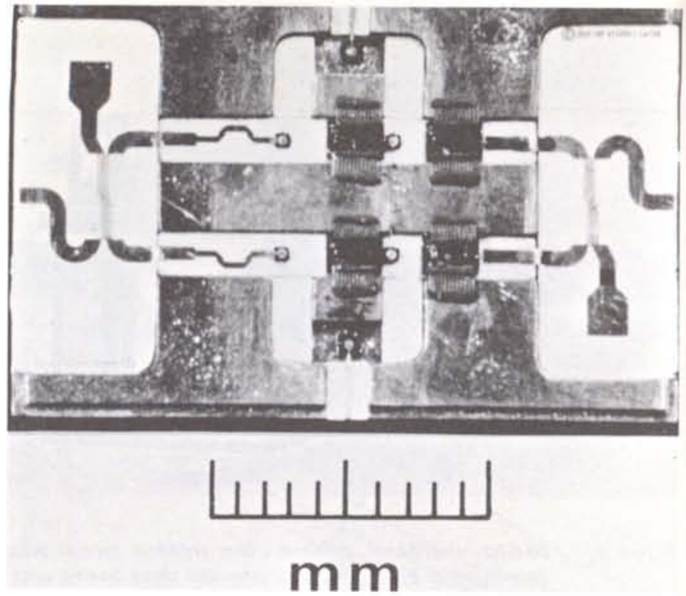


Figure 4 – Micrograph of an 11 GHz FET developed at Plessey (UK).

The reasons for choosing repeaters with down-conversion and main amplification in the 11 GHz frequency range are many. A particular family of transistors – GaAs Field Effect Transistors or FETs – can be developed which provide adequate gain per stage with good stability and bandwidths up to several GHz (Fig. 4). Low-noise performance and sufficient power to drive transmitter tubes or mixers can be achieved with other devices of the same family. Double-gate FETs will allow gain control, modulation and can possibly also serve mixing functions. The idea of concentrating development and qualification effort on a few families of microwave devices will certainly increase the probability of success and reduce the component qualification expenditure which is today a substantial, and largely non-European, component of project costs. In fact, the early availability to the circuit designer of well-characterised components to be used throughout his design can be as cost-effective as the increased performance achieved with the best available parts and design. In view of the rather large bandwidths envisaged, the 11 GHz frequency range is nearly optimum for lightweight filters and design experience is available from previous projects.

IMPLEMENTATION OF THE MILLIMETRE-WAVE TECHNOLOGY DEVELOPMENT PROGRAMME

The previous sections have broadly outlined the need for a programme, its objectives and the areas to be covered. How is the technology programme implemented?

Because of the continual limitations on space research budgets and because of the widespread interest in the results obtained, most basic millimetre-wave technological research has been and will continue to be conducted outside the aegis of ESA or other space organisations. Using this wealth of research results and on the basis of prospective missions and system configurations, ESA collects such detailed research information in the form of 'Applied Research Dossiers', in this case one devoted to 'Millimetre Wave Techniques'.

The dossier covers efforts ranging from the initial adaptation of available research results to the classical but often contradictory space-technology constraints of low-mass, high efficiency, stringent thermal environment, long life and high reliability, to the development and qualification of specific pieces of equipment ready for project use.

Because of the magnitude of the overall technology development programme, its costs must be shared between national, space and communications agencies, and ESA budgets. An essential role of ESTEC's Space Communications Division is then to ensure that all these contributions are co-ordinated to meet the same technical objectives and that while minimising duplication results are made available to all parties via the published dossiers.

The most important area where early work is needed and to which ESA is committed is the definition of system configurations and of the basic parameters – bandwidths, radiated power density, size of ground stations, use of space diversity – that dictate the essential equipment specifications. There are two objectives to be pursued here: the first is to establish system configurations which will subsequently be compatible with optimum performance and economy, and the second to ensure that the early work on equipment development is on the right track.

Experience from the ECS Supporting Technology Programme shows that the requisite interval between the start of pre-development and the implementation of an operational system can realistically be estimated at ten years, at least in Europe. On the other hand, as demonstrated by the use of European communications equipment on the Canadian Telesat and on America's Intelsat-V (parametric amplifiers, antennas and travelling wave tubes), an early start allows a good foothold to be established in external markets. □

Introducing New Technology into On-Board Data-Handling Systems

M.A. Perry, P. May & W. Walker, Data Handling Division, ESTEC

The performance of an on-board data-handling system is directly dependent upon the technology employed and in recent years the commercial product has evolved dramatically in a direction compatible with space applications. Important improvements in miniaturisation, low power consumption and cost reduction have been achieved and the availability of these improved technologies has played a major role in the introduction of a new modularised on-board data-handling system now being developed as part of ESA's applied research programme. The choice of technology must take account of the intended application, as well as quality, reliability and cost. From the applications point of view, the most important criteria in the selection of components for space application are scale of integration, speed and power consumption.

Anyone who has been watching the evolution of the domestic radio set will have noticed how this household article has changed over the years. Crystal sets were first replaced by valve (vacuum-tube) receivers, and these were later followed by transistor radios and more recently by 'single chip' radios where all the receiver functions are integrated into a single semiconductor device. The electronic technology of the thirties which supported the raucous prattle of those massive early receivers would be simply inadequate for today's 'hi-fi' stereo tuner. This is but a simple illustration of how new capabilities and new technology tend to go hand in hand. By 'technology' we imply here the means by which abstract ideas of a system design are converted into a concrete form – it is the art of constructing hardware.

Extrapolating this argument to other disciplines is not unrealistic, and one can observe that the overall performance and size of a spacecraft data-handling system is dependent upon the technology employed. In the last few years, industrial capability in microelectronics has evolved rapidly and a new generation of components has become commercially available. This has offered system designers a chance to satisfy a growing demand for hitherto unobtainable performance, but to achieve this potential improvement for the next generation of equipment will require an expedient and judicious selection of technology.

DATA-HANDLING SYSTEMS

The on-board data-handling system of a spacecraft represents a unique communications link between all its subsystems and the world outside. It collects and transmits housekeeping and payload data to ground; it monitors and reports the status of spacecraft subsystems to the operations centre; it receives commands sent from the ground station and relays these to their destination in the spacecraft; it preprocesses and compresses on-board data prior to transmission to ground. Without this vital link, the spacecraft would be out of touch with the Control Centre and would become non-functional. The capability of the on-board system very largely determines the capability of the spacecraft as a whole, and there is constant pressure to improve this.

The system's capability can be thought of as a combination of several interdependent factors, including:
- the average information rate that the system can handle, or the speed of the system
- the number of channels that can be addressed to give or take information
- the mass, volume and power consumption
- cost and reliability.

Data-handling system requirements are becoming more comprehensive as the level of ambition associated with space projects continues to grow. The number and

TABLE 1

Satellite	Launch date	Mass (kg)	Information rate (bit/s)	No. of channels
ESRO II	1968	75	128	144
Cos-B	1974	300	640	354
Meteosat	1977	280	166000	617
Surveillance satellites	1980's		over 50 million	1000 (approx.)

complexity of the expected functions of on-board equipment continues to rise, yet due to launch constraints mass and power consumption must not escalate. Table 1 illustrates the trends that are taking place.

A typical satellite data system may now have four or five hundred data-acquisition channels and perhaps two hundred command channels. Each channel requires between two and four wires, and the scale of the numbers involved clearly indicates that satisfactory interfaces and interconnections can only be achieved by adopting a systematic approach involving a high degree of standardisation.

In the past, data systems were highly centralised, like the one depicted in Figure 1a. All electronic functions such as formatting, signal conditioning, analogue-to-digital conversion and data storage and processing were provided by a central complex of equipment. It is quite usual to find several kilograms of cabling in a satellite and as the number of channels grows the cable loom becomes comparable in weight to the equipment boxes it feeds.

A new concept is needed for the larger systems of the future, based on the outline in Figure 1b. Here the centralised equipment complex is devolved both in function and in location of intelligence. The several identical remote units are tied together by a single party line and are managed by a much smaller central unit. This system offers considerable savings in wiring, but it requires that many functions be duplicated in each remote unit. It offers many advantages associated with modularity:
- flexibility and ease of expansion
- parallel development of compatible equipment
- easier updating of system hardware.

Modularity brings with it a hardware overhead which can only be contained if the function density – the number of functions per unit mass – is increased substantially. Whilst modular data systems have been used on the ground for some years because of the advantages already cited, their introduction into spacecraft has been delayed by the lack of suitable 'low-mass' technology.

This state of affairs is now about to change and a standardised modular on-board data-handling system is being developed by the Agency, the aim being to increase equipment density by a factor of at least three or four.

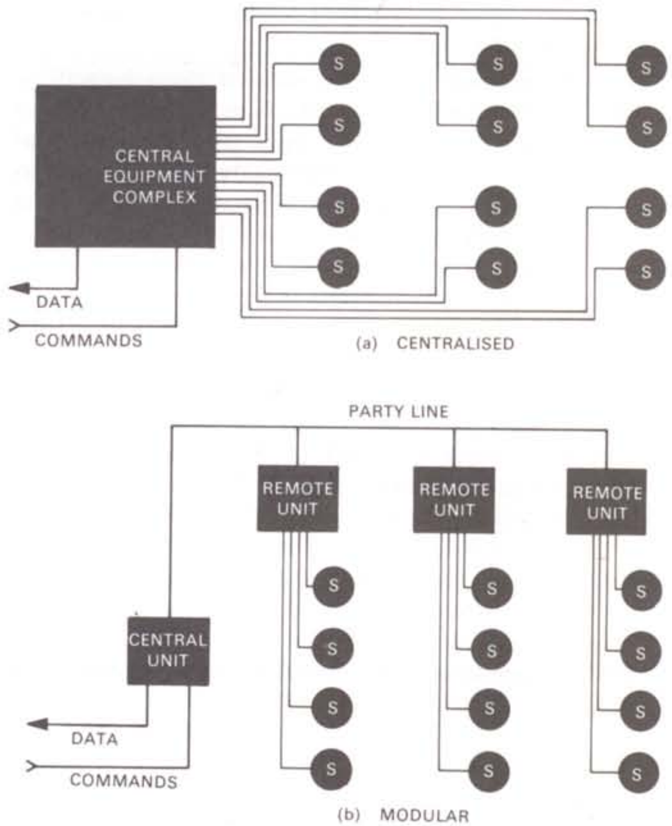


Figure 1 – Data system organisation.

LARGE-SCALE INTEGRATION

The costs of developing ab initio a new components technology simply to meet a unique ESA requirement would be so high as to be out of all proportion to the scale of the Agency's overall on-board data-handling activities. Moreover, the probable usage of components required by foreseeable Agency programmes is very small compared with the world-wide commercial market. It is therefore preferable for ESA to design data-handling systems that use components for which a large commercial demand exists, and which can also meet the necessary performance and reliability requirements for space flight. The

TABLE 2
Hardware Trends in Aerospace Computers

Year	Mass (kg)	Volume (l)	Power (W)	Technology
Pre-1962	40	31	262	Discrete
1963	26	47	85	Discrete
1971	20	12	20	SSI
1974	4.1	4.8	15	SSI/MSI
1977	0.004	0.0015	0.3	(unqualified)

advent of microelectronics and the evolution of new semiconductor technologies have provided the revolution in equipment design that makes this possible.

In Table 2, some aerospace computers are compared as a simple illustration of the progress in the state of the art. As more and more complex circuitry is crammed onto a single solid chip, the 'scale of integration' is increased. Small-Scale Integration (SSI) describes the implementation of simple functions, such as amplifiers or simple bi-stable flip flops which have only 10 to 20 transistors. With Large-Scale Integration (LSI), a whole (micro) computer comprising many thousands of transistors may be fabricated on a single chip of silicon less than a quarter of a square centimetre in area, and packaged in an encapsulation weighing about 4 g.

It is a matter of opinion whether such LSI devices should be classed simply as components, because they are elementary, cheap and small in themselves, or as miniaturised subsystems. Many designers are already well aware that the software and interface problems associated with minicomputers do not vanish just because of micro-miniaturisation; in fact, they can get worse, because of constraints imposed by the technology itself. The selection of suitable 'components' therefore requires an understanding of both the technology and the system requirements. In effect, some aspects of equipment and component design have become merged into one.

The introduction of this type of device into equipment brings new problems. Designers can only use components of this complexity if they are provided with expensive support facilities normally associated with the application of fully engineered systems. To prevent inefficient investment, it is necesary to standardise on a small range of LSI devices, but the selection must be made with care otherwise equipment design will be adversely compromised.

The majority of LSI devices are catalogue items produced for a diverse range of customers and in generai one can find a device that fits the required function. Nevertheless one can also identify requirements which are peculiar to on-board data handling which are not met in an optimum way by available commercial devices. In this case a custom design can provide a powerful alternative whereby many small devices are replaced by a single LSI.

In the past custom-designed LSI was prohibitively expensive for small production quantities because of the high initial fixed cost. However the recent availability within Europe of uncommitted logic arrays (ULA) may solve this difficulty. The applicability of these devices to space applications is being evaluated.

A ULA is an integrated circuit on which upwards of 1500 passive and active elements are present. But the final interconnection between these elements which defines the combinational and sequential logical behaviour is omitted.

The interconnection is defined by the user to suit his own requirement. Since all processing up to the final interconnect is standard for all devices regardless of application, economies of scale can be achieved, and the user obtains a custom-designed LSI device of reasonable complexity at a reduced cost.

THE EFFECTS OF SPACE RADIATION

Semiconductor devices fall into one of two categories:
- bipolar devices, which depend for their working upon the properties of the semiconductor bulk
- metal-oxide-semiconductor (MOS) devices which depend upon the properties of the semiconductor surface under a layer of silicon oxide.

Of the MOS technologies, Complementary MOS (C-MOS) is best suited to the requirements of space applications, and is superior to bipolar technologies

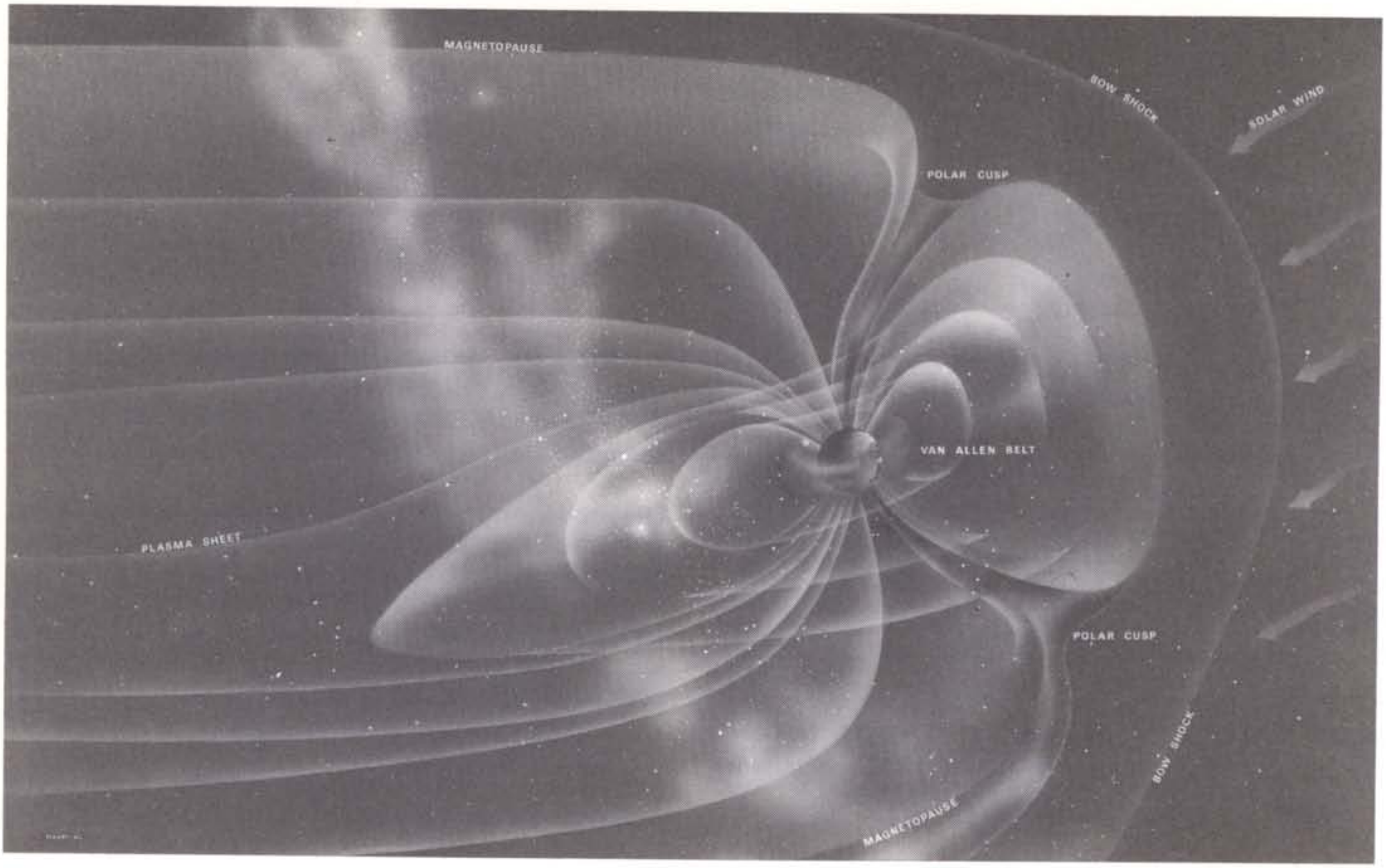


Figure 2 – Radiation in the Van Allen belts.

TABLE 3

Technology	Failure level rads (silicon)	Approx. lifetime in geosynchronous orbit (1.5 mm shield)
Bipolar	2×10^6	10 years or more
Old CMOS	2×10^5	1 year to 6 years
Current CMOS	2×10^3	4 days to 3 weeks

because it offers greater speed, higher packing density, extremely low power consumption, and wide supply voltage and high noise immunity. MOS technology is widely favoured for LSI devices, but the devices are then highly sensitive to space radiation. This problem has only become important in recent times partly because recently introduced changes in the fabrication processes have improved the quality and electrical performance of MOS devices at the expense of increased radiation sensitivity.

This is illustrated in Table 3, where the probable lifetimes are listed for semiconductor devices flown in a geosynchronous orbit, shielded by 1.5 mm of aluminium.

The Earth's magnetic field traps high-energy electrons and protons in the Van Allen belts, which encircle the equator from 600 km to more than 40 000 km above the Earth's surface. Electrons with energies between 0.5 to 5 MeV and protons in the range 5 to 35 MeV are present in large numbers (Fig. 2), and they can penetrate several millimetres of aluminium and still retain enough energy to cause cumulative ionisation damage to MOS components. This susceptibility to ionisation damage colours any decision to use MOS technology on spacecraft. Operating life can be prolonged by the addition of up to 6 or 7 mm of shielding, but the mass penalty incurred detracts from the mass benefits of using MOS unless the equipment item is physically small.

Thus an optimum design becomes a carefully balanced selection of interdependent compromises, based on detailed analysis of spacecraft configuration, orbit, and radiation susceptibility. To increase the radiation hardness of a family of components would require process changes that would have a far-reaching effect on the commercial viability of those devices. With the development of new semiconductor technologies already ruled out on economic grounds, the only strategy is to learn to build systems with what is currently available. Much can be done by choosing a spacecraft configuration such that

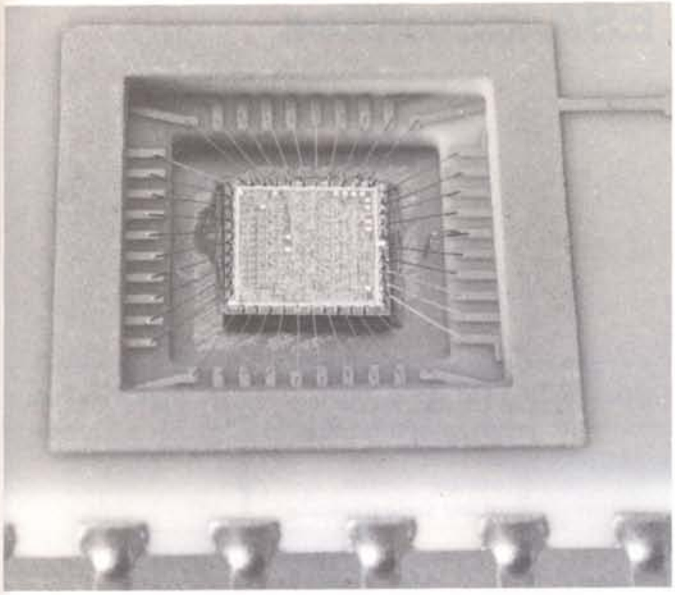


Figure 3 – An uncommitted logic array: An example of semiconductor LSI on a chip approximately 6 mm square.

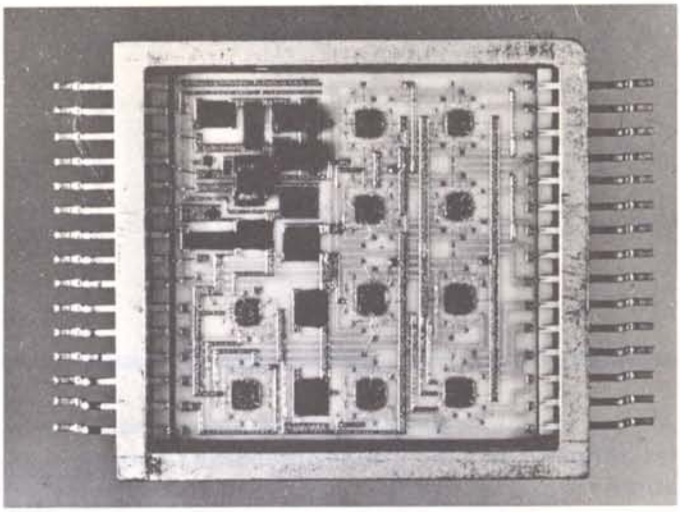


Figure 4 – A typical thick-film hybrid assembly. The substrate is about 2.5 cm square.

sensitive units are shielded by those that are less sensitive and by carefully packaging sensitive equipment.

In this context, it is proposed, in collaboration with quality assurance experts, to fly an experiment in which a number of MOS devices are subjected to radiation damage in space, to compare the correlation between shielding, absorbed total dose and observed damage with theoretical predictions. The aim will be to verify tentative design methodologies and develop standard test methods for radiation hardware measurements.

PACKAGING AND INTERCONNECTION

The capabilities of a mechanically and electrically modular system depend very much on the packaging and interconnection methods used. The system must be broken down into an optimum family of units whose shape, form and fit must fulfil all electrical requirements whilst still permitting modules to be assembled in any meaningful configuration.

Besides the usual problems of low mass and ability to withstand severe vibration, there are special problems of intermodule electrical connections and thermal conductivity, since many densely packed LSI devices generate a great deal of heat. Whilst modularity gives potential for functional expansion and introduction of future modifications, paradoxically this benefit can only be fully realised if all anticipated expansion requirements are taken into account during the design stage. In addition, provision must be made for radiation shielding which can be tailored from mission to mission. A contract has been placed with industry to study these problems and to define and evaluate a suitable modular packaging system.

The packing and interconnection problem is no less important inside a module. The use of printed-circuit boards is likely to continue for some time, but the application of hybrid thick-film techniques holds promise for integrated-circuit packaging. There are many detailed process variations in this hybrid technology, but in general silk-screen techniques are used to print conductor patterns onto an alumina substrate using conductive inks containing gold and other metallic particles. Active devices such as transistors are mounted as bare chips (typically 1.0 mm square) and connected to the substrate by bonding with wire (typically 0.025 mm in diameter). The scale of miniaturisation thus achieved permits a small subsystem to be assembled onto a few 2.5×5 cm substrates. This approach has the advantage of allowing different component types, such as integrated circuits, resistors and capacitors, to be mixed in a single package, and it may therefore be an attractive technology for interface circuits, and other circuits which can be used repeatedly.

CONCLUSIONS

We have attempted to show how the performance of a data system can only be improved if new technology is introduced. Suitable technology is available, but its application in space awaits the solution of the problems associated with radiation sensitivity and choice of suitable packaging methods. □

Control and Stabilisation of ESA Satellites

D.N. Soo, Attitude and Orbit Control Division, ESTEC

All the Agency's satellites that have already been launched or will be in the forseeable future rely on some form of attitude control and stabilisation. In addition, the geostationary satellites need an orbit-control capability to fulfil their operational tasks. Satellites require the ability to point certain items of equipment in specified directions; on an astronomical mission, for example, the telescope must be pointed at different stars, while on a telecommunications satellite the antennas must be directed towards discrete locations on the Earth's surface. The attitude accuracy and manoeuvre requirements vary widely from mission to mission, from fractions of an arc second in some cases to several degrees in others. The satellite subsystem responsible for this control function, commonly called the Attitude and Orbit Control Subsystem or AOCS, consists of sensors for measuring such variables as attitudes and angular velocities, signal-processing electronics, which implement a suitable control program from the sensor information, and actuators and propulsion units to develop and apply forces and moments to the satellite.

SYSTEM REQUIREMENTS

The attitude and orbit control requirements originate from the character of the mission and the nature of the payload. They determine the destination or location of the satellite, its attitude stability and accuracy, and the orbital station keeping and attitude reorientation manoeuvres (Table 1). In general, for a satellite to meet its attitude-control requirements, a number of different control sequences must be used, the main modes of operation being:

- a coarse acquisition mode, which gives the satellite a specified orientation from arbitrary attitudes and rates, and which frequently includes an attitude search requiring large-angle slew manoeuvres
- a fine acquisition mode, which brings the satellite to operational attitude after coarse acquisition and places the operational attitude references (e.g. Earth and Sun) in the fields of view of the appropriate sensors
- a normal mode, which establishes the satellite in its operational attitude with the normal-mode sensors pointing at and tracking their reference targets
- a ΔV mode which provides the satellite with attitude control during linear velocity changes (ΔV manoeuvres).

TABLE 1

Attitude and Orbit Control Subsystem Requirements

1. Orbital Characteristics
   - Orbital parameters
   - Orbit control and station-keeping
2. Orientation Requirements
   - Primary pointing (Earth, Sun, stars, planets)
   - Secondary pointing (solar arrays, pointing antenna)
   - Requisite stabilisation (two-axis, three-axis)
   - Reorientation (manoeuvre attitude and rates)
3. Accuracy Requirements
   - Attitude error
   - Attitude error rate
4. Satellite Characteristics
   - Inertias
   - Configuration/shape

In the event of a failure of one of the control-system components, most satellites have alternative or back-up modes in the form of control loops that use different combinations or reconfigurations of unfailed sensors and actuators. These back-up modes usually have reduced performance, degraded reliability and increased energy consumption.

SYSTEM DESIGN

In its basic form, the attitude control system can be described by a functional block diagram typical of an automatic control loop. Figure 1 shows the main units of a typical system, indicating the interconnections and interfaces between the various control elements, and the technological disciplines involved.

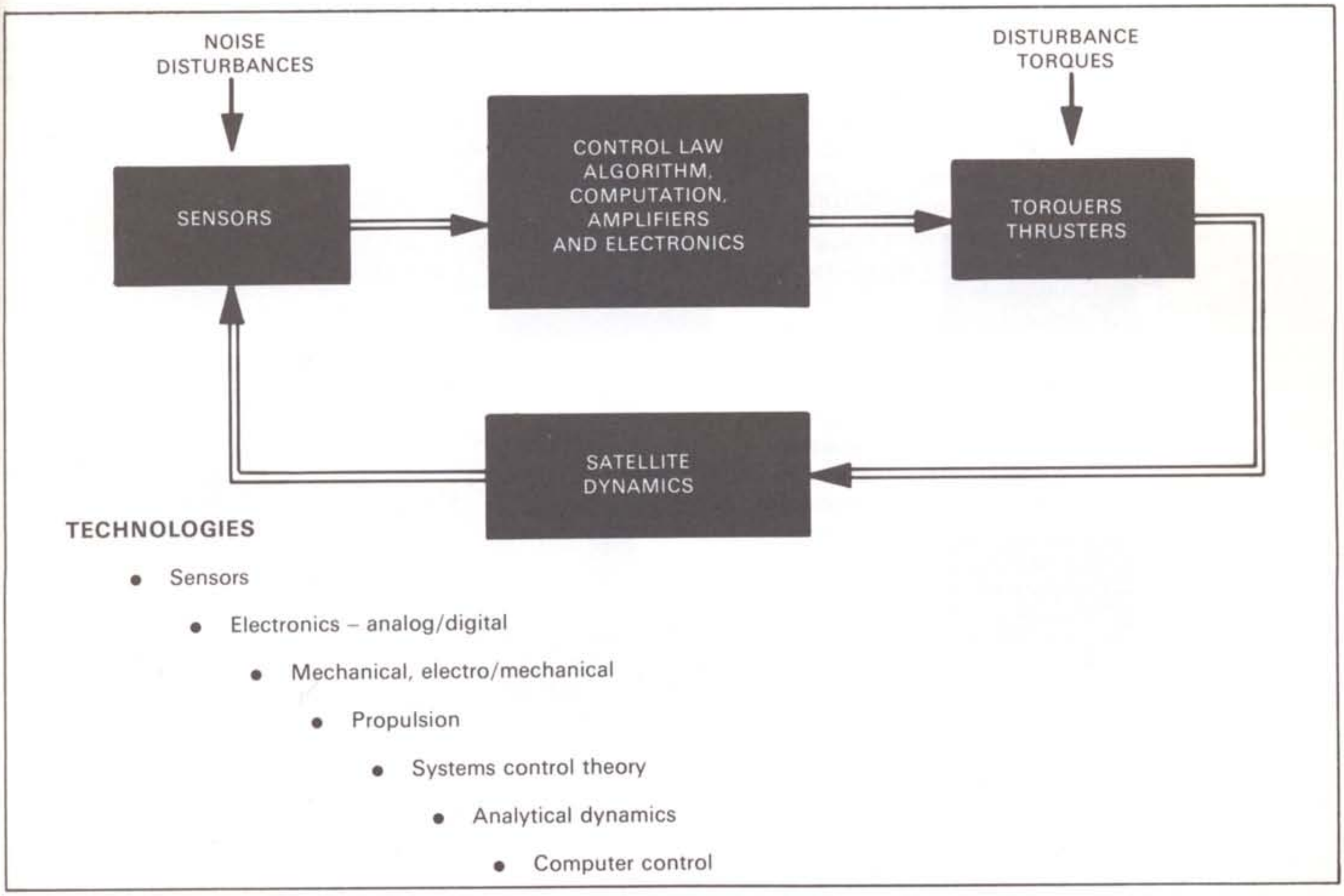


Figure 1 – Block diagram of a typical attitude and orbit control subsystem.

The control system in a satellite cannot be designed without taking into account its interfaces with the remainder of the payload; their impact and other functional requirements can greatly affect the choice and design of the control system. Important constraints can arise as a result of:

- the sensor type and field-of-view, thruster locations and overall spacecraft configuration
- the power available on board the satellite and presence of an oriented solar array
- mass and volume restrictions
- redundancy, reliability and lifetime
- coupling of control loops due to kinematic and inertial effects.

Figure 2 illustrates the type of task involved in achieving a well-balanced design for the overall system. The most important single factor in selecting a suitable system is usually the availability of appropriate hardware in the form of sensors and actuators.

AOCS units currently available or in an advanced state of development in Europe to meet the needs of future ESA satellites demanding high accuracy, long life and low cost

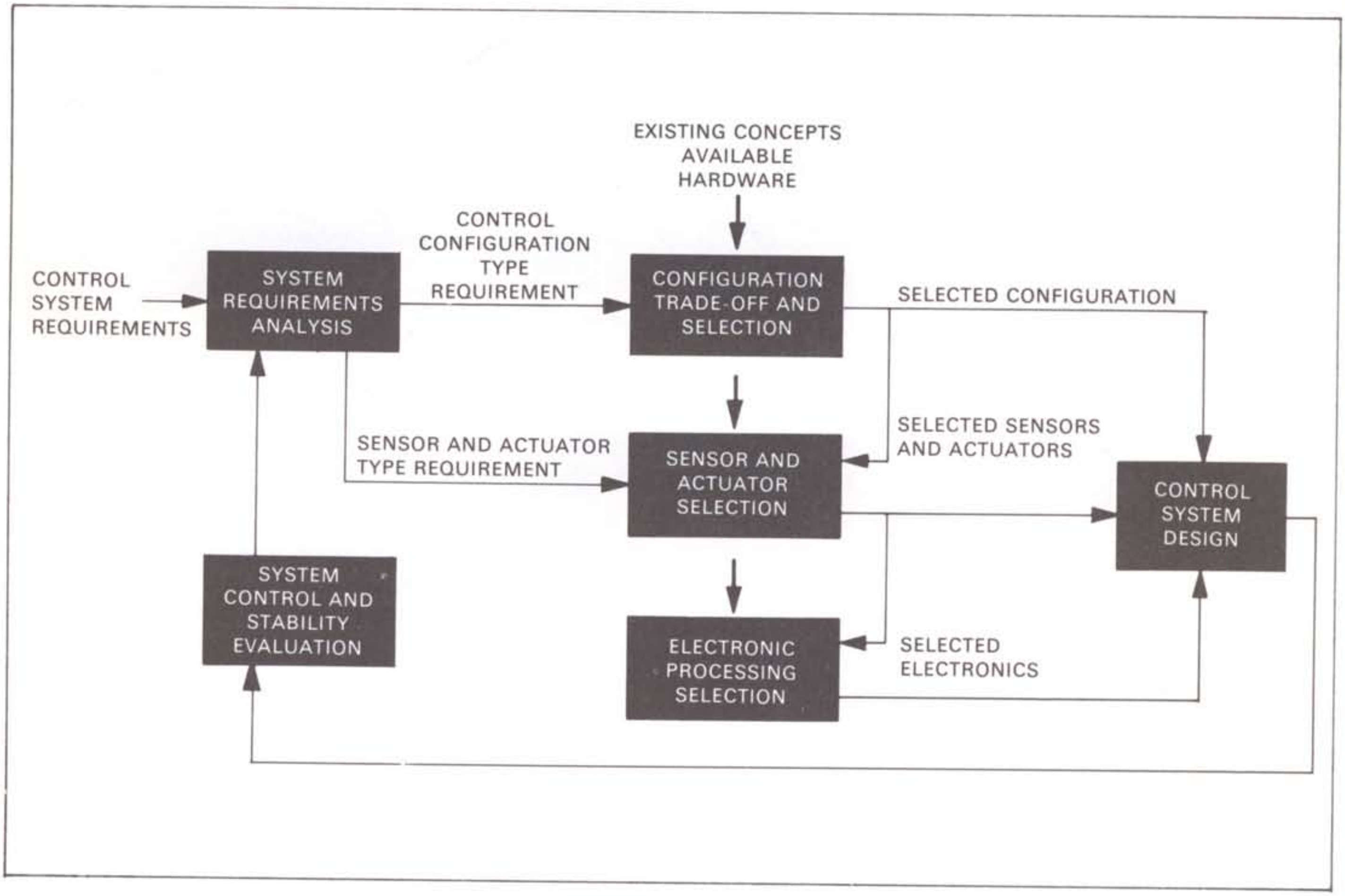


Figure 2 – Attitude and orbit control subsystem design methodology.

include:

- Sun and Earth sensors (infrared and albedo detectors) for spinning and three-axis-stabilised satellites
- star trackers and scanners for high-accuracy pointing
- cold-gas, hydrazine monopropellant, catalytic and thermal decomposition, and bipropellant propulsion systems
- electric propulsion systems
- flywheels (fixed, single and double gimballed), reaction wheels (both types of wheel with ball and magnetic bearings)
- apogee boost motors (solid and liquid propellants)
- nutation dampers
- programmable control electronics based on LSI techniques.

TYPES OF SYSTEM

There are several methods of controlling the attitude of a satellite. Some make use of the natural torques that disturb a satellite in orbit to generate useful control torques, while other more active methods rely on special units that form part of the satellite's payload.

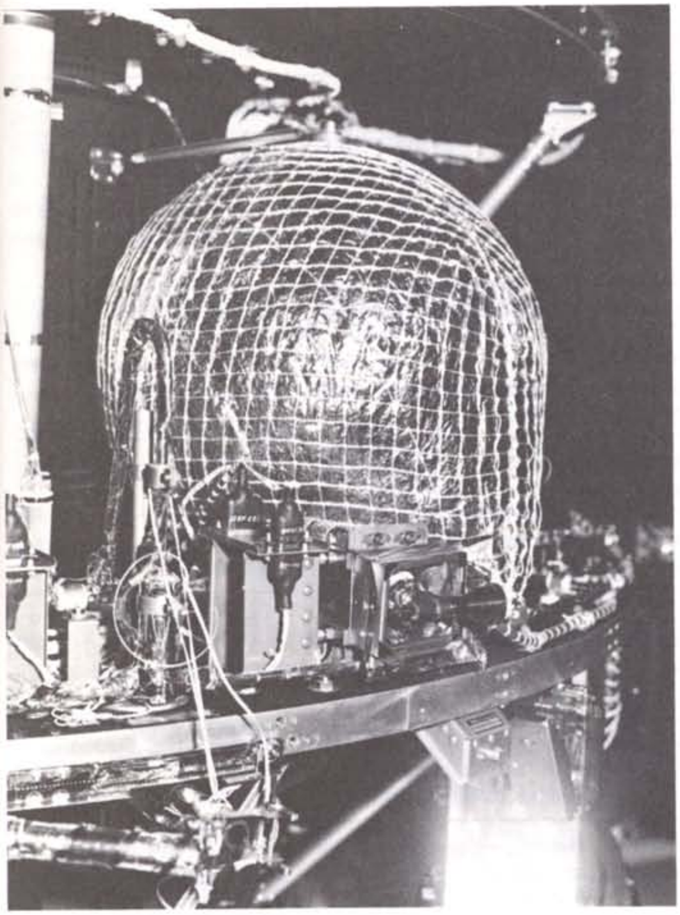


Figure 3 – Hydrazine tank and one of the nozzled thruster units used for attitude and orbit control of the spin-stabilised Geos satellite.

The first three of the methods listed below are suitable only for purely passive attitude control, the accuracy achievable is not high, and they have not been used so far on an Agency spacecraft.

- *Gravity gradient*. The torque resulting from interaction of the Earth's gravity gradient with the distributed mass of the satellite can be used to orientate it passively to the local vertical.
- *Solar stabilisation*. Solar radiation pressure can be applied to stabilise a satellite that has the Sun as its primary reference. The torques produced can also be used for vernier or trim control of active control systems.
- *Aerodynamic stabilisation*. The significant aerodynamic forces acting on low-orbit satellites can be used for attitude control.
- *Magnetic stabilisation*. The interaction of one or more magnets mounted in a satellite with the Earth's magnetic field can be used to produce useful control torques. In a passive scheme, permanent magnets are used to line up the satellite with the local magnetic field vector, just as the needle of a compass seeks magnetic north. In an active application, a switchable electromagnet is used to produce an average torque vector in a prescribed direction, allowing greater attitude-control possibilities.
- *Spin stabilisation*. When a significant amount of spin is imparted to a satellite, it effectively becomes a gyroscope characterised by its angular momentum. The momentum provides a 'stiffening' that attenuates the effects of disturbing torques on the satellite. The latter then has a tendency to stay in a fixed orientation in inertial space, but torques transverse to the spin axis still precess the angular momentum vector. Disturbing torques in the spin-axis direction modify the spin rate. In addition to the attitude drift, the satellite has a virtually undamped nutation wobble motion. To overcome and control the wanderings of the spin axis, the motion must be detected and corrective torques applied to keep it within specified error limits.
- *Momentum bias/Dual spin*. Satellites using this attitude-control method consist of two interconnected rotating bodies. The more slowly rotating of the two (usually Earth-oriented) is referred to as the despun body, the other as the rotating body. This method is basically similar to spin stabilisation in that it relies on the inertial stiffness of a large angular momentum vector.
- *Momentum exchange*. This method of stabilisation makes use of a wheel in the satellite which can be accelerated or decelerated to produce reaction torques and an exchange of momentum between the wheel and the main body of the satellite. The wheels can also be used for attitude manoeuvres. All momentum exchange devices are capable of storing only a finite amount of momentum; when this condition is reached they are saturated. The control

TABLE 2
ESA Satellite Control Systems

Satellite	Configuration type	Sensors	Actuators	Others
ESRO-IA, IB	Magnetically stabilised along Earth field lines	Solar-aspect sensor and magnetometer	Permanent magnets	Hysteresis damping rods
ESRO-II	Spin stabilised with switchable magnet	Solar-aspect sensor	Switchable electromagnets	Ball-in-tube nutation damper
HEOS-1, 2	Spin stabilised with gas jets	Solar-aspect sensor fan-beam albedo sensor	Compressed cold-gas thrusters	Ball-in-tube nutation damper
TD-1	Three-axis stabilised momentum exchange	Sun sensors, conical scan horizon sensor, gyroscopes	Three reaction wheels, cold-gas thrusters	
ESRO-IV	Spin stabilised with switchable magnet	Pencil-beam Earth-IR sensor, solar-aspect sensor	Switchable electromagnet, quarter-orbit principle	Ball-in-tube nutation damper
Cos-B	Spin stabilised with gas jets	Fan-beam Earth-albedo sensor, solar-aspect sensor	Compressed cold-gas thrusters	Liquid-in-tube nutation damper
Geos	Spin stabilised both in transfer and synchronous orbits	Pencil-beam Earth-IR sensors, solar-aspect sensor, accelerometers	Hydrazine propulsion for attitude and orbit control, apogee-boost-motor solid	Liquid-in-tube damper
OTS-Marots	Spin stabilised in transfer orbit, momentum bias in synchronous orbit	Pencil-beam Earth-IR solar-aspect sensor, two-axis Earth sensors, gyroscopes	Momentum flywheels. Hydrazine propulsion for orbit and attitude control, apogee-boost-motor solid	Liquid-in-tube damper for transfer orbit, rotating solar array
Meteosat	Spin stabilised in transfer and synchronous orbits	Pencil-beam Earth-IR sensor, solar-aspect sensor, accelerometers	Hydrazine propulsion for attitude and orbit control, apogee-boost-motor solid	Liquid-in-tube damper, plus active nutation control in transfer orbit
ISEE-B	Spin stabilised with gas jets	Pencil-beam IR sensors, solar-aspect sensors	Compressed cold-gas thrusters	Liquid-in-tube nutation dampers
Exosat	Three-axis stabilised mass expulsion	Star sensor, three-axis gyro package, Sun sensors	Hydrazine propulsion, catalytic thrusters for orbit control, gas generator for attitude	Oriented solar array

system must provide an independent source of control torque so that the saturated momentum can be dumped (desaturated).

– *Mass expulsion*. In this case thrusters or reaction jets are used to produce the control forces on the satellite. Two opposed thrusters, for example, mounted on opposite sides of the satellite produce a control torque but no nett force. If the thruster line-of-action passes through the satellite's centre of mass, a linear velocity is imparted to the satellite which can be used for orbital control.

ESA SATELLITES

The wide variety of control and stabilisation systems used on ESA satellites is clearly apparent in Table 2. Most have utilised spin stabilisation for attitude control, largely because it affords a simplicity of approach that is not possible with an active system. All spinning satellites require attitude sensors to monitor motion of the spin axis, an electronics unit containing signal-processing logic and amplifiers to drive the torquers, and dampers to damp the nutation wobble.

Geos and Meteosat are geosynchronous satellites and orbit (i.e. velocity) control is needed as well as attitude control. Hydrazine propulsion is used to perform both functions because a cold gas system would be very much heavier, hydrazine having a much higher specific impulse (a sort of 'miles per gallon' measure of performance).

The TD-1 satellite carried the most complex attitude control system flown to date by ESA and was actively controlled in all three axes. Functionally, the control system comprised three control loops, two for Sun-pointing and one for Earth-pointing. The Sun-pointing loops used Sun sensors as attitude detectors, and the Earth-pointing loop used a rate-integrating gyroscope, the drift being corrected once per orbit by an infrared sensor. Cold gas jets and reaction wheels were used for torquing, the gas jets also 'unloading' the saturated momentum wheel.

OTS and Marots are three-axis-stabilised telecommunications satellites to be placed in geosynchronous orbit from an initial elliptical transfer orbit with an apogee approximately at synchronous altitude (6.7 earth radii). At this furthest point from the Earth, an apogee boost motor will be fired to give the satellites the necessary velocity to achieve geosynchronous orbit. These satellites therefore have two attitude-control modes, a spinning transfer-orbit mode and a three-axis-stabilised operational or geostationary mode.

The operational mode relies on a high-speed flywheel, an Earth sensor to detect and measure attitude errors in two axes, and a hydrazine propulsion system. The inertial stiffness of the flywheel provides short-term stability, and attitude errors are corrected by firing the hydrazine thrusters and by introducing small changes in flywheel speed. Strong torques imposed on the satellite during thrusting to periodically adjust its orbital velocity

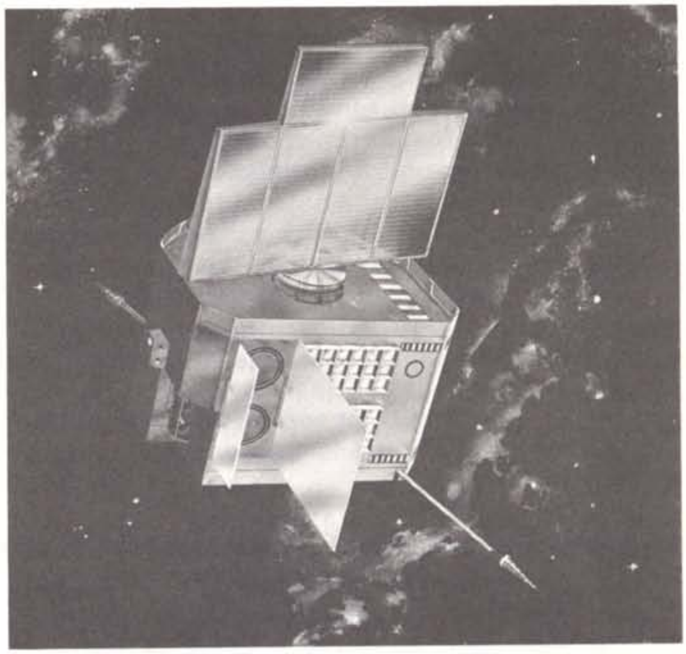


Figure 4 – Artist's impression of Exosat, the Agency's three-axis-stabilised scientific satellite to be launched in 1980.

(station-keeping manoeuvres) must be controlled actively by special control loops.

Exosat will be a three-axis-stabilised scientific satellite with an extensive attitude manoeuvring and orbital control capability. The attitude-measurement system for this astronomical observatory-type satellite will comprise a star sensor, Sun sensors and a three-axis gyroscope package. The control actuator system envisaged is a monopropellant hydrazine propulsion system. Catalytic decomposition thrusters will be used for orbit control and the gases generated by catalytically decomposed hydrazine, stored under pressure in a special chamber, are to be used for attitude control.

The Agency has already accumulated a great deal of experience in satellite control and stabilisation in developing the systems for the above missions and technological research studies and hardware development are being continued with a view to meeting the needs of future generations of European spacecraft, both for scientific and applications roles. □

Electric Propulsion – A Controversial Must for Long-Lived Applications Satellites

H.A. Pfeffer, Attitude and Orbit Control Division, ESTEC

Many of today's commercial and scientific satellites are designed to remain truly geostationary above the Earth for lifetimes of several years and sophisticated on-board propulsion systems are needed to counteract the natural forces that tend to perturb such an orbit. With a view to overcoming the mass restrictions that dog the chemical systems currently used for station keeping, the Agency has been investigating the viability of electrical propulsion as a possible alternative. This article discusses the rationale of station keeping and attempts to highlight some of the technology and system considerations inherent in employing electric propulsion.

When placed into an orbit with a semi-major axis of 42 164 km, a satellite's period of rotation is equal to that of the Earth. If moreover, the orbit is circular, and its plane coincides with the globe's equatorial plane, the satellite appears stationary when seen from the Earth. The advantages of this 'geostationary' orbit stem from the fact that the satellite is permanently in view of a large portion of the Earth's surface (42.5%), making it ideal for a multitude of scientific and commercial missions, direct television broadcasting and permanent meteorological observation being but two typical examples. However, the geostationary orbit is a costly one to achieve, the launcher having to provide a slightly greater velocity increment than would be needed to accelerate the same payload to Earth escape velocity. Once acquired, the geostationary orbit remains extremely sensitive to initial injection errors and perturbing effects of any kind, because differentials with the Earth's rotation are directly apparent and accumulate rapidly. A small velocity error (nominal satellite velocity ± 3075 m/s) causes the satellite to drift away rapidly from its intended longitudinal position, while an inclinational error Δi (typical values 1/2 – 1°) leads to daily north-south excursions of total amplitude $2\Delta i$. Any error in eccentricity leads to a diurnal oscillation in satellite longitude.

Nature is also at work perturbing the geostationary orbit. The ellipticity of the Earth's equator causes a shift in satellite longitude which must be compensated at regular intervals, and the Sun and Moon exert gravity-gradient torques on the orbit, because the orbital planes of the Earth (the ecliptic), the Moon and the satellite are not coplanar. The net effect of these torques is to precess the angular momentum vector of the orbit, causing the satellite's inclination to drift with time. The maximum drift rate is about 0.9°/year, but the velocity increment required to compensate it, or in other words to provide North-South Station Keeping (NSSK), is considerable (Fig. 1).

The velocity increments required for maintaining a satellite truly geostationary, then, are as follows:

	Satellite lifetime 5 years	10 years
For compensation of launcher errors and initial station acquisition	100 m/s	100 m/s
For longitudinal (east-west) station keeping (at 2.5 m/s yr)	12.5 m/s	25 m/s
For inclination (north-south) station keeping (at 50 m/s yr)	250 m/s	500 m/s
Total velocity increment required	362 m/s	625 m/s

It is quite apparent from the above rough outline that, with lifetimes of 10 years for applications satellites rapidly becoming the norm, NSSK will represent the major in-orbit propulsion requirement. But the 500 m/s demanded implies that an 800 kg satellite will have to carry almost 200 kg of hydrazine if existing chemical propellant technology is to be relied upon for stationing – equivalent to the mass of the spacecraft's whole payload! Even with more advanced chemical propulsion systems of higher performance, the amount of propellant needed remains of the same order, the 200 kg perhaps becoming 160 kg. Because of the large propellant masses involved (with the mass of the tanks adding another 15%), system designers try to do without NSSK whenever possible, for example by having the ground-station track the satellite con-

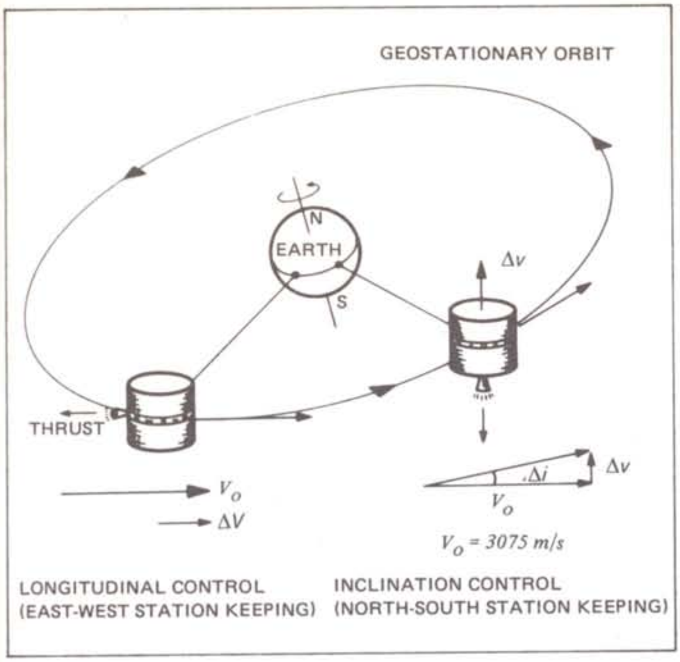


Figure 1 – Principles of East-West and North-South Station Keeping (NSSK).

tinuously, or by 'nodding' the satellite antennas, or by steering the whole satellite body.

For some missions however, such as that of direct TV broadcasting to small domestic ground terminals, daily north-south satellite excursions must not exceed 1/2° if the signal received by the low-cost fixed antenna is to remain of adequate strength.

In such a case, there is no way around the need for NSSK, and the amount of chemical propellant required becomes a serious handicap from two points of view. Firstly, for the return on investment in the complex satellite and its launcher (some 60-70 M$) to be commercially interesting the satellite must be capable of remaining on station for several years, in which case the chemical propellant will occupy a very large fraction of the spacecraft's total mass budget, as we have seen. This mass penalty detracts directly from the useful payload and thence degrades the potential economic return. As an example, each 50 kg that can be made available on a communications satellite represents a further possible channel with an additional revenue potential of 3 M$ per year. Secondly, the useful satellite lifetime is constrained by the amount of propellant that it can carry for NSSK, even when all other systems are still operating faultlessly. This applies equally to any back-up satellite, which must also maintain station during stand-by. This one could even deplete all its NSSK propellant before it is needed operationally.

Clearly, under these conditions the apparently trivial problem of NSSK has a serious financial impact. Within the context of European launchers with finite capabilities, one obvious solution would be to employ a propulsion system for NSSK which requires at least an order of magnitude less propellant than the chemical systems, namely electric propulsion (EP). With this system, the power to generate thrust by expelling matter is supplied by a dedicated electrical source, rather than by the inherent thermodynamic energy of the chemical propellant. Of the many possible EP systems, the electrostatic ion engine has emerged as holding the most promise for providing high propulsive performance with high efficiency. It relies for its operation on the fact that a particle carrying an electric charge (usually a caesium or mercury ion) is accelerated by an electric field. In practice, the liquid mercury, which is stored in a tank, is vaporised into a chamber within which electrons are swirled by the combined effects of static magnetic and electric fields. These fast electrons (40 eV) collide with the mercury-vapour atoms and knock out an electron to produce positive mercury ions. These ions then diffuse inside the chamber until they reach a pair of metallic screens which are held at different potentials. Here, the ions are vigorously accelerated and then ejected into space as a high-velocity beam (20 000–100 000 m/s). To prevent the satellite itself from charging up negatively and thereby eventually not being able to emit any further ions, a second source injects electrons into the emitted positive ion beam to neutralise it.

All this appears quite elegant, but the practical realisation is rather complex, the technological problems numerous and the interactions with the spacecraft significantly more involved than for a chemical propulsion system. Without detailing all of the considerations, an idea of interlinked system implications can be obtained by considering the power question. The power to accelerate the ions must be provided by an external power supply. The kinetic power present in the ion beam is equal to one half the product of the thrust and the ion velocity. Since the ion (or exhaust) velocity is a direct measure of propulsive performance (in terms of amount of propellant ejected to deliver a prescribed thrust impulse), if the amount of mercury carried is to be one twentieth of the equivalent amount of chemical propellant, the exhaust velocity should be twenty times larger to provide the same propulsive performance. If, in addition, a jet power of say 200 W is not to be exceeded, the thrust that is then deliverable is only 0.01 N, which is 1000 times less than that of the

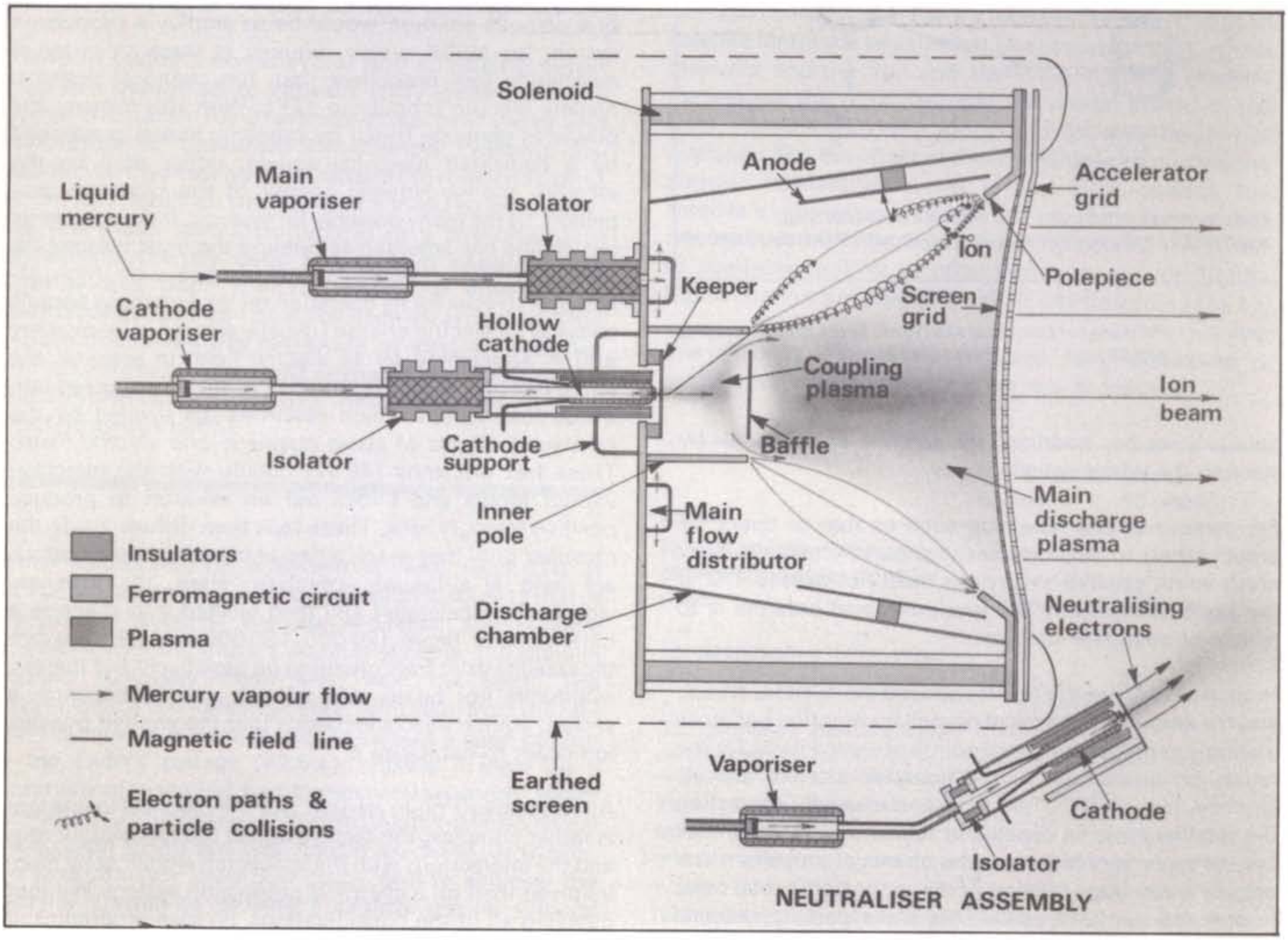


Figure 2 – The operating principle of a classical electron-bombardment ion engine (Kaufman type): the British T4 ion thruster.

chemical engine. Consequently the ion engine must operate for thousands of hours in applications where the chemical engine would only accumulate hours of operation in order to provide NSSK for say 10 years. These very long ion- engine on-times, which amount to a few hours each day for NSSK, bring operational and system constraints in terms of power sharing with the satellite payload, interactions with the satellite's fine attitude control system, the possibility of electrical noise interactions with the payload, etc.

As a secondary consideration, these operating times of several thousand hours allow even small problems or failure probabilities to develop into serious life-limiting factors (grid erosion, sputtering, contamination, short circuits, heater failures, cathode degradation, etc.). Before EP can be accepted for operational purposes, therefore, lengthy life testing of both critical components and complete systems will be required.

The typical ion engine requires high voltages (1 to 2 kV)

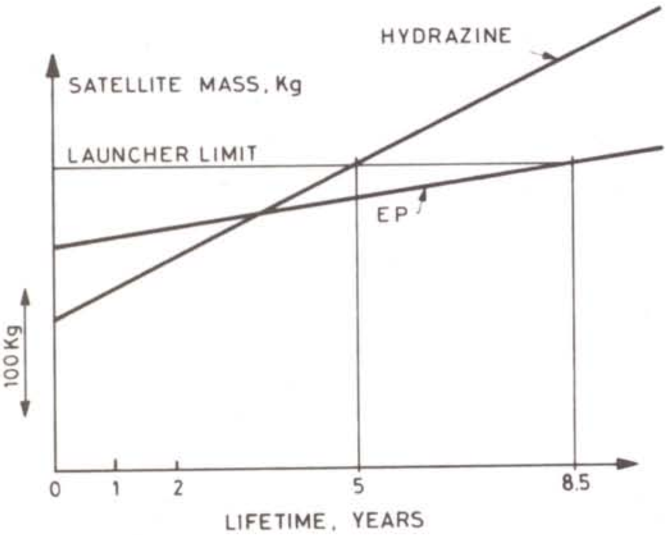


Figure 3 – Satellite mass as a function of lifetime with hydrazine and with electric propulsion for NSSK.

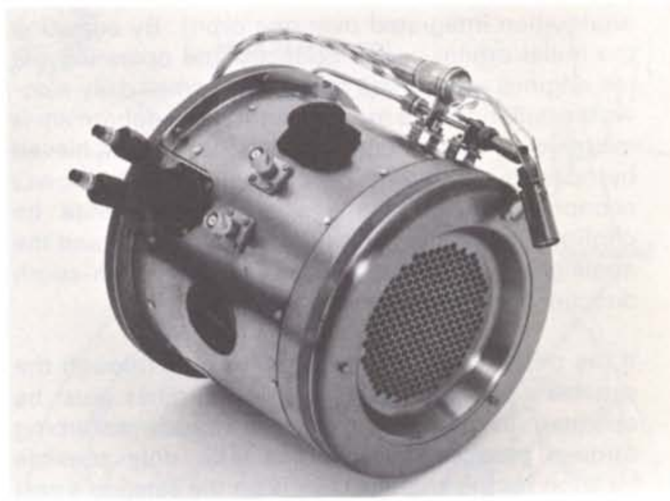


Figure 4 – RIT 10 radio-frequency ionisation thruster developed in Germany.

to operate its acceleration grids, as well as many (up to 12) separate power supplies to serve its heaters, biases, etc. The power-conditioning electronics unit needed to cater for these different functions is complex, voluminous and significantly heavy (say 5 kg), and one such unit is required for each thruster. Thus, although the propellant needed for 10 years of NSSK may be less than one tenth that of the chemical alternative, some of this considerable saving is eroded by the higher dry mass of the EP system. Nevertheless, the overall mass saving still remains very significant (Fig. 3).

A further consideration is the mounting of the engines on the spacecraft. By contrast to chemical engines, which are small and can be accommodated easily and strategically on the satellite body, the classical ion engine is not only quite bulky – a typical 0.01 N thrust engine is 20 cm in diameter and 15 cm long – which makes it cumbersome to implant, but it can also be very polluting compared with chemical engines. The primary focussed fast ion beam must not impinge on any satellite surface because it would cause significant erosion damage or sputtering. About 10% of the propellant stream leaves the thruster grids without having been ionised (neutral vapour losses) and is dissipated in all directions. Some of these atoms can be deposited on the cooler surfaces of the satellite by condensation and thereby affect surface properties, or they can collide with a fast beam ion when still in the neighbourhood of the engine exhaust plane. The result of this collision is a charge exchange giving a slow ion and a fast neutral. The slow ion is attracted by the accelerating grid, causing the grid material to be sputtered away on impact. This material in turn will be emitted and may have adverse consequences if allowed to accumulate on, for example, the satellite's solar array. All this can make ion thruster installation a problem, particularly for NSSK on today's satellites which carry large north-south directed solar panels. The thruster axes must then be angled by at least 35° to the ideal north-south direction to prevent beam impingement. Besides the resulting loss of useful thrust, this angling also has two further consequences:

- If the thrust vector is desired to pass through the satellite's centre of mass, it must lie in the Earth-satellite-north plane, and the perturbing thrust component is then directed radially inwards (i.e. along the satellite-Earth line). This increases the apparent gravitational pull of the Earth, so that the satellite's orbital period becomes shorter, but its altitude remains unaffected (this may seem surprising at first sight, but this radial inward force would produce no work when integrated over one orbit). By adjusting the initial orbital period correctly and operating the ion engines at alternate nodes, only small daily east-west oscillations are induced and true synchronism is maintained. This scheme allows NSSK to be achieved by operating only one EP engine at a time (power economy), but it requires that the satellite be configured to accept engines on its rear face, and the angling of the thrust vector to the north-south direction could be as much as 45–55°.

– If the thrust vector is not made to pass through the satellite's centre of mass, the ion engines must be operated in pairs so that the attitude-disturbing torques produced cancel out. The only sensible location for the engines then is on the satellite's east and west faces, the thrust vector of each engine being in the plane tangential to the orbital path. The east-west thrust components of the engines cancel and the result is a pure north-south force. This configuration allows the inclination of the thrust vector to the north-south direction to be reduced to about 35°, but the drawback is that two engines must be operated simultaneously, doubling the power consumption and reducing engine redundancy, since failure of one engine then implies loss of the pair.

It would appear from all these considerations that what electric propulsion gives with one hand in terms of the large mass saving and the tremendous extension in satellite lifetime, it takes away with the other, through its complexity. But the net result is still overwhelmingly in favour of EP for NSSK because:

(a) the inherent problems of EP have already been largely solved, and
(b) the mass saving offered by EP for long-term NSSK can be reflected in either increased communications capability (more revenue), increased redundancy in the satellite payload (longer design life), or considerable extension of lifetime on station (spare satellite of indefinite lifetime, longer operating life).

The possible financial benefits in terms of additional income range from say 3 M$/year from an extra channel, up to 70 M$ every few years because of the need to launch fewer satellites. These figures must be reduced by the estimated cost of qualifying EP technology for space application (say 5 M$, including a flight demonstration) and of using it operationally in place of an equivalent chemical system (say 1 M$ extra per satellite), but the economics are still very heavily weighted in favour of using electric propulsion for NSSK.

Several electric propulsion technologies for NSSK have already been or are currently being developed in Europe, including:

- a caesium contact ionisation system (France)
- a caesium and mercury electron bombardment ionisation system (France and UK)
- a mercury system with radio-frequency ionisation (Germany)
- a caesium field-emission system (ESA)

While the first four systems are being developed under national funding, the last is financed by ESA as part of its technological research programme. The national systems nearest to a flight application are the German radio-frequency and British electron-bombardment systems, for which most technological problems have been solved, development is nearing completion, and significant demonstrations of adequate lifetimes are being accumulated. These technologies are seen as representing the most probable first generation of electric propulsion systems, while the field emission principle with its profound departure from the more classical national lines represents a very attractive second generation because of its inherent simplicity. Indeed, while the classical technologies have to invest quite a significant amount of energy in the generation of the ions themselves, the field emission principle allows the ions to be drawn directly from liquid metal covering a multitude of very sharp tips by applying a sufficiently strong electric field. Serious consideration is presently being given to the possibility of flight testing the British or German technologies on a heavy satellite to be launched by the Agency's Ariane launcher, and the operational introduction of electric propulsion on European satellites may soon become a reality after more than 10 years of intensive research. □

Heat Pipes for Space Use

A. Accensi & C.J. Savage, Structures and Thermal Control Division, ESTEC

The evolution from relatively simple spin-stabilised satellites to the large sophisticated spacecraft of today, which are generally three-axis-stabilised, have high pointing and alignment requirements, and often generate considerable quantities of heat in relatively compact subsystems (power-conditioning, communications subsystems, etc.), has provided the thermal engineer with a number of taxing problems. The need to develop heat-pipe technology to solve these problems was foreseen in the late 1960s and the work is now well advanced. Although no European satellites have yet carried heat pipes, several US missions have used them successfully (ATS-6), and the US/Canadian CTS satellite employs a 200 W travelling wave tube cooled by an American heat pipe. Heat pipes have now been developed in Europe, under both Agency and national funding, to the point where they can be seriously considered for satellite use. Without these devices many of the missions presently envisaged will be confronted by extremely complex, and in some cases insoluble, thermal problems.

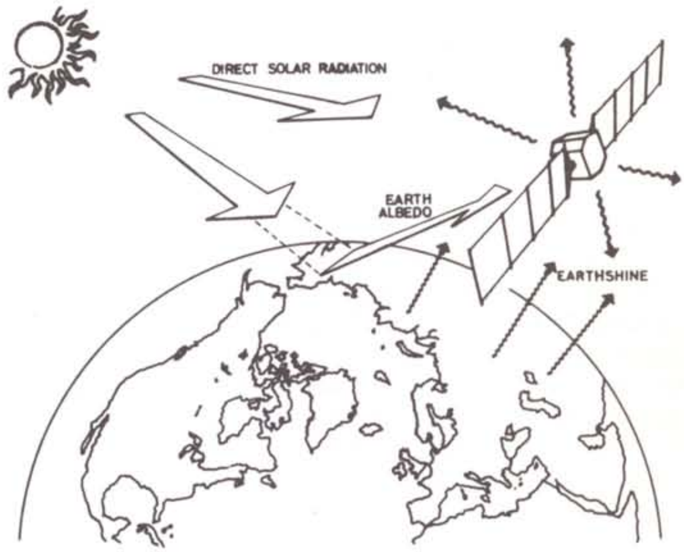


Figure 1 – Satellite external heat balance.

Satellite thermal design is concerned essentially with balancing the heat absorbed from the Sun – either directly or indirectly after reflection from the Earth – and from the Earth ('earthshine'), together with the satellite's internal electrical dissipation, against that lost by radiation to space, whilst maintaining acceptable temperature limits for the satellite's equipment (Fig. 1). Although this overall heat balance can only be achieved through the medium of radiation, it can be a very effective process because of the large differences in temperature between the heat sources and sinks involved. The Sun radiates at about 6000 K to a satellite operating at perhaps 300 K, which in turn radiates to space at about 3 K. Within the spacecraft, heat is transferred by a combination of conduction through the structure and radiation, and both of these processes are limited by the fact that most items of satellite equipment must operate at very similar temperatures. Conduction paths within satellites are generally poor, due to the lightweight structures employed, and once equipment surface finishes and geometrical considerations have been optimised, little can be done to further increase radiative heat transfer. Problems associated with heat transfer within satellites, and within specialised structures such as radiators, have increased with satellite size, complexity and power consumption, and we have now reached the point where new techniques must be employed if the feasibility of future missions is not to be jeopardised.

The solution lies in the use of heat pipes, which are basically devices of very high effective thermal conductance, and which can be used to 'isothermalise' radiators, telescope structures, equipment mounting platforms, etc., or to transport heat from individual boxes to a radiator. In fact, heat pipes can find application wherever a high thermal conductivity is required. No power is required for their operation, and there are no mechanical moving parts: they are essentially robust, lightweight, tubular structures, generally bendable, and inherently highly reliable.

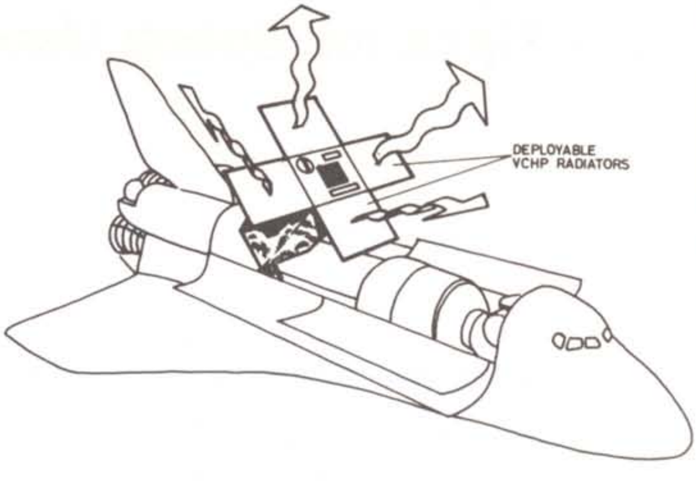


Figure 2 – 'Thermal canister' installed on Spacelab.

THE NEED FOR HEAT PIPES

The requirements of modern spacecraft place severe constraints on the thermal control subsystem, and future spacecraft will, if present trends continue, have still more complex thermal requirements. On communications spacecraft, for example, considerable amounts of heat are dissipated in relatively few discrete units. If conventional solid radiators are used, large temperature gradients occur in the radiator which may result in unacceptably high component temperatures. In addition, a significant mass penalty is incurred due to the thickness of metal required for heat-conduction purposes and, because of the nonisothermal radiating surface, most efficient use is not made of available radiator area. These problems can be overcome by incorporating heat pipes in a simple honeycomb radiator to provide efficient heat transfer across the radiating surface. Heat pipes also allow the units to be mounted in positions remote from the radiator, a situation which might be highly desirable in order to minimise radio-frequency losses, and which would allow a single radiator to serve a number of subsystems.

The thermal problems experienced with scientific satellites are generally of a different nature. Modern scientific satellites, and astronomy satellites in particular, require very accurate alignment. To achieve this, temperatures and temperature gradients in telescopes, mirrors, etc. must be carefully controlled. Changes of less than 1°C across telescopes constructed from aluminium are sufficient to produce distortions that are incompatible with alignment requirements. In addition to the constraints on gradients, the temperature itself must also be accurately controlled, to avoid focussing problems caused by thermal expansion of the telescope tube assembly. The temperature gradients can be eliminated by using heat pipes, and the temperature control requirement can be met using Variable Conductance Heat Pipes (VCHPs) or, since the power requirements are low, by using electrical heaters.

An additional problem, common to many earth-survey and some scientific missions, lies in the provision of 80–150 K temperatures for infrared detectors and telescope structures. Such temperatures can be achieved passively by using suitably designed radiators but these become relatively ineffective at low temperatures and, although heat loads are generally low, it is important to minimise all temperature gradients, both in the radiator and between radiator and heat source. Such radiators are also extremely sensitive to external heat loads. A third type of heat pipe, known as a thermal diode, can be used to provide protection during periods when the radiator temperature rises due to heat input from the Sun, Earth, Moon, etc. As its name suggests, a thermal diode conducts heat only in one direction and would be inserted between the radiator and heat source to prevent heat flowing back from a hot radiator. Continuous low temperatures at the heat source could be provided either by a suitable phase change material thermal capacitor, or by using two similar radiators located such that they are not both subjected to external heating simultaneously.

The arrival of Spacelab will present new kinds of thermal problems. Many of the requirements identified above will still be relevant, but since its payloads are expected to be bigger and generally more power consuming the heat pipes will have to have a somewhat higher performance. The thermal environment on the Pallet will be severe, and payloads mounted there will almost certainly need to make extensive use of heat-pipe radiator and 'feeder' systems. For equipment mounted on gimbal systems, direct thermal connection to the Pallet will not be possible, and a 'thermal canister' must be used. The experiments will be mounted in a temperature-controlled container attached to the gimbal system at one end and with experiment viewing apertures at the other. Uniform temperatures will be provided by constant-conductance heat pipes within the canister, and the temperature level will be controlled by VCHP radiators mounted near the canister's open end (Fig. 2). Heat-pipe thermal-conditioning systems may also be required in Spacelab's pressurised module for experiments with temperature stability requirements that exceed those guaranteed by the laboratory's own environmental control system.

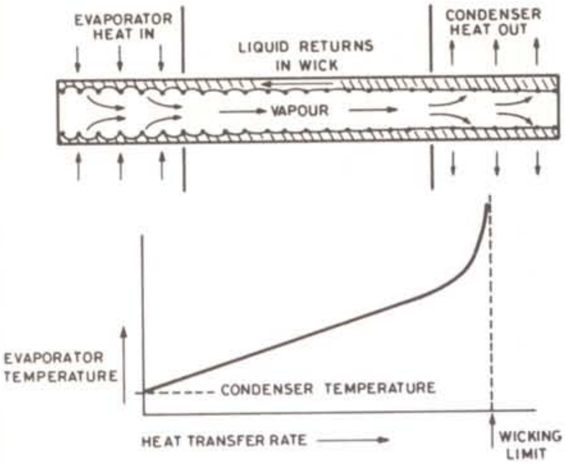


Figure 3 – Basic heat-pipe operation.

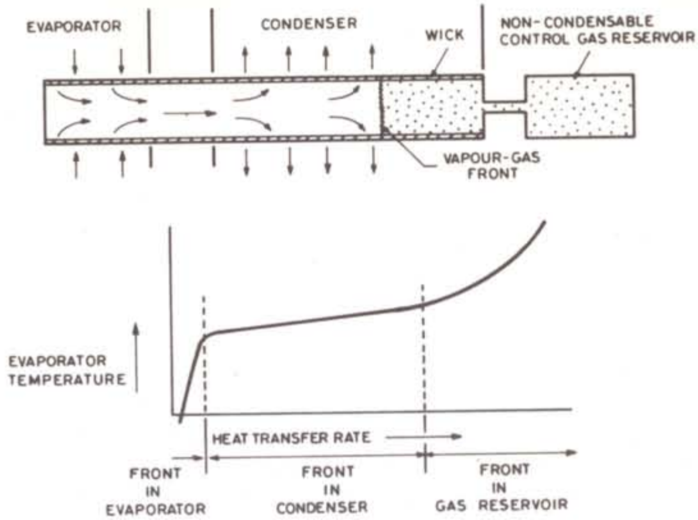


Figure 4 – Operation of Variable Conductance Heat Pipe.

HEAT PIPES – PRINCIPLE OF OPERATION

In its simplest form, a heat pipe consists of a closed tube, the inside surfaces of which are covered by a porous wick structure saturated with a volatile liquid known as the working fluid. All other gases are excluded so that the heat pipe contains only the working fluid, in liquid form in the wick and as vapour at the saturation vapour pressure in the rest of the pipe. If the pipe is heated at one end, the increase in temperature causes evaporation and a local increase in vapour pressure. Vapour then streams down the pipe and condenses wherever the temperature is lower than at the heat input, or evaporator, end. Heat is absorbed as latent heat in the evaporation process and released during condensation. If provision is made to remove heat from the other end of the pipe, for example, the heat-transfer process becomes continuous, with vapour streaming from the hot to the cold end and liquid returning by capillary action in the wick structure (Fig. 3). It is the capacity of the capillary pump to return liquid to the evaporator section which normally limits the achievable heat transfer rate*. In practice, the pressure drop in the vapour is usually quite low when this limit is reached and the inside surface of the wick may therefore be regarded as always being at a uniform temperature. Consequently, the effective conductance of a heat pipe in normal operation is not a function of length, but depends only on the properties of the evaporation and condensation regions.

As an example of the extremely high effective conductance figures that are possible, a heat pipe operating at ESTEC transports 15 W a distance of 3 m with a temperature drop of less than 1°C and a mass of about 0.22 kg. A copper rod with the same overall dimensions would weigh over 1 kg and would require a temperature difference of about 3000°C between its ends to achieve the same heat flow rate!

Since the heat pipe relies on the presence of both the liquid and vapour phases, it can, of course, only be operated at temperatures between the freezing point of the working fluid and its critical temperature. The practical working range is rather narrower than this, however, since at the low pressures encountered near the freezing point the vapour mass flow rate is fundamentally limited (e.g. by 'sonic' vapour choking), and the high-temperature limit is usually dictated by structural considerations (strength of tube, welds, etc.). Typically, heat pipes are operated at temperatures consistent with an internal pressure in the range 0.5–50 atm.

VARIABLE CONDUCTANCE HEAT PIPES (VCHP)

As the name suggests, in a Variable Conductance Heat Pipe the effective thermal conductance can be varied, usually as a function of the temperature of the evaporator section. There are a large number of mechanisms available, but only the most common form of VCHP, which uses a noncondensing gas to block a portion of the condenser section (Fig. 4), will be briefly described here, as an example of the technique. The noncondensing gas is contained in a reservoir connected to the cold end of the heat pipe. If the pressure in the heat pipe is initially lower than that in the reservoir, gas will expand into the condenser section causing a partial blockage and resulting in an increase in temperature of the evaporator section. Due to the sweeping action of the vapour, a fairly sharp front develops between gas and vapour, and an

* There are a number of possible limits, the principal ones being the sonic, entrainment, wicking and boiling limits. The limit applicable in a given situation depends on the temperature, working fluid and geometry, but in general in the temperature range of interest in spacecraft the wicking limit is the dominant one.

equilibrium is eventually established with this front part way along the condenser section. If the temperature in the evaporator section now rises slightly, it causes a relatively large (exponential) increase in pressure, compressing the gas into the reservoir and uncovering additional condenser area. For large variations in input heat load, therefore, the temperature of the evaporator section will remain within quite narrow limits. The degree of temperature control achievable depends on the particular design, but an increase of 5°C for a factor five increase in heat input rate is readily attainable. Tighter temperature control can be achieved if an active system is employed. The temperature of the equipment being cooled is sensed and used to control a small heater on the gas reservoir. The resulting reservoir temperature changes drive the front along the condenser and hence control the heat-pipe evaporator temperature.

THERMAL DIODES

There are many mechanisms available whereby a heat pipe can be induced to conduct heat in one direction only. Perhaps the most popular system, and the lightest, uses an excess-liquid reservoir, which is not connected to the normal wicking system but is located in the evaporator region, in good thermal contact with the wall of the pipe. In normal operation, the excess-liquid reservoir dries out and the heat-pipe wick remains fully saturated. If the temperature gradient reverses, condensation occurs in the old evaporator zone and in particular in the excess-liquid reservoir. Since there is no link with the wick, this process results in a steady transfer of working fluid into the reservoir until the wick dries out and the heat pipe ceases to function.

HEAT-PIPE CLASSIFICATION

Heat pipes can be classified according to three criteria: function, working fluid, and wick type. The first two have already been mentioned, but the third requires a brief explanation. There are three basic wick types (Fig. 5), each with their own particular advantages and disadvantages; namely, homogeneous wicks, artery wicks, and axial grooves. The advantages and disadvantages of each are listed in Table 1, where it can be seen that the choice of

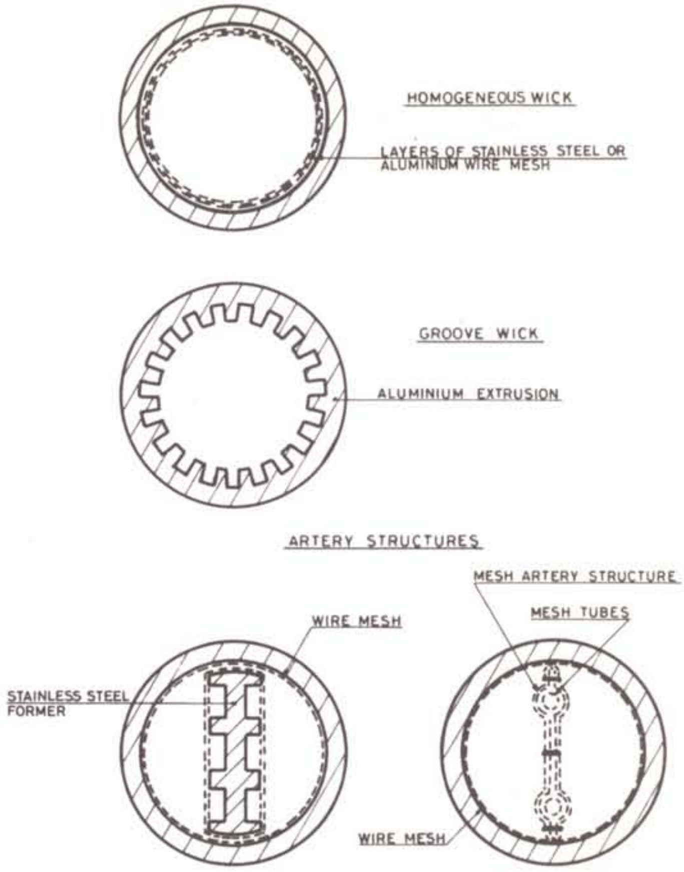


Figure 5 – Heat-pipe wick structures.

wick type depends on the given application, e.g. heat transport capacity required, whether constant conductance or VCHP, whether operation against a tilt will be required during ground testing, etc.

ESA HEAT-PIPE DEVELOPMENTS

CONSTANT-CONDUCTANCE HEAT PIPES

ESA's own heat-pipe development programme was started in 1970 with an exploratory contract with the Institut für Kernenergetik (IKE), Stuttgart, under which a number of wick structures, materials and working fluids were investigated. This work was followed in 1972 by a contract to develop a bendable heat pipe for telecommunications satellites. One of the conclusions from the first contract had been that a simple homogeneous wick could not provide the necessary heat transport (tens of watts) over the distances involved (of order 1 m) for the telecommunications application. The extruded-groove pipe, whilst extremely simple, proved heavier than an artery pipe for the same heat transport capacity and was very sensitive to tilt during ground testing. An artery design was therefore indicated for the telecommunications heat pipe, and since then ESA-sponsored heat-pipe activities have tended to follow this approach.

TABLE 1

Advantages and Disadvantages of Different Wick Types

Wick type	Advantages	Disadvantages
Homogeneous wick	Simple, cheap, reliable, heat pipe can be made in small diameter and so is easily bent. Can operate against significant tilt.	Low performance. Susceptible to boiling problems due to the thick wick employed.
Artery wicks	Highest potential performance. Can operate against significant tilt. If care is taken to avoid gas entrapment, they have the highest potential performance as VCHPs. Less sensitive to boiling problems than homogeneous wick.	Complex (expensive). Gas entrapment problems when used as a VCHP.
Axial grooves	Cheap, simple (pipes are usually made from aluminium extrusions), high performance, no gas-entrapment problems. Insensitive to boiling problems.	Very sensitive to tilt (satellite testing problems). Relatively poor performance as VCHPs due to the high axial conductivity of the aluminium extrusions.

In fact, at that time, homogeneous heat pipes had already been developed by Sabca for the Belgian government, and Dornier System was just starting to develop grooved heat pipes for the German government, so all three basic heat-pipe wick types were covered in Europe.

The early telecommunications heat pipes were made from aluminium with a stainless-steel wick structure and were subjected to the usual vibration and thermal qualification tests. Two pipes, one containing ammonia and one acetone, were flown in the International Heat Pipe Experiment* (IHPE) in October 1974. At the same time, life tests were started on this design, using ammonia as the working fluid. During development of the IHPE, it had become apparent that some noncondensible gas was forming in the pipes, and this was confirmed by the life tests, which further indicated that the reaction continued for many months. The problem was due to use of both aluminium and stainless steel in the same pipe and 21 months of life testing of 'new' pipes, constructed entirely from one metal, have so far shown no gas in the stainless-steel pipes and only slight gas formation in the aluminium ones.

* The IHPE, containing heat pipes from DFVLR, ESA, and NASA centres, was launched on a Black Brant sounding rocket from White Sands, New Mexico.

VCHPs AND DIODES

ESA's first VCHP contract was placed in 1973 when IKE developed a stainless steel 'constant-temperature heat pipe' using a high-performance modular artery structure. The device was gas-controlled and used active feedback control to maintain the evaporator temperature constant to within a fraction of a degree. Although capable of very high heat transport rates without the control gas, performance fell significantly when the gas was added, due to partial artery depriming caused by gas which had dissolved in the working fluid. This effect must clearly be anticipated and allowed for when designing VCHPs with complex arteries. At the other end of the heat-transport scale, a small VCHP was then developed to control the temperature of small components, such as microwave sources, by entirely passive means (Fig. 6). The first contract had involved heat dissipations of hundreds of watts, the second less than 8 W. During 1974 and 1975, in anticipation of a need for VCHP radiators for communications satellites like Marots, a gas-controlled version of one of the grooved heat pipes already developed by that time was manufactured and tested by Dornier System. This pipe is still operating satisfactorily after over two years of continuous running. More recently, in an attempt to improve on the control obtainable with grooved VCHPs, which are limited by the large axial conductance of the aluminium extrusions, work has

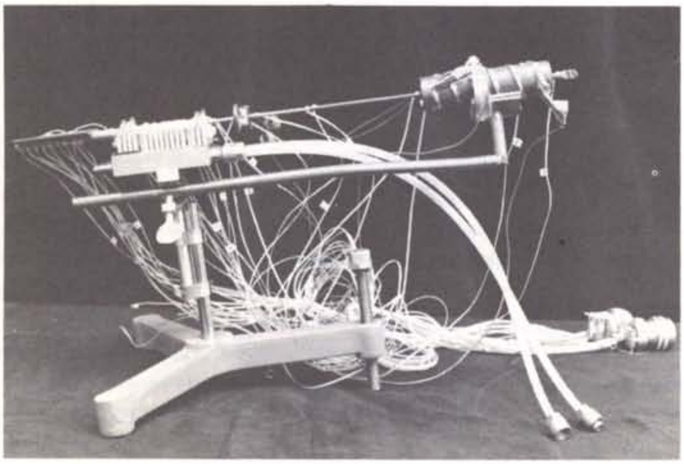


Figure 6 – Engineering model VCHP for temperature control of a microwave source.

started at Sabca on a high-performance, bendable artery VCHP made from stainless steel. In parallel, a heat-pipe diode for operation in the 0–50°C range is under development at IKE.

RADIATORS

It was clear as early as 1972 that one of the first space applications for heat pipes would be to control the heat flow in radiators, and in 1973 constant conductance 'telecommunications' heat pipes from IKE were incorporated in both solid and honeycomb radiator panels in support of the ATC (Air Traffic Control) satellite programme. The radiators, together with 'control radiators' containing no heat pipes, were tested at ESTEC during 1974, and although some noncondensible gas could be detected in the pipes (they were the early ones containing both aluminium and stainless steel), the improved thermal performance of the heat-pipe radiators was clearly demonstrated.

Also during 1974, it was realised that for maritime-communications-type missions such as Marots, a constant-conductance heat-pipe radiator alone might not be adequate, due to the changes in payload heat dissipation during eclipse and throughout the mission. A technology-model VCHP radiator was therefore developed, using extruded-groove VCHPs (Fig. 7). During 1976 this radiator was successfully tested at ESTEC, where it is still undergoing life testing. Having clearly demonstrated the technology and advantages of such a radiator, Dornier System undertook, for the Marots programme, the design of a radiator based on the previous one, but modified to meet this satellite's requirements and to respect its mechanical and other interfaces.

NATIONAL HEAT-PIPE ACTIVITIES

In parallel with the ESA-sponsored activities, extensive heat-pipe and radiator developments have occurred within national technology programmes, particularly those of Belgium, France and Germany, and have contributed substantially to the development of European heat-pipe technology: this article would not be complete without a brief mention of these efforts. Both the French and German programmes have included zero-gravity testing on sounding rockets, and Germany also contributed an experiment for the IHPE.

In 1969, as part of the Belgian national programme, Sabca developed a 3 mm diameter homogeneous wick heat pipe, and in 1972 an agreement was established between SNIAS and Sabca covering space applications of heat pipes. Since then, and with the support of the French national programme, a range of space radiators (both constant conductance and VCHP) has been developed and tested at SNIAS, using homogeneous and artery wick heat pipes from Sabca.

Heat-pipe development under the German national programme has been centred at Dornier System with the development, since about 1973, of aluminium extruded-groove heat pipes and radiators. A large range of extrusions is now available, with various cross-sections, groove geometries, and wall thicknesses, enabling heat pipes to be built for operation anywhere in the range 100 K to 100°C. Radiator development has included both constant-conductance and VCHP designs.

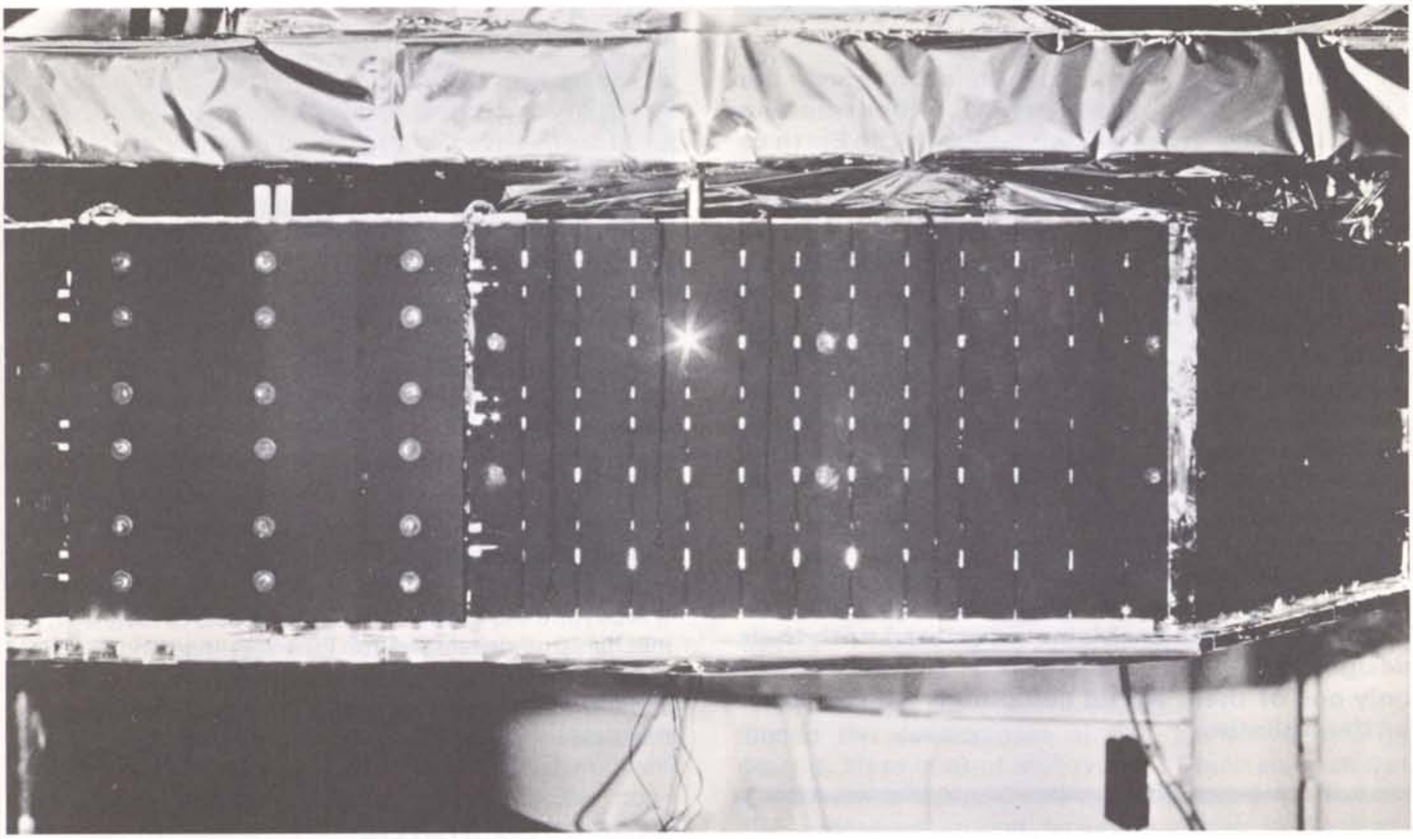


Figure 7 – Technology model VCHP radiator.

CONCLUSION

The most important task now is to apply existing heat-pipe technology and expertise to solve the many thermal problems identified or confirmed by spacecraft studies now in progress.

Important activities for the future include: development of high-performance VCHP radiators, designed to overcome the limitations of aluminium grooved heat pipes; application of heat pipes to the thermal problems of Spacelab payloads, particularly on the Pallet; and development of special radiators (e.g. cryogenic). Zero-gravity investigations, both of fundamental heat-pipe mechanisms (vapour/liquid shear, vapour/gas interface stability, etc.) and of advanced heat-pipe systems will also be needed.

Traditional means for satellite thermal control will not be adequate to meet the demands of many of the space missions currently under study or foreseen for the 1980s. That this would happen was anticipated some years ago, and as a result complementary development programmes were initiated by ESA and within national space programmes to develop heat pipes. As a result of these combined efforts, there now exists in Europe a large pool of heat-pipe expertise capable of supplying all foreseen needs into the early 1980s. For later missions, more advanced heat-pipe systems will be required and development work must proceed without delay to ensure their timely availability. □

Why Mechanisms are Critical to Spacecraft Performance

H.M. Briscoe, Structures and Thermal Control Division, ESTEC

At first sight, a spacecraft in orbit gives the appearance of a passive machine, either spinning about one axis or stabilised to look at the Earth or some other heavenly body, and gives no outward impression of the intense activity taking place inside it. Most of this activity is, of course, electronic in character, but there are also a number of complex mechanisms upon which the spacecraft depends to carry out its mission. Some of these mechanisms, such as deployment devices, only operate once, but others must function faultlessly through the life of the spacecraft, which may extend to seven or eight years in orbit for communication and earth-resources survey satellites.

In this brief article it is possible only to give a general impression of the nature of such mechanisms and the problems associated with their design, development and test. A full account of only one of them would completely fill this issue of the Bulletin.

TYPES OF MECHANISM

The variety of mechanisms to be found on a spacecraft is prodigious and the list for ESA's programme alone will include:

- deployable booms for placing scientific experiments outside the influence of the satellite
- deployment control dampers to prevent damage to the boom from the shock at the end of deployment
- momentum wheels and control wheels to stabilise nonspinning satellites
- gyroscopes to provide attitude and rate information
- de-spin mechanisms to allow the antenna of a spinning communication satellite to point continuously towards the Earth
- solar-array deployment mechanisms to enable large solar arrays to be unfolded in orbit.
- solar-array drives to keep the solar array pointing towards the Sun throughout the orbit
- antenna pointing mechanisms to enable the antenna of a three-axis-stabilised communication satellite to be beamed to a spot on the Earth
- tape recorders for the storage of data on-board, which is then relayed to the ground once per orbit
- scanning and slewing mechanisms for a wide variety of scientific observation instruments and for attitude-control sensors
- spin-up and ejection mechanisms to launch small throw-away package-type satellites from Spacelab.

A planetary explorer satellite such as Viking, two of which are now operating on the surface of Mars, is full of complicated mechanisms to scoop up samples of soil and transfer them to an analyser, which is itself a complex mechanism. Control of the earth-sampler arm from the ground has enabled one Viking to move aside a Martian rock which was obstructing operations.

It is beyond the scope of this short article to review all the mechanisms developed for ESA satellites and we have therefore selected a few of the more interesting ones to show the extent and variety of the Agency's activities in this field.

GEOS BOOM SYSTEM

The Geos satellite, launched last April, is a scientific satellite designed to measure magnetic and electric fields. The boom systems can be seen in Figure 1, and comprise two short radial booms, two long radial cable booms and four axial telescopic booms.

The short radials are conventional, two-element folding booms which are coupled together by a cable system to ensure uniform motion, the deployment being controlled by two hydraulic dampers and initiated by a pyrotechnically operated cable cutter.

The long radial booms are composed of electric cables, unwound from a storage drum and carrying electric-field sensors on their ends. This system is unique in Europe and has only been used in the USA for much shorter booms. The mechanism to store and deploy the boom, and the special cable itself, were developed by ESTEC as part of the Technological Research Programme. The axial booms

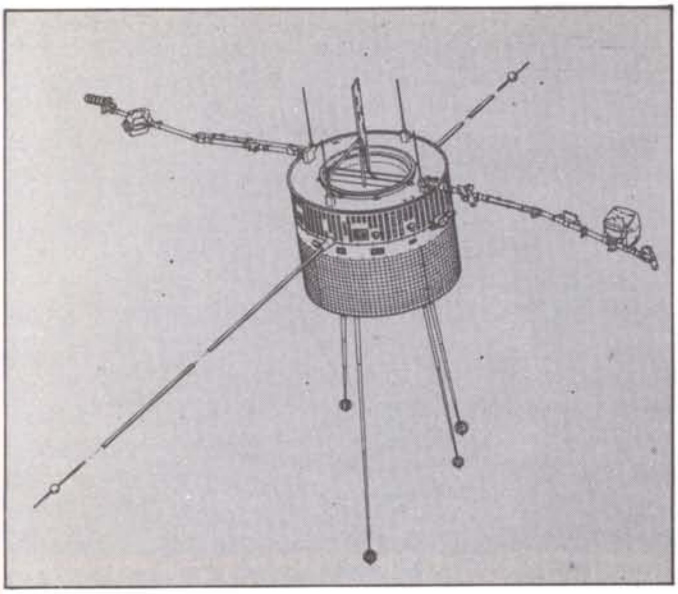


Figure 1 – The boom systems of the Geos spacecraft.

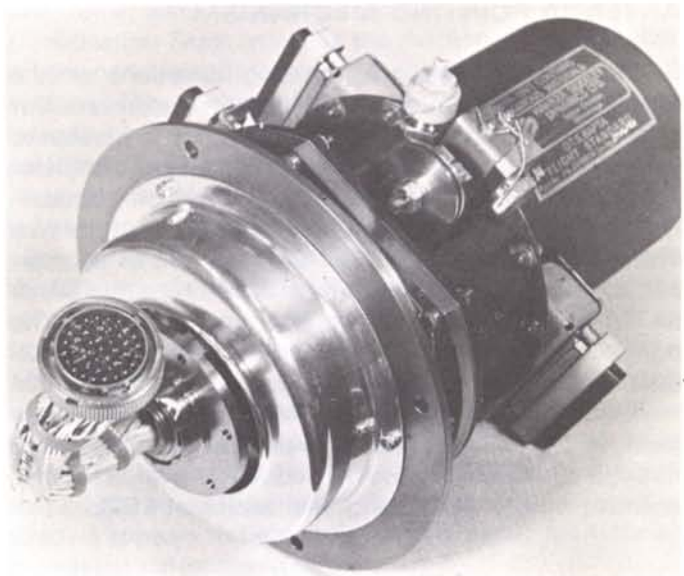


Figure 2 – The Bearing and Power Transfer Assembly (BAPTA) for OTS.

are multi-element telescopic units which have been developed in Europe, since no competing system could provide the stiffness required in this particular configuration. The booms are almost parallel to the spin axes. They are deployed by nitrogen stored under pressure in bottles and released by pyrotechnics.

The booms are a wholly European development based on work by the Royal Aircraft Establishment in the UK, the ESA Technological Research Programme, and Dornier System design.

OTS BAPTA

BAPTA is an acronym for Bearing and Power Transfer Assembly and it is in fact a solar array drive. The Agency's telecommunications Orbital Test Satellite (OTS) and all three-axis-stabilised communication satellites in geostationary orbit, have a requirement to keep the solar panels pointing towards the Sun, which requires rotation of one revolution per 24 hours relative to the spacecraft.

As part of the Supporting Technology Programme, ESA funded the development of two competing BAPTA designs. Three units of each type were built and tested at the European Space Tribology Laboratory (ESTL) an ESA-sponsored ground facility at Risley in England, where one of each type is currently undergoing life test. Both can meet OTS requirements but, not surprisingly, Hawker Siddeley Dynamics has selected its own design (Fig. 2) for the satellite, for which it is prime contractor.

The BAPTA is composed of a shaft mounted on two ball bearings lubricated by a thin film of lead, and driven directly by a DC motor. There are no gears in the machine and the motor is pulsed to provide a stepwise, open-loop drive. The slip rings are also dry-lubricated, since the brushes are made of a compact of silver, copper and molybdenum disulphide. The bearings are preloaded by means of a flexible diaphragm and a pyrotechnically released off-loading mechanism protects them from overload during launch. No oil whatsoever is used in the machine, to avoid contamination of the slip rings and wide variations in bearing torque with temperature.

ANTENNA POINTING MECHANISM

In order to maintain the pointing directions of the antennas of communication satellites in the presence of certain orbital perturbations, it is necessary to be able to steer the antenna on command over a half cone angle of about 3°. The antenna is therefore mounted on a gimbal-type mount, which is driven by actuators about the two orthogonal axes (Fig. 3). The development of such an attitude pointing mechanism was undertaken by ESA as part of the OTS Supporting Technology Programme. The principal difficulty lay in achieving the accuracy of 0.02° over the full ambit of the mechanism in a varying thermal environment. The gimbals are driven by linear ball screw jacks, lubricated with lead, powered by a stepper motor through a unique irreversible reduction gear. The mechanism is now undergoing final testing at ESTL.

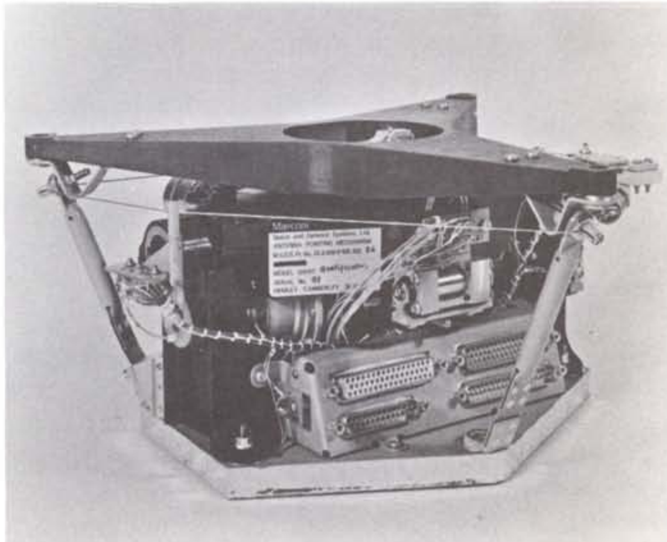


Figure 3 – Antenna Pointing Mechanism.

RELIABILITY AND THE SEARCH FOR PERFECTION

Whatever the function of the mechanism, there is one quality that is universally required - reliability. The temptation to write absolute reliability must be resisted since, in fact, it does not exist. Every machine has some mode of failure and the objective of the designer is to recognise it and to either minimise or eliminate it. The failure of one single mechanism on a satellite will at best reduce its operational capacity and at worst wreck the entire mission. Should a solar-array fail to deploy or a momentum wheel cease to rotate, the satellite cannot operate and the mission is a failure.

In an electronic system, a well-known method of achieving high reliability is duplication for redundancy. The additional mass incurred is usually small and the ability to provide automatic switching from one circuit to another in case of failure often makes the approach very practical. But in the case of most mechanisms this ready solution is impossible without incurring an enormous mass penalty, so we are finally faced with the need to attain the utmost extreme of reliability in a mechanical device.

The approach to achieving it is guided by Carlyle's well-known assertion that 'genius is the capacity for taking infinite pains'. This does not mean that a spacecraft mechanism engineer must be a genius, although it helps, but it does mean that he must have both the imagination to foresee every way in which it is possible for the mechanism to fail and a meticulous eye for detail. Very few mechanism failures are due to a poor initial concept; most of them are the result of inadequate attention to detail or a lack of understanding of subtle physical interactions. The creation of a space mechanism will therefore involve the following steps:

- an equipment specification
- study of competitive concepts
- detail design of chosen concept
- build
- development test
- qualification test
- life test.

To realise this sequence, a number of models of the mechanism must be built, which would normally be

- a development model
- an engineering model
- a prototype model
- a flight unit
- a flight spare.

In most cases the flight spare unit will be the refurbished prototype which has been used for qualification, whilst in some cases the development model and the engineering model may be the same unit, thus reducing the overall requirement to three units for the satellite programme. This number is the absolute minimum to satisfy the requirement for qualification and acceptance testing, about which we will say more in a moment.

The most important step in both the achievement and demonstration of reliability of the mechanism lies in the test programme to which it is subjected. We have already identified the two major types of mechanism on a spacecraft as those which operate once and those which must operate throughout the life of the satellite. Naturally the test programmes for each of them will be different. To avoid a long discussion on this highly involved and sometimes contentious subject, we will confine ourselves to a brief look at a test programme for a long-life space mechanism.

In the first place, it is absolutely necessary to reproduce in the test as closely as possible the spacecraft environment in space. It is not possible to produce a zero-gravity environment on Earth for more than a few seconds, but since the effect of gravity on the performance of a mechanism is usually small the need to simulate zero gravity is usually ignored. Much more damaging to mechanism performance are high and low temperatures, rapidly changing temperatures and ultra-high vacuum, and these cannot be ignored.

The mechanisms are therefore tested at ESTL, where vacuum chambers equipped with thermal shrouds are available to carry them out (a description of this facility and the work carried out there appeared in ESA Bulletin No. 6, August 1976). The test conditions are arranged to simulate as closely as possible the rapid change of temperature that the mechanism may experience as the satellite passes into and out of the eclipse period of its orbit. In extreme cases where the mechanism is fully exposed, temperatures can range from −130° to +100°C, but where the mechanism is located inside the satellite this range is reduced to a modest −30° to +60°C or less. A solar-panel drive mechanism (Fig. 2) would be tested over this range of temperature.

The formal tests are of three types:

Qualification Tests, in which the mechanism is subjected to temperatures in excess of those expected in the satellite. The objective is to prove that the quality and integrity of the design are adequate to meet the performance requirements with an acceptable margin.

Acceptance Tests, in which the model destined for flight is subjected to temperatures that represent the limits it is expected to encounter in flight. The objective is to prove the integrity of the build of the unit. The lower limits of the acceptance test are designed to avoid possible damage from the more extreme qualification test levels.

Life Tests, which aim to demonstrate the ability of the mechanism to operate with consistent performance throughout its life in space. In many cases these tests cannot be accelerated and must therefore be set up to run for perhaps seven to ten years. If a dry lubrication system is used, it appears to be possible to accelerate life tests by increasing either speed or load.

All of these tests must be carried out with great formality and absolute control of the test conditions and procedures, and it is for this reason that they are best conducted in a facility properly equipped for the purpose.

At ESTL two BAPTA units are now entering their third year of life test, and although changes are being observed in some of the measured parameters, both units are still operating within the specified tolerances. A further BAPTA is undergoing accelerated life test and during 1977 it will be possible to correlate the results with those of the real-time test.

CONCLUSION

In this brief résumé it has been possible only to give an outline of a few of the mechanisms used in a satellite and a broad idea of the philosophy which must be applied to their development. Driving the entire activity is the ever pressing need to reduce costs, which must always be traded against the even more pressing need to achieve long-life success in space. A failure on the ground may be expensive and annoying, but the same failure in space can be calamitous. Finding the right balance between these two conflicting requirements is the problem exercising our minds in ESA today. Only time and more effort will lead to ultimate success. □

The European Space Battery Test Centre

H.J. Young & D. Goudot, Spacecraft Power Supplies Division, ESTEC

The oldest form of electrical energy source, the electrochemical battery, is still used on almost all spacecraft as a means of converting and storing electrical energy. A section was formed at ESTEC in 1968 to provide functional support for projects in matters concerning primary and secondary batteries, fuel cells, and more recently, metal-hydrogen cells. This section's tasks include the supervision of the general evolution of terrestrial batteries, the preparation and execution of research and development programmes, the space qualification of new products, participation in the work of ESA project teams, the co-ordination of European battery activities including consultancy in national programmes, and finally the establishment of European battery-specification standards.

With the advent of applications satellites, and in answer to the generally increasing demands from spacecraft engineers for improvements in power-source energy-density, life and reliability, new products and new techniques are continuously being evolved. To maintain the proper and necessarily improved support to 'customers', there has been a parallel evolution in ESTEC's facilities. The aim is to achieve a more co-ordinated and rationalised approach to the technology of electrochemical power sources with the aid of an advanced test centre that is unique in Europe.

Typical examples of existing applications of batteries on board satellites are the following:

- during eclipse periods when solar energy is not available
- for standby power immediately before and after launch and prior to deployment of solar arrays
- for pyrotechnic and motor operation for boom and solar-panel deployment
- for peak-power lopping when the primary source is insufficient
- for provision of additional power for electric propulsion.

Although the particular requirements of Spacelab, for example, merit serious consideration of both primary (i.e. non rechargeable) batteries and short-life fuel-cell applications, all ESA's past satellites have been equipped exclusively with secondary batteries. Consequently, the Agency's current programme is still directed mainly towards improving the capabilities of such secondary systems. Development of both nickel-cadmium and silver-cadmium systems is a continuing process and for the longer term aims the applied research programme is concentrated on nickel and silver hydrogen cells.

PARTICULAR TESTING REQUIREMENTS OF SPACE BATTERIES

The principal requirements imposed on batteries for space use are:

- hermetic sealing
- mechanical/environmental compatibility
- electrical compatibility
- life expectancy (longevity being paramount for applications satellites)
- high energy density.

Normally, batteries and like devices rely upon energy-transfer internally by ionically-conducting aqueous electrolytes; they are therefore sensitive to environment, particularly temperature, and are irreversibly affected by abuse. Contrary to popular belief, the technology is both complex and inconsistent. Partly theoretical, it largely relies on empirical understanding achieved only by considerable investment of time and money in its systematic development, evaluation and test.

Progress has been made using rudimentary, but very labour intensive methods of data acquisition and analysis. Information, in consequence, has been fragmented and not in keeping with the magnitude of the task. A wealth of specific information has been obtained for specific purposes, but this cannot always be readily extrapolated to other situations.

The technology has made significant strides forward with the introduction of new couples, new manufacturing techniques, lightweight designs, new approaches to feedthroughs, use of electrochemical impregnation for electrodes, and so on. Whilst subjective testing such as orbital simulation will always be an essential feature of quality control, the achievement of a means whereby it is possible to identify individual failure modes for any system must be the real objective. Accurate battery-life prediction could be critical to the success of an applications satellite, for example. Unfortunately, accelerated life testing of batteries has so far proved very difficult to apply. Despite the investment of considerable funds, there has been little success in establishing definitions for such tests.

Approximately three years ago, it was recognised that improvement of the project-support capability of ESTEC's battery section was necessary to adjust to this evolving situation. There was a growing need for both quantitative and qualitative performance data to support the general trend in power-system design. A contract was subsequently signed in 1975 with Construcciones Aeronauticas SA, Madrid for the design, manufacture and installation of a complete battery test facility for ESTEC. Hardware installation is now complete and software development is well advanced, with acceptance testing scheduled for October 1977.

THE NEED FOR A CENTRALISED BATTERY-TESTING FACILITY

Until 1973, the testing of space batteries in Europe was divided between about ten different, mainly industrial, laboratories. The vast amount of work that they have done has provided valuable results, contributing substantially, for instance, to identification of the degradation produced by overcharging and to the definition of the advanced charging concepts that will be applied on the Agency's OTS telecommunications satellite.

The scattered nature of the battery-testing activities was, however, seen to have several disadvantages. In addition to the comparative inefficiency and expense resulting from duplication of personnel and equipment, it proved difficult to adapt to the changing needs dictated by the different tests and orbital simulations. Moreover, the data obtained at the different laboratories could not be easily compared or processed by computer, and long setting-up times were delaying the start of urgent tests.

As ESTEC was also faced at this time with a large increase in the number of tests to be conducted in connection with the Agency's on-going programmes, it was felt preferable to try to concentrate all activities at a single 'computerised centre' with a large growth potential, rather than to expand and modify the existing facilities. Additional advantages to be gained from the creation of a centralised European Space Battery Test Centre were the proximity of location to the specialised project-support staff, the possibility of implementing Europe-wide test procedures and qualification standards, and last but not least the prospect of rapid distribution of comprehensive computer-compiled test reports and statistical analyses to European industry.

GENERAL DESCRIPTION OF THE BATTERY CENTRE

The Test Centre that is to be provided is based on a real-time, automatic data-acquisition and control system, with 2000 analogue input channels, which can control up to 100 test stations either individually or in combination. The design allows for eventual expansion to 5000 channels and 256 controlled outputs. The test stations will be able to accommodate up to 40 cells in series, and voltages, currents, temperatures, pressures (or their derivatives), accumulations of ampere-hours or watt-hours etc. can be measured and controlled, to accuracies better than 1 mV for voltages and better than 1% for currents, pressures and temperatures.

The general objectives in designing the Centre were reliability in continuous operation commensurate with life-cycle testing for 8 and 10 years, ease of maintenance by module or card-level replacement, and ease of operation.

The Centre occupies an area of approximately 450 m^2 and air conditioning maintains a nominal 20°C, 55% RH environment when heat dissipation is equivalent to 100 kW.

TEST SYSTEM CONFIGURATION (FIG. 1)

Two PDP 11/45 computers are to be operated in an actively redundant, master-slave, mode. With other

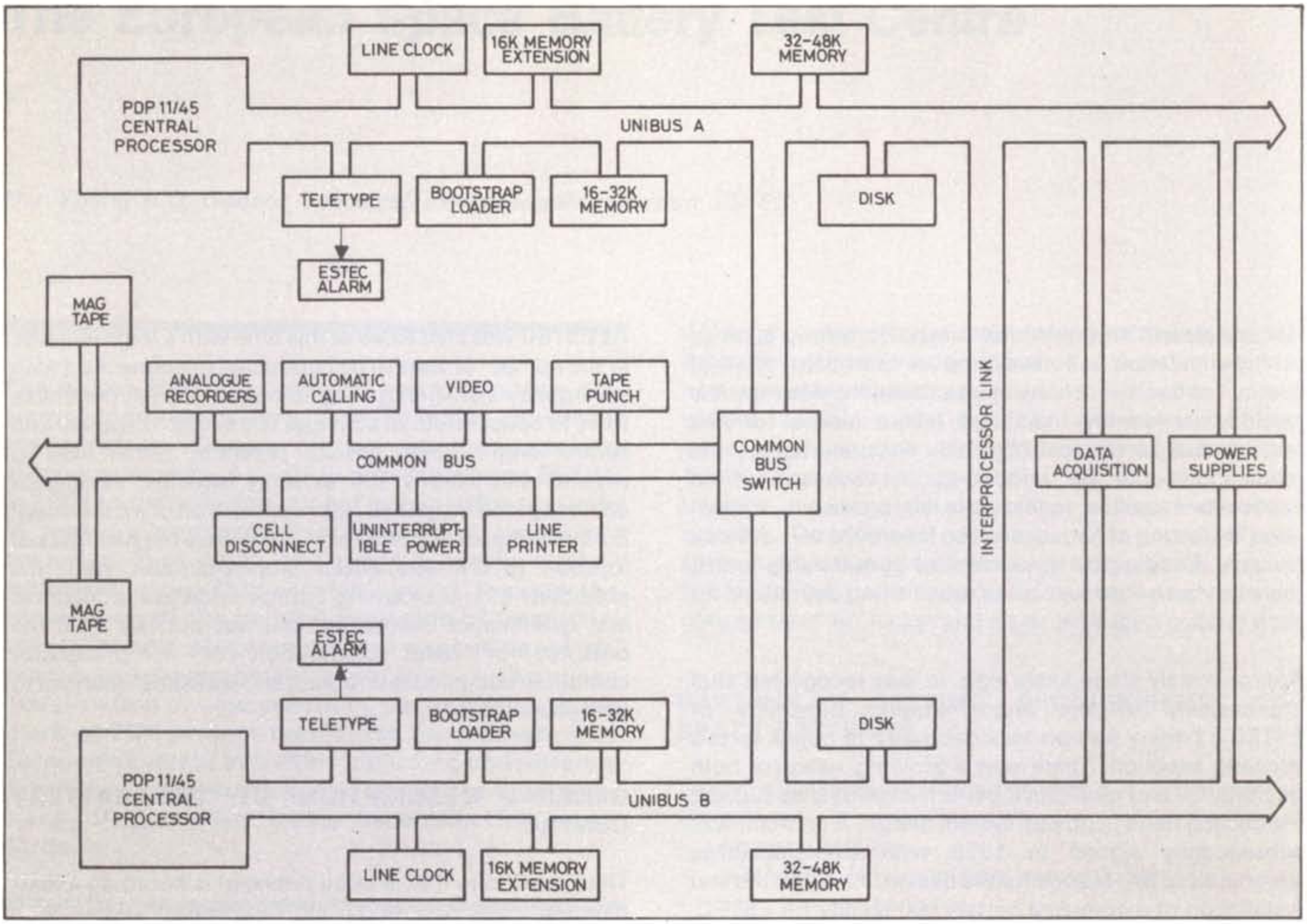


Figure 1 – System configuration of the European Space Battery Test Centre.

essential parts of the system, data acquisition and alarm subsystems, they are fed by an uninterruptible power supply from ESTEC's emergency circuit. The operating software is a standard package supplied by the computer manufacturer (Digital Equipment Corp.).

The system is organised into eight functional subsystem groups: data processing, data acquisition, power supplies, individual cell disconnection, analogue recorders, uninterruptible power, automatic calling, and test bays, the principal features of which are summarised in Table 1.

DATA OUTPUT

Measured data is initially recorded on disk, where it is compared scan by scan for data-compression purposes. After analysis, 'final' data is sent to magnetic tape recorders via the common bus. When running at full capacity, it will be possible for the Centre to fill one 10-inch data tape every 24 hours. These tapes will be removed and processed further with the assistance of ESTEC's ICL computer. A separate tape will be compiled for indexing and recording significant events occurring during operations.

Further data reduction can be effected off-line with graph plots, histograms or tabulated data, as required by the particular test specification. Test data tapes are to be stored within the air-conditioned environment of the Centre.

LAYOUT OF THE CENTRE

The accommodation is divided into two areas, one for tests and the other for control. The uninterruptible power supply and standby battery are situated in a separate annex. The test area accommodates all harnesses, overhead cable trays, test bays, various thermal chambers and general test equipment. The control area accommodates the remainder of the equipment, which is mounted on a suspended floor cooled by re-circulated air provided by the air-conditioning units. Signal and power harnesses, which contain a total of about 80 km of wires, pass

TABLE 1
Summary Description of ESBTC Subsystems

Subsystem	Function	Description
1. Data processing	– Overall system control – Data handling and recording – Error detection – Operator interface	– Two PDP 11/45 computers with 48000 word memory and standard peripherals – Common bus, with automatic inter-bus-switch and interactive terminals – Operating software package (DEC. RSX-IIM) – Applications software
2. Data acquisition	– Collection and multiplexing of analogue signals – Analogue to digital data conversion	– 2000-channel, 3-level multiplexer operating between 36 and 86 channels per second with 3rd level redundancy – Two Fluke 8200 A digital voltmeters – Two selfcontained calibration sources maintaining accuracy to ± 1 mV. – DC signal harness
3. Power supplies	– Control of voltage, current and operating mode of all applied tests	– 100 addressable and programmable power supplies manufactured by Fontaine, providing combinations of V_{max} 30, 50 and 80 V, I_{max} 5, 15 and 30 A – Digital to resistance converters 1024 steps 0-V_{max}, 256 steps 0-I_{max} – Mode control modules – Power harness
4. Individual cell disconnect	– Study of individual cells – Cell batch selection – Battery reconditioning	– Three 15-cell capacity test bays modified by addition of power relays and associated logic for cell switching
5. Analogue recorders	– To provide monitoring and immediate supervision of tests in progress	– Five 12-channel (programmable) multipoint analogue recorders, Philips type PM 8253 – 60 digital-to-analogue converters – address decoding and digital data link
6. Uninterruptible power supply	– To provide 'no-break' power to the essential subsystems during total mains failure	– 3-phase rectifier 220 V/110 V DC 15 kVA – 140 AH nickel-cadmium battery – Single phase output inverter 110 VDC/220 V 12 kVA – Static bypass circuit automatically operated in event of conversion failure
7. Automatic calling	– Transmission of alarms generated within the system to duty engineers (a) via internal system in working hours (b) via PTT lines in silent hours	– Automatic calling unit manufactured by Becker Telecomms. BV. Following alarm this unit can make 10 dialings sequentially to any of four previously programmed PTT subscriber numbers – Audio-visual installation for internal communication of alarm conditions
8. Test-bay stations	– To provide interconnection facilities between test specimens, the power and measurement harnesses	– 100 test stations providing solderable feedthrough input connections to the data acquisition subsystem, and standard multi-pin connectors into the power-supply subsystem – Current shunts providing 100 mV input at 5, 15 and 30 A max. current values are mounted on to each TBS

between the two areas.

The Centre's principal equipment is illustrated in Figures 2–5.

UTILISATION OF THE CENTRE

After acceptance testing and the necessary trial period, it is planned to put the Centre into full operation in early 1978. The forecast usage for that year is illustrated in Table 2. Some of the tests listed there are in fact continuations of earlier contracts with industry from which up to five years' experience is already available. This continuity in testing is essential if the battery lifetimes for applications satellites with mission lifetime requirements of seven years or more are to be predicted realistically.

TABLE 2
Planned Usage of the Battery Centre

Activity	Utilisation Percentage
Evaluation of new couples currently under development:	
– silver-hydrogen	5
– nickel-hydrogen	8
– improved nickel-cadmium	5
Space qualification of commercially available cells:	
– silver-cadmium or nickel-cadmium	7
Parametric assessment of the influence of thermal and electrical conditions on battery lifetime	40
Final performance assessment and flight qualification of batteries	4
Life testing (particularly for geostationary orbit)	16
Special tests (e.g. reconditioning, parallel operations of several batteries, failure analysis)	6
Simultaneous cycling during satellite flight (simulating actual environment and operations)	5
Tests requested by national agencies or by commercial customers	4

Figure 2 – Data processors, data acquisition equipment and peripherals in the control area.

Figure 3 – General view of the test area, showing the battery preparation benches, with the main environmental test chambers behind.

The activities listed in the table are organised to provide testing information at all stages of a project:

- in the early planning phase, to provide results on the potential of new couples, such as metal-hydrogen cells, and to help in conjunction with specialised electrochemical techniques in identifying possible degradation mechanisms
- during the project design phase, to help industry define optimum charge and discharge conditions and design the battery's thermal environment. Special tests are also scheduled at the request of a project, to assess the impact of a particular design feature. One example is the assessment of battery reconditioning as a means of maintaining initial performance under

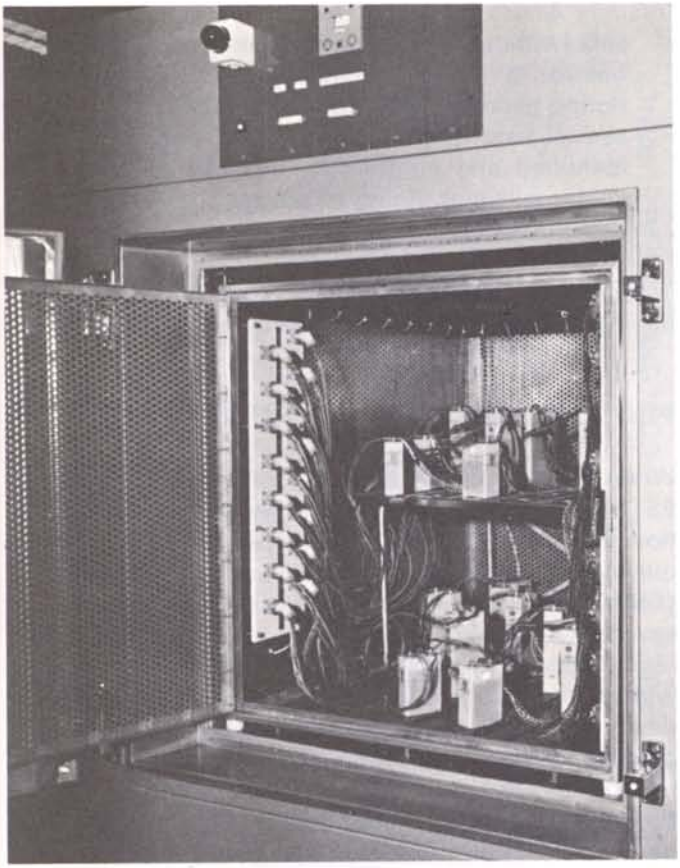


Figure 4 – Detail of test chamber.

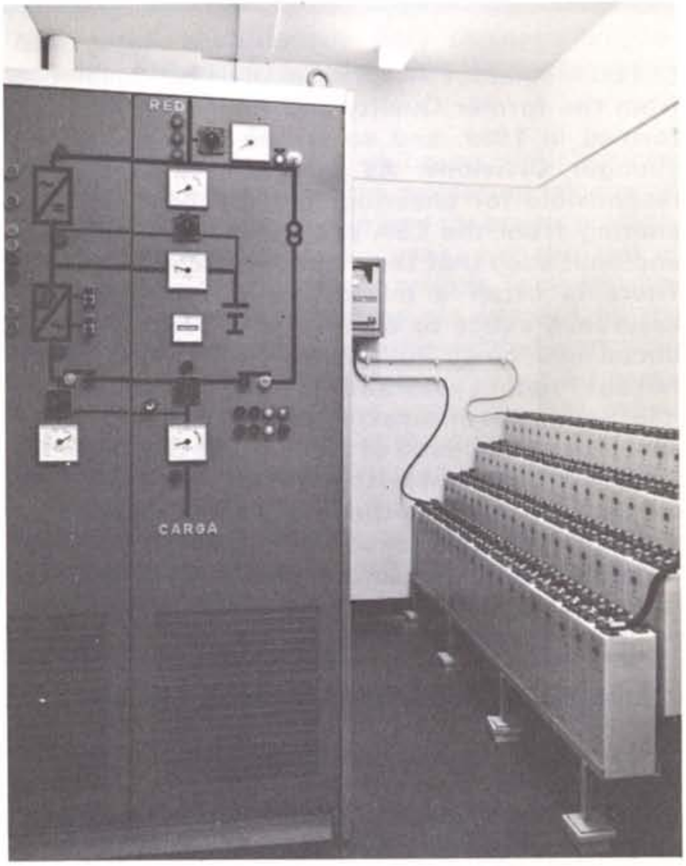


Figure 5 – Emergency power-supply equipment and nickel-cadmium standby batteries.

geostationary orbital conditions
- after battery manufacture, for flight qualification or acceptance. This is quite a complex activity in the case of silver-cadmium cells as it involves the final step of cell matching and formation
- after launch, by cycling cells under the same conditions as observed in orbit. This is useful for geostationary satellites in planning spacecraft operations and tracing the source of any anomalies that occur.

Finally, it should be mentioned that the Centre can provide a service to external customers if excess testing capacity is available, a possibility that has already been taken advantage of by a manufacturer of heart pacemaker batteries.

CONCLUSION

The aim has been to outline the purpose and operation of the European Space Battery Test Centre at ESTEC and the need to use it as a co-ordinating centre for aerospace applications. Expertise in this domain is necessarily a long-term investment and without centralisation it would be a much less economic and effective activity. The intention is to provide a Centre with a flexibility of operation sufficient to meet all forseeable needs and with a readiness to diversify activities if and when necessary to study any form of battery-allied power source. □

ESTEC's Product Assurance Activities

D.A. Nutt, Product Assurance Division, ESTEC

ESTEC's Product Assurance Division developed from the former Quality and Reliability Division formed in 1969, and so is one of the Centre's younger Divisions. As its name implies, it is responsible for ensuring that the products emanating from the ESA programme are designed and built such that they will perform as required. There is often a misconception that product assurance exists to ensure that everything produced must be of 'Rolls-Royce' standard . . . this is not so! Product assurance is most effective when it is directed to ensure that the end product has an acceptable likelihood of meeting the performance required consistent with cost and time scale. This departure from the ultimate standard implies that certain risks are taken and indeed the most valuable product- assurance engineer is one who is able to assess the degree of risk and advise the project manager accordingly.

DEFINITION OF PRODUCT ASSURANCE

The concept of product assurance as practised within ESA may be seen as a combination of tasks comprising design, conformance and integrity assurance.

Design Assurance is the assurance that the design is compatible with the reliability, safety and maintainability specified for the end product. This includes the theoretical prediction and analysis, as well as choice of parts, materials and processes and the establishment of quality levels for these.

Conformance Assurance is the assurance that the product is manufactured in conformance with the design and meets the specification. This includes configuration control (control that the product is built in accordance with drawings and specifications and that these are properly updated), nonconformance control (reporting reviews and actions on nonconformancies); and quality control (inspection of parts, materials, processes and parameters related to the quality of the product).

Integrity Assurance is the assurance that the product is safe (without risks to user or environment) and that all hazards to the product are controlled (to ensure that during handling, transportation, storage, testing and use all hazards from persons and environment are identified and controlled). Integrity assurance includes activities during all project phases, from early design to operation and scrap.

The relationships between these areas of activity during the life-cycle of a project are illustrated in Figure 1.

PRODUCT-ASSURANCE REQUIREMENTS

When the Product Assurance Division was established at ESTEC, no requirements had been defined to indicate how European industry should operate in the fields of quality and reliability to ensure that the Organisation (ESRO) would receive hardware suitable for operation in space. At that time (1969) the majority of European contractors had virtually no experience and there was a wide divergence in the technical expertise available to them. One of the Division's first tasks, therefore, was to produce a document, now well known throughout industry as QRA-1, entitled 'General Provisions for the Product Assurance of ESRO Spacecraft'. This document has been revised over the years as both industry and the Organisation gained experience and it has been supplemented by numerous specifications, procedures and standards dealing with more specific needs in greater detail. Such documentation must of course be applied to projects in a flexible manner, since it has always been recognised that the product-assurance requirements must be 'tailored' to suit individual project needs. The requirements applicable to a low-cost, short-lifetime scientific spacecraft, for example, are much less arduous than those applicable to an applications spacecraft, for which orbital lifetimes of seven to ten years are needed to ensure a commercial operation.

ORGANISATION OF PRODUCT ASSURANCE ACTIVITIES

The Product Assurance Division is organised into three Sections, dealing with systems work, materials and

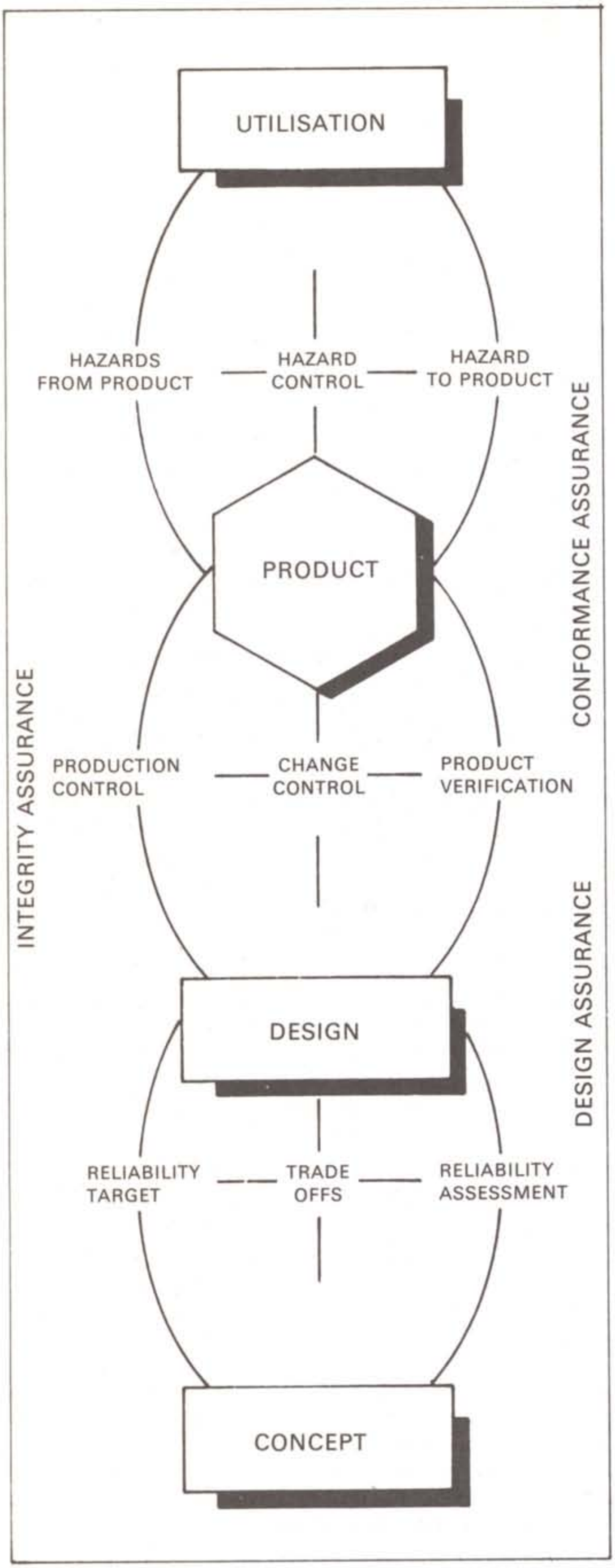


Figure 1 – Assurance activities during the life-cycle of a space project.

electronic/electrical components. In addition to this 'home-team', approximately thirty engineers are detached to work as 'integrated support' within the various project teams.

One of the disadvantages of having staff members dispersed in this manner is the problem of information flow between the 'home-team' and the project product-assurance engineers and vice versa, and also that of experience interchange between projects. To combat this, regular Co-ordination Meetings are attended by the project product-assurance managers and the Heads of the three 'home' Sections. There is also a Product Assurance Configuration Control Board, consisting of representatives from project product-assurance and the home Sections, which reviews ESA product-assurance procedures and standards and advises the Head of the Product Assurance Division of their suitability. This ensures that the most recent project experience is fed into such documentation.

On the documentation side, Parts Problem Notifications are produced by the Components Section on an approximately six-weekly basis. They collect together recent project and general information on component matters and are distributed to national centres within the ESA Member States and to NASA, as well as to all interested parties within ESTEC. The Materials Section also produces a document on Co-ordination of Materials Activities, which fulfils a similar rôle, but covers the field of materials used in space.

These meetings and publications are designed to ensure the best information exchange possible within the existing manpower constraints.

THE WORK OF THE SECTIONS

THE SYSTEMS SECTION

The Systems Section covers the technologies of reliability, safety, quality and configuration control, while at the same time being responsible for the ESA product-assurance specification system and for the general quality-assurance surveys of facilities supplied by ESA and its contractors. It will soon be responsible also for arranging for National Inspectorate support to the various ESA spacecraft projects and qualification activities.

The tasks of the Section in the field of reliability are essentially threefold. The first is to ensure the availability of up-to-date data on component failure rates for use in spacecraft system reliability calculations. These calculations are necessary to highlight design weaknesses and to permit comparative evaluations of alternative design solutions so that the 'optimum' one may be selected. In this context, the 'optimum' solution is one in which reliability, weight, power consumption, etc. are optimally balanced. Data on component failure modes are also needed to evaluate how spacecraft systems would fail as a result of failure of any particular component, the aim being to minimise the dependence of a system to function on any particular component, and hence to eliminate as far as practicable so-called single-point failures.

The second responsibility of the Section is to carry out basic theoretical work to increase the accuracy of reliability prediction. With ESA's increasing involvement with applications spacecraft designed to serve a future commercial market, this work is of great importance. If the reliability predictions are pessimistic, the system designer will be forced to incorporate redundant systems to increase overall reliability; increased redundancy means increased weight, which in turn means reduced payload capability.

Thirdly, the Section is required to provide 'reliability' support to those projects that do not have integrated specialists of their own in this area and to assist those that do at times of peak workload.

In addition to the Section's responsibility for producing and updating the various quality-assurance procedures, it is charged with carrying out audits of the environmental test facilities located at ESTEC, IABG and CNES and with ensuring that the necessary corrective actions are followed through. General quality audits of contractors' plants are also scheduled when effort is available and quality assurance at the European Space Tribology Laboratory in the UK is also supervised. Quality-assurance support is also given to the smaller ESA projects and to the larger ones at times of peak demand.

THE COMPONENTS SECTION

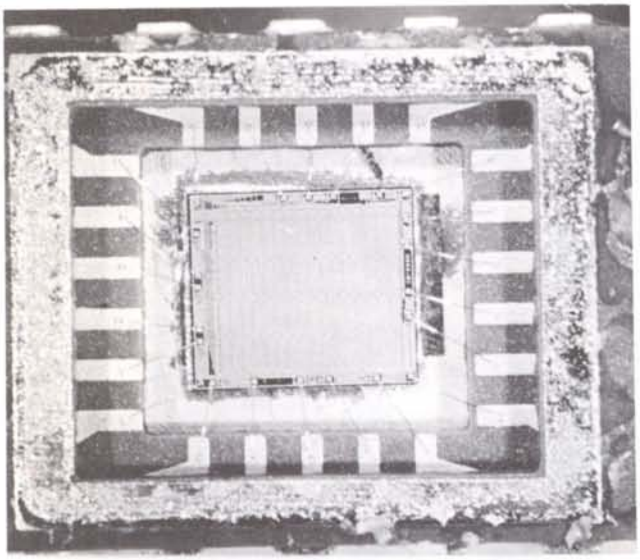
The work of this Section falls into three main areas: component evaluation and qualification, component support to the ESA spacecraft project and applied technology teams, and the study and evaluation of advanced component technologies.

Component Evaluation and Qualification

The major effort in component evaluation and qualification is directed towards a co-ordinated European effort in which the ESA Space Components Co-ordination Group (SCCG) plays a key rôle. This advisory group to the Agency's Director General draws its membership from component experts representing the ESA Member States and it is supported by industry through the representation of Eurospace, representing component user industry, and CEMEC, representing component manufacturing industry. The Components Section of the Product Assurance Division provides the Secretariat and contributes to the technical work by providing support from its specialist engineers. The principal aim is to ensure that the majority of the components needed for European spacecraft can be obtained from European manufacturers.

The main work of the SCCG has been the preparation of a common European specification system for component qualification. It has only been possible to achieve progress in this domain through the willing co-operation of the national space centres, which have devoted an appreciable amount of effort to these joint tasks. More recently, this co-ordinated approach has been directed to the preparation of a list of component types which have been used, and will continue to be used, in ESA spacecraft projects in significant numbers. These have been termed 'standard components'. Many of them which are manufactured in Europe have already been qualified within the national or Agency programmes, but in some cases it is necessary to update these qualifications. Other components on the 'standard' list have not been qualified (generally those procured from American sources), and the SCCG has drawn up an 'SCCG medium term qualification programme'. This programme, planned to span the three-year period 1977-1979, will be funded within the ESA budget and is expected to involve some 800 000 AU in external contracts.

In addition to the work on the 'standard' component programme the Components Section also evaluates and qualifies some less widely used components which fulfil essential functions, examples being high-power transis-



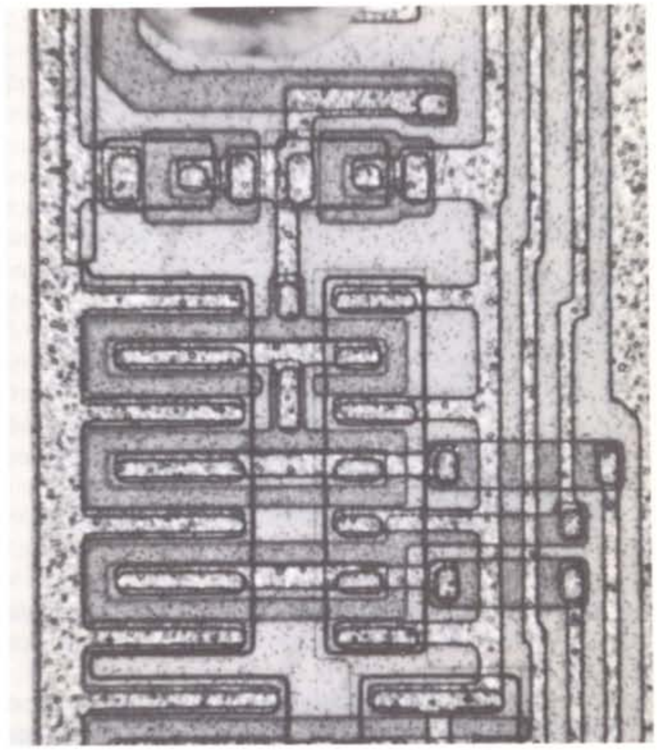


Figure 2 – Typical modern, complex integrated circuit: a 1024 bit random-access memory.
Above: Semiconductor chip and bonds (× 6 magn.).
Right: Detail of one input, showing protection network and inverter (× 400 magn.).

tors and diodes for power-supply subsystems and high-frequency transistors and diodes for use in communications spacecraft.

Component Support to Projects
Support to projects is provided during all phases, from definition of requirements, through component selection, to the sampling of delivered flight-standard parts which are submitted to destructive physical analysis to check their quality, and further to the failure analysis of those components that fail during ground testing of the subsystems into which they are built.

The component engineers involved in this work each have a responsibility for particular component technologies or special laboratory techniques. This means that a specialist engineer directs a laboratory analysis, translates laboratory results into corrective action, and follows through with the particular user contractors and with the component manufacturer. By operating with such technical specialists based upon an advanced laboratory facility, considered to be the foremost in Europe for this type of work, ESA has been able to build up a high degree of credibility with both component users and, equally importantly, with manufacturers both in Europe and in the United States.

Evaluation of Component Technologies
The laboratory at ESTEC is unique in that in one integrated facility, any component can be put through a full range of inspections and electrical characterisation tests and an elemental analysis made of the materials used. The laboratory facilities reflect the 'physics of failure' approach adopted by ESTEC, and the equipment used ranges from the very simple, but cleverly used, to the highly complex.

For nondestructive inspection, the laboratory is equipped with hermeticity test equipment to measure the leak rate of sealed devices, and X-ray inspection equipment which provides a 'real-time' TV image of the component at × 27 magnification. The 'real-time' capability allows the dynamic X-ray inspection of such devices as thermostats and relays.

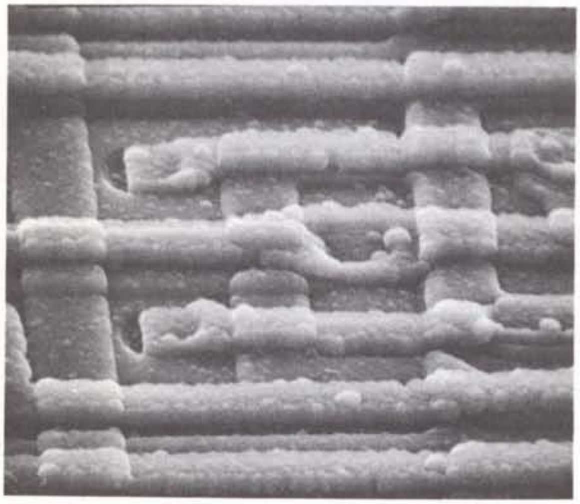


Figure 3 – SEM photograph of one memory cell of the circuit shown in Figure 2 (× 1225 magn.).

The environmental test capability includes mechanical and thermal shock equipment and an ultra-centrifuge capable of applying an acceleration of 140 000 g to an integrated circuit. One item of specialised inspection equipment finding great application at the moment is the particle impact noise detector, a small vibrator with a highly sensitive acoustic pick-up and amplifier. It is possible with this equipment to detect a particle as small as 0.1 μg inside a transistor package.

The laboratory is comprehensively equipped for optical microscopy and micro/macro-photography. The microscopy facility includes a large viewing screen allowing group discussion, interference contrast for enhancement of small topographical variations and an infrared image converter which is used mainly for the dynamic observation of light-emitting diodes for homogeneity of emission and visualisation of crystal defects.

The Scanning Electron Microscope (SEM) facility is a 'mini-laboratory' in its own right. In its simplest application, the SEM produces three-dimensional images with magnifications of × 150 000 and a resolution of 200 Å. In its most complex application the SEM can provide information on the behaviour of active junctions some

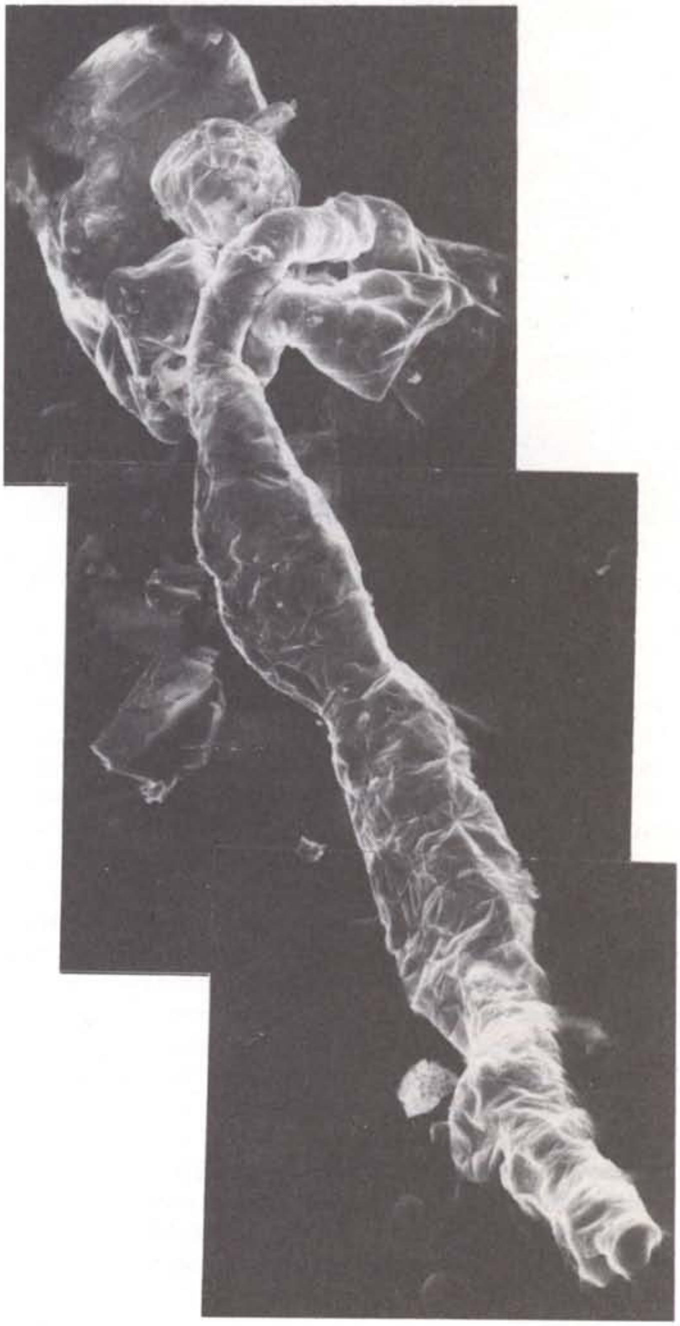


Figure 4 – SEM photograph of a contaminant particle removed from a transistor for X-ray analysis (× 550 magn.).

microns below the surface of the device being examined. Potential differences down to 0.5 V can be imaged, and by turning the primary electron beam on and off in synchronism with the signal a device under study can be 'frozen' at any point of its operating cycle. The addition of a solid-state X-ray detector with a multichannel analyser and minicomputer also allows the instrument to be operated as a scanning microprobe capable of elemental identification down to sodium (atomic no. 11) with a spatial resolution in the region of 1 μm. The main application of X-ray analysis is in the identification of contamination inside sealed components.

The SEM facility is not only used in component work, but also provides a service to the whole of ESTEC. Support is provided particularly in the field of metallurgical failure analysis to the Materials Section and the SEM has been used for such diverse activities as the examination of diffraction gratings for a spacecraft experiment and of a fractured brake cable for the safety and security office!

Future Trends in Component Technology

In electronics, the trend has always been towards smaller, lighter devices capable of increased performance, but at the same time consuming less power. Increasingly, discrete components such as conventional resistors, capacitors, and transistors, are being replaced by integrated circuits and by complete functions built in hybrid thick and thin film technology. An increasingly important rôle will be played in future system design by semiconductor memories, uncommitted logic arrays and microprocessors. The component reliability and quality engineer has to adapt his methods to meet the challenges of these advancing technologies and it may be necessary to adopt quite revolutionary techniques. It will not be enough to ensure that a highly complex microcircuit performs its intended functions; it will be equally important to ensure that it does not perform functions which are *not* intended.

THE MATERIALS SECTION

The Materials Section carries out similar tasks to those of the Components Section except that its work is concerned with the performance characteristics of materials in the space environment. It has well-equipped laboratories in ESTEC to enable it to meet its responsibilities. As the Section was described in an article in ESA Bulletin No. 6 (August 1976) only the main activities will be dealt with here.

Conventional materials properties such as hardware tensile strength, which are of importance in the use of materials in a normal atmospheric environment, are generally quite widely available and it is therefore on the special properties of materials in the vacuum and radiation environment of space that the Materials Section concentrates. These are (i) the degree to which a material 'outgasses' under vacuum (and measurement of the proportion of these 'outgassed' products which may recondense on the cold surfaces of a spacecraft), and (ii) the thermo-optical properties of surface finishes and the degradation of these properties due to ultraviolet and particle radiation.

With the advent of the manned Spacelab project the flammability and toxicity of materials have become very important properties from the point of view of crew safety. The ESTEC facilities are among the very few laboratories equipped to perform this type of work.

A significant amount of the Section's work is devoted to the analysis of 'material' failures and to evaluation of the adequacy of manufacturing processes for particular space applications. In addition routine contamination monitoring is carried out at the major vacuum test facilities used in Europe by ESA to test its spacecraft (at CNES, IABG and CNES), to ensure that no spacecraft degradation occurs during these tests.

The Section publishes data on materials and processes in the ESA PSS/QRM series of documents to assist the Agency's spacecraft contractors in their choice of materials for spacecraft fabrication.

CONCLUSIONS

The work of the Product Assurance Division covers a wide range of activities from theoretical reliability assessment to a thorough technical understanding of advanced electronics and materials technologies. In each and all of these fields, progress and developments are rapid and it is constantly necessary to review, in co-operation with industry, the methods and practices employed to ensure that they are effective and above all that they are *cost-effective*. □

Major Spacecraft Hardware Testing in Europe

K.H. Heffels, Test and Engineering Services Division, ESTEC

Flightworthy or not? – that is the key question which must be answered during a spacecraft flight-readiness review, where flightworthy means that the spacecraft will survive the stringent environmental conditions during launch and subsequent mission phases and will fulfil all its specified functions for the expected duration of the mission. Unfortunately, reuse of earlier hardware designs and even the best design analysis are no insurance against manufacturing deficiencies or erroneous handling during integration. Since ground simulation will always be an approximation of the true flight environment and ground testing at spacecraft level will never span periods approaching mission durations, a judicious combination of analysis and testing is always necessary to arrive at a flightworthy spacecraft.

MAJOR ENVIRONMENTAL TESTS

Within the scope of this article, major environmental tests and associated physical measurements are either those performed at spacecraft level or those that require facilities not dedicated to the testing of specific parts of spacecraft, such as antenna testing. The purposes of these tests and measurements as performed in the course of ESA projects, the type of facilities required, and any major test limitations can be briefly described as follows:

Sinusoidal vibration tests
Sinusoidal vibration tests are performed:
- to demonstrate the ability of a spacecraft to withstand such vibrations, especially during launch
- to determine resonant conditions as an aid in and to verify structural design analysis, and
- to determine constraints for other, subsequent vibration tests.

The tests are performed for each major spacecraft axis, normally on an electromechanical shaker. Input levels are controlled and response is measured by accelerometers mounted at critical points on the spacecraft.

Random vibration tests
The purpose of these tests is to demonstrate that the spacecraft can withstand the predicted vibrational environment of the launcher. Various vibration levels are imposed simultaneously on the spacecraft over a wide spectral range. In that the induced spacecraft motion is neither cyclic nor repetitive, random vibration testing is fundamentally different from sinusoidal testing. It is usually performed by connecting the spacecraft rigidly via interface structures to an electrodynamic vibrator. While this test is important for design, and particularly manufacturing quality verifications of a spacecraft structure, its realism is questionable in that it is presumed, incorrectly, that the transfer of vibration from launcher to spacecraft occurs only via the solid spacecraft/launcher interface. This and the dynamic response characteristics of the spacecraft result in over- or underestimating of certain of its elements. The realism of the test decreases with increasing spacecraft size, mass and complexity.

Acoustic noise tests
The purpose of this test is the same as that of the last, except that spacecraft vibration is not induced via the launcher/spacecraft interface, but by generating an acoustic environment similar to that to be experienced in the nose cone of the launcher. Acoustic vibration tests are conducted in reverberant chambers using powerful 'loudspeakers' to simulate the noise levels of particular launchers. These tests are also not fully representative of the vibration experienced by a spacecraft under true flight conditions, since they ignore the input via the rigid launcher/spacecraft interface. Nevertheless, they are more representative than the random vibration test on a shaker for large, heavy and complex spacecraft.

Thermal balance tests
The purpose of this test is threefold:
- to demonstrate adequate thermal control to maintain the spacecraft temperature within prescribed limits when in orbit
- to verify the spacecraft's thermal design, and
- to verify or to provide inputs for the mathematical thermal model of the spacecraft that predicts its thermal behaviour in orbit.

The vacuum, Sun illumination and the otherwise near-black absorbing environment of space is simulated in

Figure 1 – Geos being lowered into ESTEC's Heat-Balance Facility.

these tests and the spacecraft's response in operating and nonoperating modes is monitored via a large number of thermocouples attached at strategic points to the spacecraft.

Thermal vacuum tests
The object here is to ensure that a spacecraft will perform properly in vacuum at and between design temperature extremes. Thermal cycling tests between specified limits are usually included. In contrast to heat-balance testing, thermal vacuum work requires neither Sun simulation, spinning, nor solar-aspect control equipment, which means that the facilities needed are much simpler and less expensive to operate. The decision to combine thermal-vacuum tests with heat-balance tests in a heat-balance facility depends on a trade-off between test duration, cost and facility availability.

Rapid depressurisation tests
The purpose of this test is to verify that a spacecraft will not be damaged by the depressurisation encountered during launch ascent. Depending on the venting rate of a spacecraft, considerable pressure differentials can occur across its shell and across the surfaces of the instruments that it carries.

Mechanical functioning tests
The ever-increasing mechanical complexity of European spacecraft with deployable solar arrays, booms and antennas, etc., necessitates ground tests to check that the release, deployment and locking mechanisms of such appendages will function properly. The test facilities needed for Geos, for example, involve large vacuum installations to reduce air drag, with built-in spin machines for determining changes in spin rate during deployments.

Electromagnetic compatibility (EMC) tests
EMC tests are conducted to demonstrate that the electrical interference levels between the various units of the spacecraft and the disturbance that it causes in the surrounding electromagnetic field are within specified limits. Apart from the instrumentation needed to generate, measure and record noise levels over a very wide frequency range, the tests at spacecraft level require large shielded rooms to eliminate external interference.

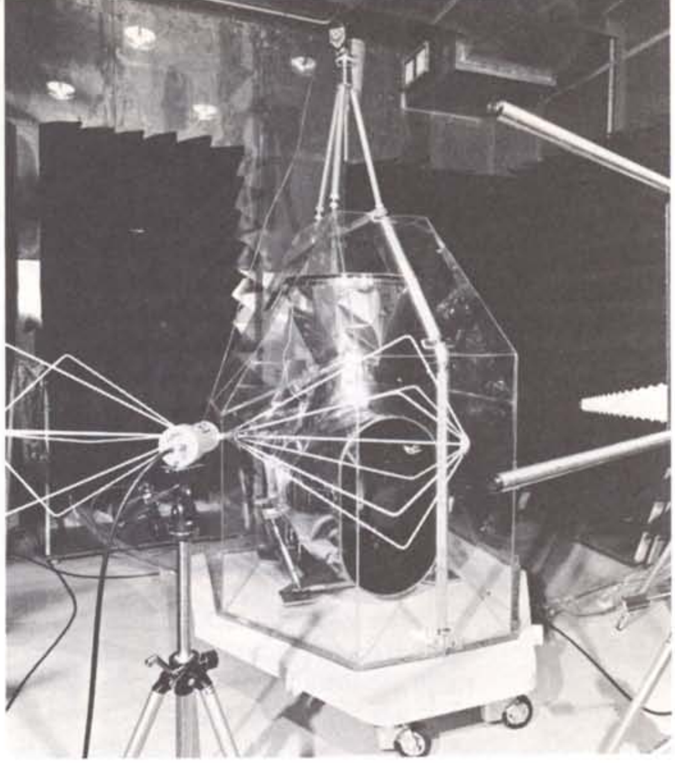
Magnetic tests
Since the missions of several European scientific satellites include the measurement of magnetic fields in space and since the magnetic moment of spacecraft hardware can interfere with some attitude-control subsystems, tests are performed to verify:

- that the spacecraft itself will not disturb the surrounding magnetic field beyond specified limits, and/or
- that the on-board subsystems and scientific instruments will not interfere with each other.

The ground facilities must permit the measurement of permanent, induced and stray magnetic moments and fields with sufficient accuracy. This involves compensation for the Earth's field and its fluctuations, and for any manmade disturbances at the test site.

Physical measurements
Physical measurements are made at spacecraft level of mass, centre of gravity, moments of inertia, balancing and alignment. These properties must lie within specified limits for the various spacecraft configurations when stowed for launch, for example, and when its arrays and sensors are fully deployed. Just as in the electrical performance tests, physical measurements are also made after, as well as before, the environmental tests to ensure that no physical changes have occurred during these stages.

Figure 2 – Meteosat radiometer ready for testing in ESTEC's EMC chamber.



MAJOR ENVIRONMENTAL TEST INSTALLATIONS IN EUROPE

The environmental tests outlined above are within the capabilities of European test installations for ongoing European projects. Almost all the test facilities are located in three test centres, ESTEC in the Netherlands, IABG in Germany, and CST (Centre Spatial de Toulouse) in France, and together they represent an investment of more than 35 million dollars.

ESTEC has a wide range of facilities capable of performing almost all necessary testing of spacecraft weighing up to 500 kg, with maximum dimensions of the order of 2.4 m. Acoustic noise, magnetic and linear-acceleration tests at spacecraft level, however, are usually conducted at IABG, and linear-acceleration tests can also be performed at CEA-CESTA in Bordeaux.

The most outstanding facility at ESTEC is the Dynamic Test Chamber. With an internal diameter of 10 m and height of 14 m, it is unique in Europe. It was originally built for high-precision measurements of the physical properties of spacecraft and high-precision dynamic balancing, but it is now also used for other tests, ranging from satellite boom-deployment studies to ejection testing of the large Ariane launcher fairing (8.65 m long and up to 3.20 m in diameter).

Two other important items at ESTEC that merit mention here are the heat-balance facilities, providing solar simulation to a maximum of 1.3 solar constants and thermal cycling in the 193-323 K range at spin rates adjustable from 0 to 20 rpm, and a 14 t shaker with a maximum force capability of 133 kN peak in sine and 142 kN rms in random mode, a frequency range of 5-2000 Hz, and a maximum acceleration of 75 g.

The Centre Spatial de Toulouse has the largest heat-balance facility in Europe with a maximum simulated solar intensity of 1.5 solar constants, and a thermal cycling capability in the 100-360 K range. It can also handle test items weighing up to 1000 kg, which is about twice the capability at ESTEC. Consequently, Europe at present relies completely on CST for the heat-balance testing of spacecraft in the OTS, Marots and Meteosat size and mass classes.

CST's other main facility is a large electrodynamic vibrator giving a peak force of 170 kN in sine mode and 150 kN rms force in random mode, and a maximum acceleration of 90 g, with a frequency range of 5-2000 Hz. For acoustic-noise, EMC, linear-acceleration and magnetic-test facilities, CST relies itself on other European test centres.

IABG's centre is noted for its magnetic and acoustic test facilities. Its magnetic test facility is by far the largest of its type in Europe, if not in the World. The residual field within the test volume is 10^{-5} times Earth's field intensity, and a field homogeneity of $<5\,\gamma$ and a stability of $\pm 0.5\,\gamma$ are provided in a spherical working area 3 m in diameter. A maximum magnetic field intensity of 50 gauss at 0.1 to 3 Hz can be provided for magnetisation and demagnetisation.

IABG's acoustic test facility is of the reverberating-chamber type. A sound level of 150 dB (ref. 2×10^{-4} dyne/cm^2) can be generated in the 760 m^3 test volume and the frequency range 40-10 000 Hz can be covered.

Other major installations at IABG include a thermal vacuum facility, for thermal cycling in the 100-363 K range, a shaker able to deliver a maximum acceleration of 100 g, and a heat-balance facility suitable for test specimens of ± 500 kg.

In general, it can be said that IABG is able to undertake almost all important environmental tests for small satellites, the only major exception being linear acceleration testing. Like the other two centres, IABG relies on the

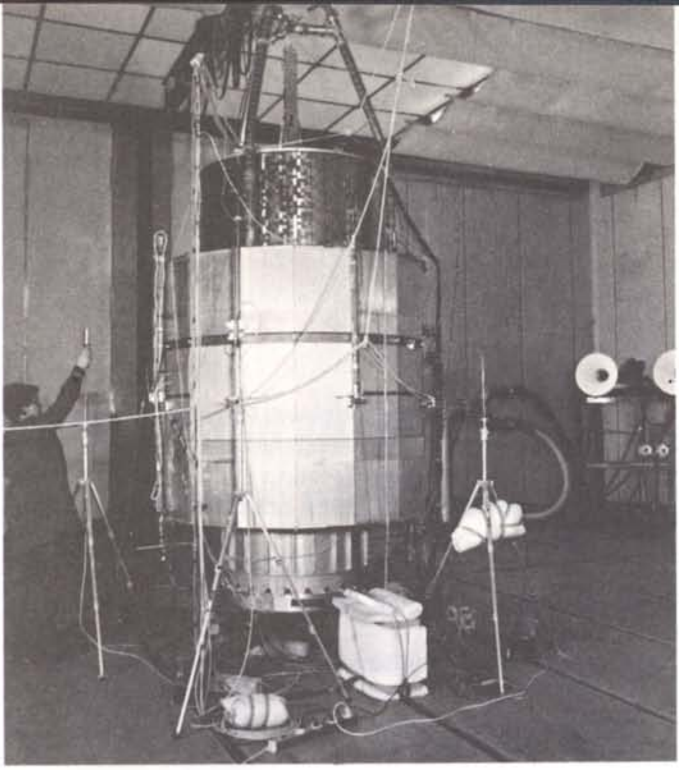


Figure 3 – ISEE-B and a structural model of ISEE-A in the acoustic noise chamber at IABG.

large, 9 m radius centrifuge at CEA-CESTA, where a 4 t load can be accelerated to 50 g.

UTILISATION OF TEST-FACILITY RESOURCES IN EUROPE

The sharing of the test load between the various European centres is subject to a number of constraints, the first being the capability limitations of the facilities themselves. Limitations exist not only for the environmental test facility proper, but also for a wide range of necessary auxiliaries; these include permissible crane height in a building, facilities for contamination control and availability of adequate areas for integration and checkout near the test facilities. The size and weight of OTS, Meteosat and Marots, for example, rule out all but the Centre Spatial de Toulouse for heat-balance testing. On the other hand, Geos, ISEE-B and Exosat have been heat-balance tested at ESTEC, because of pressure of work at the Toulouse facilities.

The second constraint stems from the permissible workload for a given facility. Any annual loading figure of more than 60% must be regarded as unrealistic in that it will not provide adequate contingency for the repeating of tests, for schedule changes in hardware test-readiness dates or, last but not least, for normal maintenance, repair and updating of the test equipment.

As a third constraint, experience has shown that it is unwise to allocate the same type of test for the various spacecraft models (structural, thermal, qualification, prototype and flight) to more than one facility, because of differences in test concept and performance, in test-gear adaptation and in test and evaluation procedures. Results obtained with a variety of spacecraft models in different facilities are then not directly comparable and the mathematical modelling used to derive the ultimate flight performance from test results is made unnecessarily complex.

Fourthly, by not involving more centres in covering a test programme for a given project than absolutely necessary for technical reasons, the overall duration and therefore cost of testing can be reduced, since fewer movements of spacecraft and the associated mechanical and electronic ground-support equipment are needed. In addition, the number of technical, schedule and contractual interfaces is minimised.

Finally, and most importantly, the installation and use of facilities in Europe are governed by the 'Convention for the Establishment of the European Space Agency by its Member States'. In essence this stipulates that the Member States and the Agency should make the best use of existing facilities, which means that new facilities must not be built whilst existing installations are not fully exploited. No major new investments in environmental test installations will therefore be made by ESA as long as there is suitable reserve capacity elsewhere in Europe.

During 1976, a total of 616 environmental tests and related measurements were made for ESA projects under the overall planning control of the Test Services Division of the Department of Development and Technology. This figure does not include all the tests made at the premises of spacecraft hardware manufacturers, typically at unit or subassembly level. Facilities used during 1976 in addition to those at ESTEC were primarily those at CST in France and IABG in Ottobrunn, Germany. A few special tests (about 2% of the total) had to be made elsewhere; at the University of Liège, Belgium, at DFVLR in Porz-Wahn, Germany, and at SNIAS and CEA-CESTA in France (Table 1).

The figures for magnetic and EMC testing in ESTEC are particularly high as they include a large number of experiment payload package tests for the Agency's Geos and ISEE-B scientific satellite projects. The small number of tests performed at CST may be misleading because the

TABLE 1

Distribution of Tests in Europe in 1976

	Location			
Class of Facility	ESTEC	CST	IABG	Others
Vibration	116	4	10	2
Acoustic	16	—	5	1
Heat balance	15	3	11	—
Thermal vacuum	54	—	2	2
Magnetic	148	—	10	—
EMC	61	—	4	—
Mechanism and dynamics	8	—	—	—
Physical measurements	81	6	12	—
Others	34	1	4	6
TOTAL	533	14	58	11

numbers do not reflect the considerable effort made in 1976 to prepare the facilities for the extraordinarily heavy test load expected during the first half of 1977, when two projects, each with two spacecraft models, were to be tested there simultaneously.

THE EVOLUTION OF ENVIRONMENTAL TESTING

The continual evolution of space activities in Europe and elsewhere, from the first scientific and later applications programmes to the prospect of manned missions and large orbiting space stations in the not too distant future, has had and will continue to have a considerable impact on test requirements and related environmental test facilities. While some of these developments primarily affect the total number of tests, others result in changing performance requirements for environmental test methods and facilities, making existing ones obsolete or demanding new ones.

Over the years, the model philosophy for space projects has changed considerably. While not so long ago it was not unusual to build up to six spacecraft models (e.g. a structural, thermal, a development, a prototype, a flight and a fully fledged flight-spare model) for a single project, it is now becoming the norm to build only three or even fewer models. In addition, knowhow and experience in flight hardware design and manufacture is being accumulated so rapidly that it is not unthinkable that, at least for some projects, only one model will be built. Eventually, it may be economical to flight-test the spacecraft and not to subject it to environmental testing on the ground at all, bearing in mind the future possibility of repairing hardware in space. Tests are also shifting more and more from the fully integrated hardware level to the sub-assemblies and units that make up the hardware.

All of these trends tend to reduce the size of the facilities required, the number of tests and thence the workload of large test facilities. On the other hand, the size, complexity and performance requirements of space hardware are growing rapidly; it must be remembered that the mass of space hardware has increased by three orders of magnitude from Sputnik to Spacelab in less than 25 years. Early spacecraft were conceived for mission durations of only a few months and now lifetimes of up to 10 years are being considered for unmanned missions. These aspects exert increased and changing demands on test requirements.

New major environmental facilities of the conventional type, compatible with the larger hardware destined for space application, need a lead time of several years before they can be ready for use. They are also extremely expensive, a new heat-balance facility compatible with a spacecraft using the full volume of the Ariane shroud costing more than 10 million dollars, this leaving aside hardware compatible with the Space Shuttle's launch capability.

To ensure that any new facilities in Europe are justified and will be adequate for the coming years, a long-term programme for the building of space hardware in Europe must be established, looking at least 10-15 years ahead. Only a programme of this type will allow testing needs and methods to be established with sufficient confidence, and permit the requisite trade-offs between alternative test methods, design and manufacturing capabilities, cost and schedule to be made.

Systems engineers, design specialists and test engineers in ESTEC's own Department of Development and Technology are striving to make these trade-offs, to establish a long-term flight qualification programme, including test requirements and methods, and to derive a sensible long-term investment strategy for test facilities commensurate with future space projects. □

Senior Staff in ESTEC's Department of Development and Technology

Monsieur J.F. Lafay (45 ans) est français. Il a obtenu le diplôme de l'Ecole Supérieure d'Electricité en 1953. Il a successivement été employé à la Compagnie des Compteurs, à la Société MATRA puis à la SEREB où il occupait le poste de Chef du Département DIAMANT. Il a joint l'ESRO en 1965 où il a occupé les fonctions de Chef du Projet ESRO IV, puis de chef des Etudes de Faisabilité. Il est actuellement Chef du Bureau OSTA (Evaluation des Systèmes et des Technologies).

Dr. K.H. Heffels (52) is German. In 1955 he graduated from the Technical University of Hanover, Germany with a thesis on the preparation of scandium and rare earth metals. From 1955 to 1965 he held various positions with Union Carbide Corporation in the United States and Belgium, and was engaged in the development of refractory metals and semiconductor materials and devices. In 1965 he joined the Energy Conversion Division of the Department of Development and Technology, ESTEC, and became Head of the Division in 1968. In 1976 he was appointed Head of the Support Services Group.

Ingénieur civil électricien-mécanicien diplômé de l'Université de l'Etat à Liège (Belgique) en 1953, M. J.E.J.G. Toussaint a commencé sa carrière au service de la 'Bell Telephone Manufacturing Company'. Il reçu le grade de 'Docteur en Sciences appliquées' de l'Université de Liège en 1961, et depuis est 'chargé de cours' pour l'enseignement de l'Electronique dans cette Université. Engagé par l'ESRO en 1963, M. Toussaint devint un des fondateurs de la Division 'Instrumentation'. Ses premiers travaux portèrent sur les équipements de télémesure et de télécommande embarqués des premiers satellites de l'ESRO, et sur les installations au sol. Il prit en 1968 la direction de la Division, agrandie par la gestion des équipements électroniques pour la vérification des satellites. Lors de l'introduction des satellites d'application dans les programmes de l'ESRO, M. Toussaint devint Chef du Bureau des 'Systèmes Electroniques', et plus récemment, il fut promu Chef du Groupe 'Technologie des Charges Utiles'.

Mr. E. Slachmuylders (41) is Belgian. He graduated in Electro-mechanical Engineering at the University of Ghent, and in Aeronautical Engineering at the California Institute of Technology. After several years of work, mainly involving automatic control, and a period at Goddard Space Flight Centre, he joined ESRO in 1964 and became Head of the Attitude and Orbit Control Division on its creation in 1968. In 1975 he became Head of the Spacecraft Technology Group.

In Brief/En bref

(1)

Le pavillon de l'ESA au 32ème Salon du Bourget

L'ESA a participé au 32ème Salon international de l'Aéronautique et de l'Espace, du 2 au 12 juin au Bourget, en présentant un large panorama des programmes en cours dans un pavillon de 500 m². Ce pavillon jouissait d'une situation très favorable aussitôt après l'entrée principale (porte sud) en face du pavillon des Etats-Unis, devant le hall A et à côté du pavillon du CNES.

Les visiteurs sont venus encore plus nombreux que par le passé – 463 627 au lieu 417 912 en 1975, soit une augmentation de 10% – et le pavillon de l'Agence a bénéficié de cet intérêt renouvelé.

Après le passage Monsieur V. Giscard d'Estaing, Président de la République française, au cours de l'inauguration officielle, le pavillon a été le lieu de nombreuses réunions, rencontres et visites dont il faut noter en particulier une réunion du Directoire, la conférence de presse sur OTS du 6 juin par le Directeur général, les visites de Monsieur Sourdille, Secrétaire d'Etat français à la Recherche, Madame J. Sauvé, Ministre canadien des Télécommunications, Monsieur A. Bean, astronaute, Monsieur Ch. Lee, NASA, Directeur des Opérations du STS, Monsieur Rowe, Administrateur adjoint de la NASA, et de nombreux contacts des responsables des programmes de Télécommunications, du Spacelab et d'Ariane.

Exposé pour la première fois, le moteur HM7 – une maquette d'essais électriques – a tout particulièrement attiré l'attention des visiteurs: c'était, avec le modèle thermique de Geos, l'élément de 'hardware' le plus impressionnant. En outre, en liaison avec l'Agence, la NASA a exposé sur la zone statique l'avion Convair 990 utilisé pour les missions ASSESS et présenté au public la mission ASSESS II qui s'était déroulée peu de temps auparavant et dont les expériences étaient à bord.

(2)

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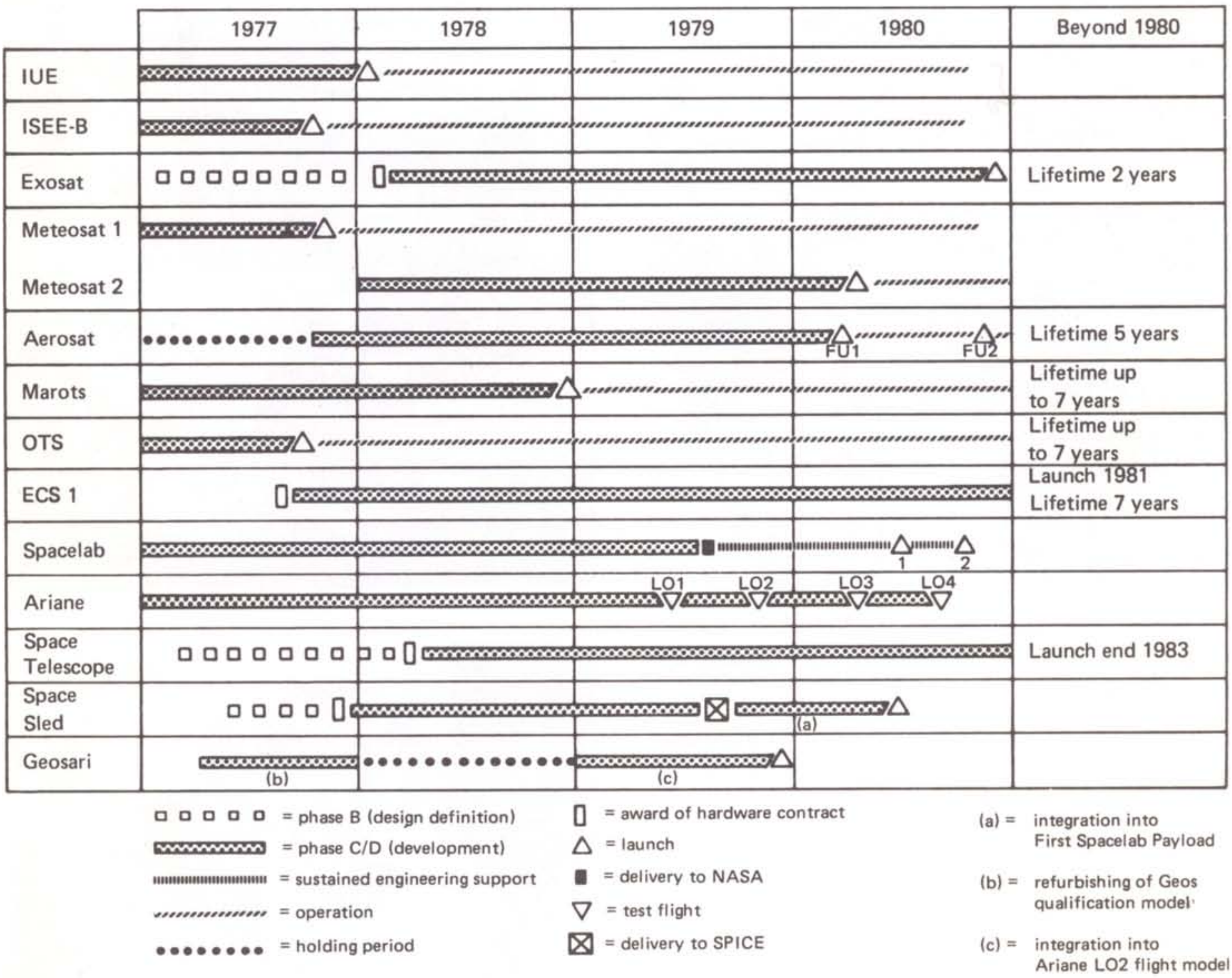
Director General Honoured by Austrian Government

In recognition of the good relationship that has developed between the Austrian Government and the Agency, the President of the Austrian Republic has bestowed on the Director General 'das grosse silberne Ehrenzeichen mit dem Stern'. This decoration was presented to Mr. Roy Gibson on 23 June in Vienna by Mrs. H. Firnberg, Federal Minister for Science and Research.

Projects under Development
Projets en cours de réalisation

THE ESA DEVELOPMENT AND OPERATION PROGRAMME (July 1977)

This special ESTEC issue of the ESA Bulletin does not carry the usual 'blue pages' of information on 'Projects under Development'. Nevertheless, as there have been important changes in schedules since the publication of ESA Bulletin 9, the overall-programme bar charts have been updated for presentation here.



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