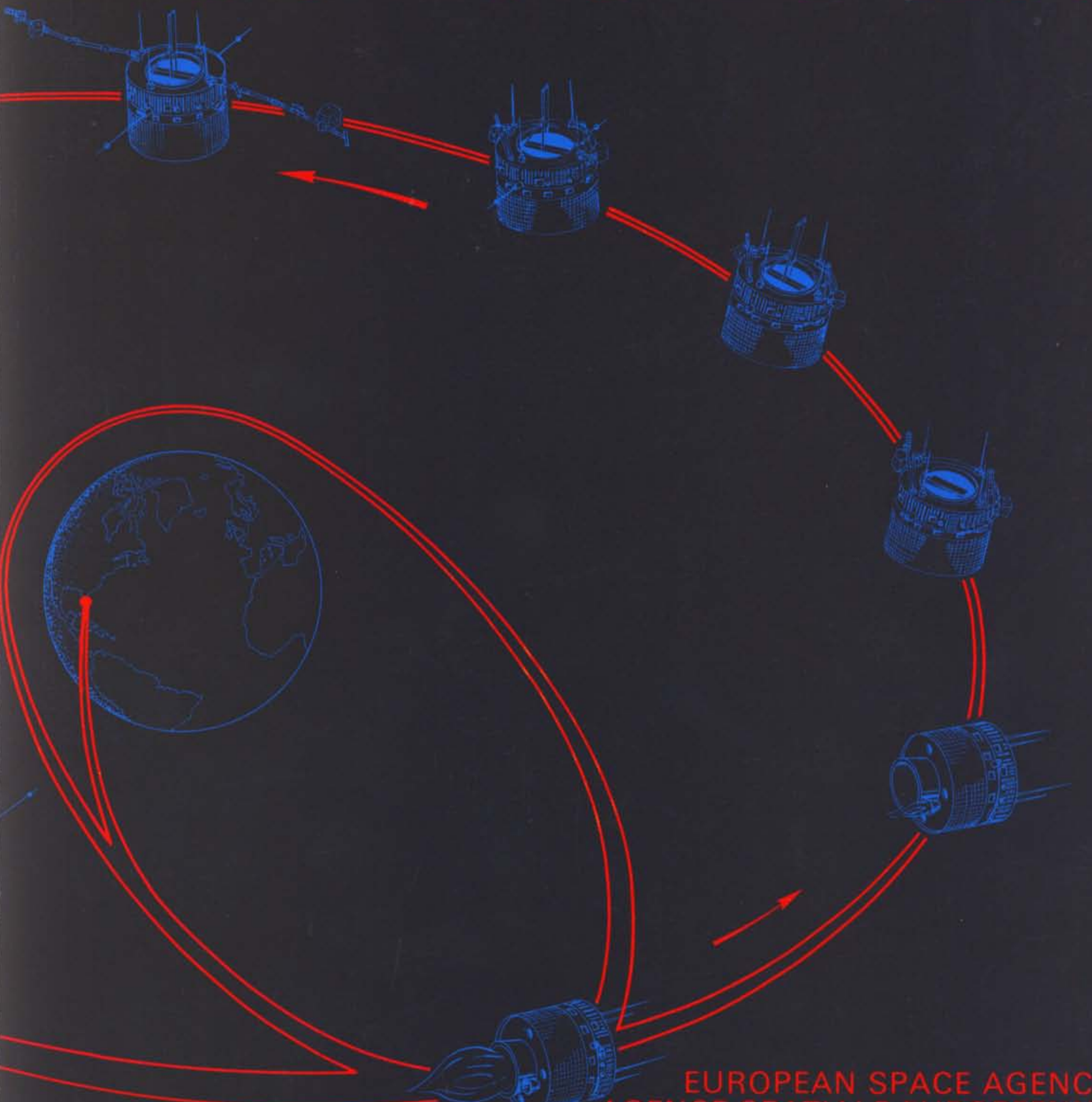
esa bulletin



No. 9 May/Mai 1977

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.

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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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Editorial Office/Bureau de la rédaction
ESA Scientific and Technical
Publications Branch
ESTEC, Noordwijk
Netherlands.

Editors/Rédacteurs
B. Battrick
T.D. Guyenne

Art Editor/Maquettiste
S. Vermeer

Circulation Office/Bureau de la distribution
ESA Space Documentation Service
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COVER/COUVERTURE:

The cover shows the Initial events in the Geos mission sequence.
La couverture montre la phase initiale des opérations de mise en orbite de Geos.

Geos Launch Failure and Rescue Operation

The Geos satellite is now orbiting and functioning well. Since it is widely known that the Delta vehicle failed to place the satellite into the foreseen transfer orbit, this simple statement needs some explanation.

At the time of writing, a formal investigation by NASA of the Delta failure is in progress, but it seems evident that the clamp band, which held together the second and third stages of the rocket, opened prematurely, with the result that the two parts were coupled only by the third-stage ignition cable. When the spin-up rockets operated, the cable snapped, and the required spin could not be imparted to the third stage. This stage ignited properly, but without gyroscopic stability, and without correct orientation the correct trajectory could not be obtained.

In the light of these events, it is surprising that the satellite/third-stage combination did not become unstable – part of the reason may lie in the excellent balance condition achieved for satellite and rocket stage.

The first indication of failure was received in the Mission Director Center at Cape Canaveral about twenty-five minutes after lift-off, when it was observed from real-time Geos telemetry data that the spacecraft appeared to have no spin but only a slow roll. In addition, the satellite was undergoing a large coning motion. Some time later a NASA orbit prediction gave an apogee height of 12 000 km – only one-third of that required for injection into a geosynchronous orbit.

The mission was not abandoned. The first priority was to stabilise the spacecraft, and agreement was quickly reached between the operations team at the European Space Operations Centre (ESOC, Darmstadt, Germany) and the project team at the Cape, to spin-up and manoeuvre into a more favourable attitude (the Sun was shining on the underside of the spacecraft and overheating the UHF antenna mechanism).

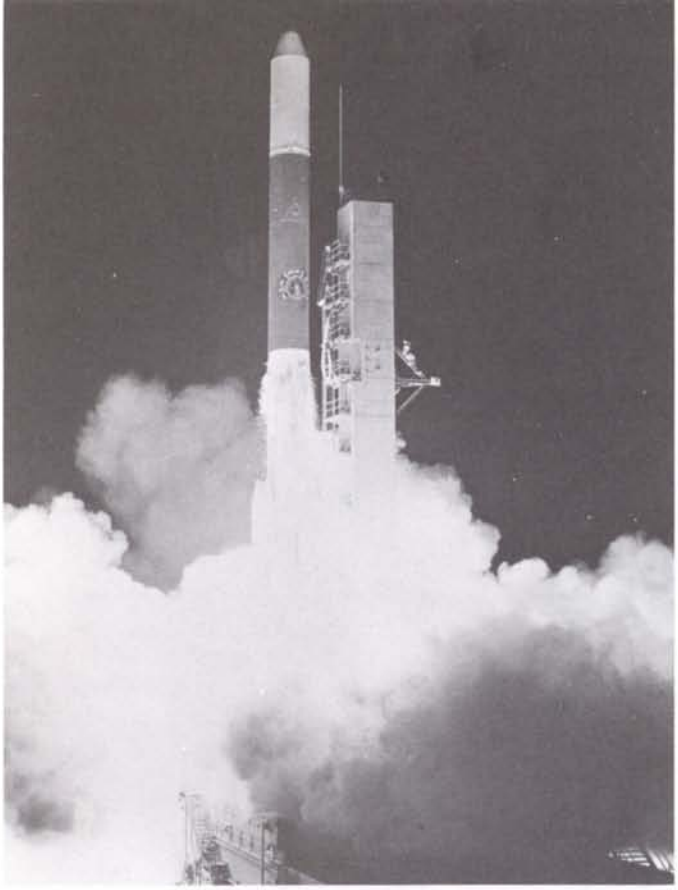
Commands were transmitted from Darmstadt to the NASA ground stations, and the hydrazine system responded excellently to these unscheduled early manoeuvres. After spin-up to 12 rpm, the coning motion rapidly died down and it was then possible to change the attitude to bring the solar-aspect angle within the prescribed range.

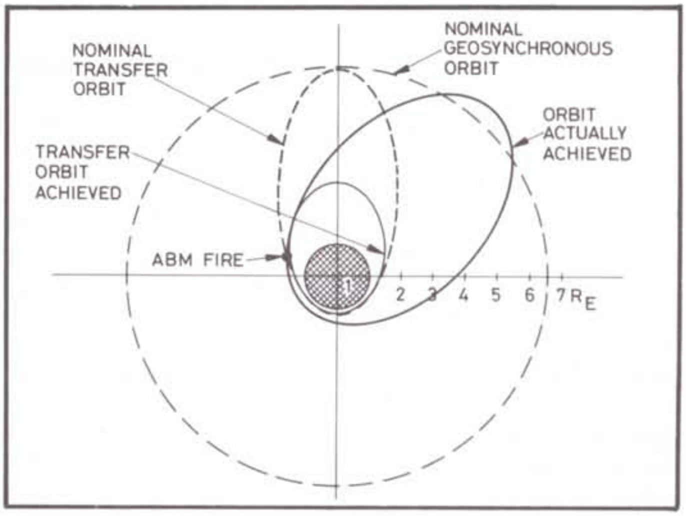
The satellite was safe for the time being, and means of raising the high point of the orbit were considered. By firing the spacecraft's novel apogee motor at the right point, a geosynchronous apogee could certainly be achieved (although a true geostationary orbit was excluded), but what would the optimum orbit be in the new circumstances?

Intensive mission analysis was immediately undertaken by teams at ESOC, ESTEC, and Goddard Space Flight Center, and three candidate orbits were chosen for detailed investigation. The experimenters participating in the launch campaign at the Cape were informed of the situation in the afternoon of 20 April, and a meeting was convened for 26 April at ESOC to choose an orbit.

It soon became evident, however, that radiation in the degraded orbit was intense and was affecting the solar array such that the critical power level necessary for apogee-boost-motor ignition was very quickly approaching. Consequently, an early decision had to be taken to obtain an improved orbit; this decision was made on Saturday 23 April, an elliptical orbit with 12 h period being chosen as this would enable the satellite to spend significant measuring periods in the vicinity of geosynchronous altitude.

Computations for the reorientation of the spacecraft and the firing of the motor were commenced, and early on Monday 25 April, the spacecraft was placed into an orbit





After the Thor-Delta launcher had failed to place Geos into its nominal transfer orbit (see cover of this issue) and only achieved the degraded transfer orbit shown above, the spacecraft's apogee boost motor was fired at the point indicated to achieve a 12 h eccentric orbit. This orbit gives very limited coverage in regions of scientific interest.

with an apogee of 38 318 km, a perigee of 2113 km and an inclination of 26.3°. Deviations between the planned and measured orbits were remarkably small, that at apogee being only 50 km.

A new schedule of spacecraft operations and experiment switch-on procedures was drawn up at the scientists' meeting the following day and was put into action the same evening. The operations were compressed as much as possible, in order to obtain the earliest start to scientific data gathering. These operations were too complex to be given here in detail, but on 27 April the UHF link was established, with high-speed data being received at Odenwald and processed at Darmstadt. The first experiment was tested on 29 April, and by 3 May all experiments were shown to be functioning correctly.

The new orbit is more favourable as far as radiation is concerned, and the alarming loss of solar-array power has been halted. The spacecraft is fully operational and is behaving well. One small detail mars an otherwise perfect performance in that one of the long axial booms deployed to only 1.95 m instead of the foreseen 2.50 m, but this deficiency will not prevent operation of the related experiment.

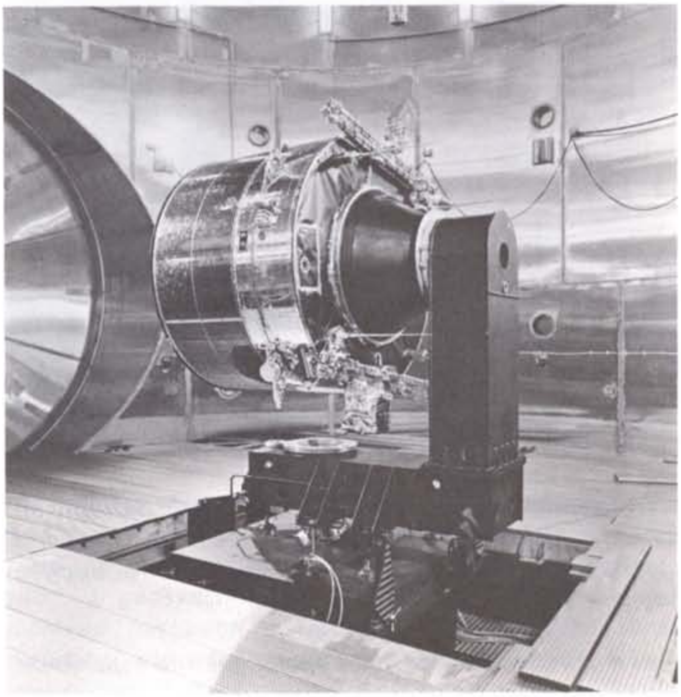
In conclusion, the technical state of the rescued Geos is good, although all those connected with the programme naturally very much regret that the original scientific objectives of the mission can not now be maintained.

It should be borne in mind when reading the articles that follow that they were written prior to the Geos launch, with the underlying assumption that the intended geostationary orbit would be achieved.

The Special Technical Features of Geos

D.E. Mullinger, Geos Division, ESTEC, Noordwijk, The Netherlands

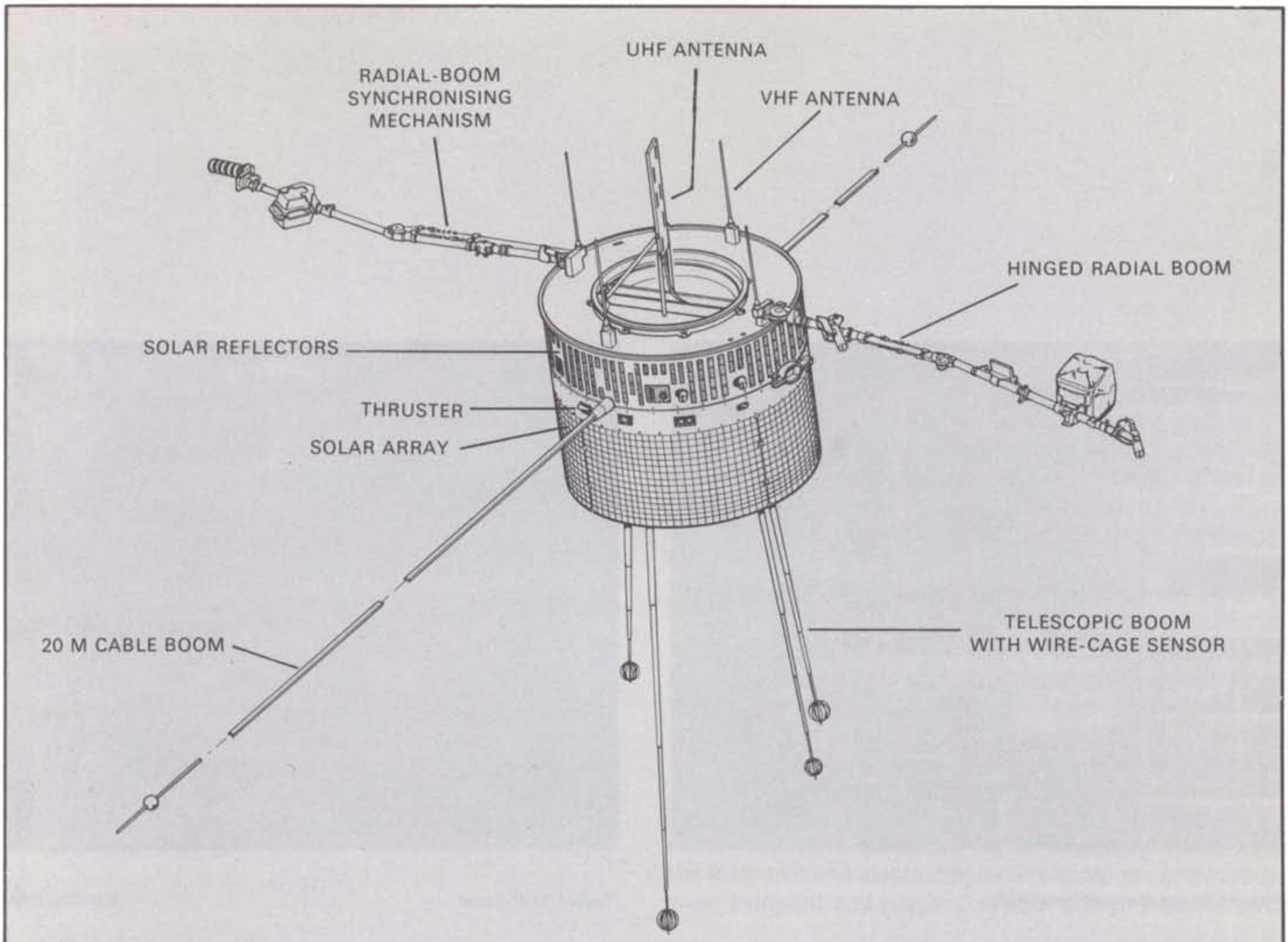
The Geos satellite is best regarded as an observatory which operates in the magnetosphere and which contains many special instruments. The observatory's design is dictated by the nature of the measurements to be made, and the sophisticated nature of the experiments has demanded very special facilities. The satellite therefore contains complex assemblies of novel equipment. The reliability needed to carry out the mission cannot be obtained by streamlining or simplification, as this would limit the measurements. Instead, duplicate facilities are provided, so that the observatory will continue to operate even if one or other of its elements should fail. This redundancy adds, however, to the complicated nature of the satellite. It has been particularly necessary to protect thoroughly against failure because so much of the satellite equipment is new, and consequently there is no long orbital experience to rely upon.



From its conception, it was recognised that Geos would need to be a very special satellite to carry out its mission. Indeed, the competitive tenders submitted by industry for its development were evaluated principally for their response to the novel features.

What are these features?

- Geos will be the first ESA spacecraft to be placed at geostationary altitude, and so has inaugurated a new era of injection procedures and orbital control. Because the satellite will be in continuous communication with the ground around the clock, a new ground station and computer complex has been constructed to receive and process the data (existing stations would have been overloaded).
- To reach geostationary altitude, the satellite carries its final propulsion stage, the apogee motor, inside the structure. A European motor has been developed especially for the mission and it has to comply with strict magnetic-cleanliness requirements.
- Once at geosynchronous height, the satellite must be manoeuvred and directed to the correct station in orbit, and this requires an auxiliary propulsion system. The system is also needed for keeping the satellite on station and maintaining pointing control of the spin axis. Hydrazine is the most effective means of propulsion for a satellite of this type, and Geos marks the first flight of a completely European-developed system. The thrusters that have been developed are more powerful than any previous European devices.
- The satellite will transmit data at UHF as well as VHF, a new feature required by the unprecedented information rate of more than 100 000 bit/s (this is equivalent to the transmission of four closely printed pages like these every second). This high rate, coupled with the continuous nature of the radio link, means that the data rate received at the ground will be two orders of magnitude higher than for any previous scientific satellite.
- Geos is the first European satellite to be controlled by an on-line computer to exploit and optimise its experiments automatically. The control loop is closed



Orbital configuration of Geos

by a fast-acting command uplink and direct participation by the experimenters is possible at any time. Easy access to the ground computer makes an on-board computer unnecessary.

- Geos carries the first European transponder giving full tracking capability from US and European ground stations (GRARR system).
- In order to deploy scientific instruments beyond the confines of the satellite body, Geos carries an arrangement of eight extending booms which makes its dynamic behaviour more complex than that of any other European satellite.
- The payload imposes unusually stringent requirements as regards minimal magnetic electric and electromagnetic interferences, and these have been successfully met.

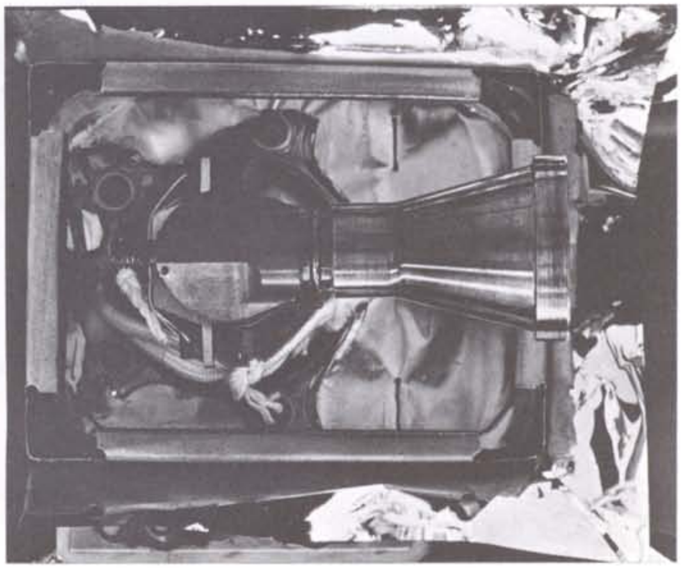
The development and testing of the spacecraft has occupied nearly four years, the work being carried out by the STAR consortium and associated companies under the management of BAC as Prime Contractor. Sixteen major companies in eleven countries have participated in the development and the work force has totalled many hundreds. The development of the experiments has in some cases lasted even longer, and several institutes in different countries joined forces to produce the sophisticated equipment needed.

APOGEE MOTOR

The motor posed two main questions for the design of the satellite – which type of propellent should be chosen, and would the motor contaminate the spacecraft? Extensive study was undertaken before two decisions could be made – to use a solid motor of high (but not too high) performance, and to retain the burnt-out motor case.

The solid motor offers the advantage of ease of handling and operation. The natural preference was for a European motor, and the design chosen drew upon the experience available from the Sirio programme. Development was

Apogee motor ready for assembly



Hydrazine thruster

undertaken as a collaborative effort by two companies, SNIA Viscosa (Colleferro) and SEP (Bordeaux).

The decision not to eject the spent motor proved to be a wise one in view of the complex mechanisms that were subsequently needed elsewhere on the satellite. Nevertheless, the matter of contamination required a special effort. The exhaust could contaminate the satellite body during combustion, and outgassing after burning could interfere with scientific measurements. Special tests were made at the start of the programme to determine the effects of the plume on the surface of the spacecraft, and to find the extent of contamination on exposed sensors in the vicinity of the nozzle. This pioneering work showed that no danger was to be expected.

For magnetic cleanliness, the motor case is made of nonmagnetic titanium, but the arming device is driven by an electric motor. Several types of motor were investigated, culminating in the development of a special motor with magnetic compensation.

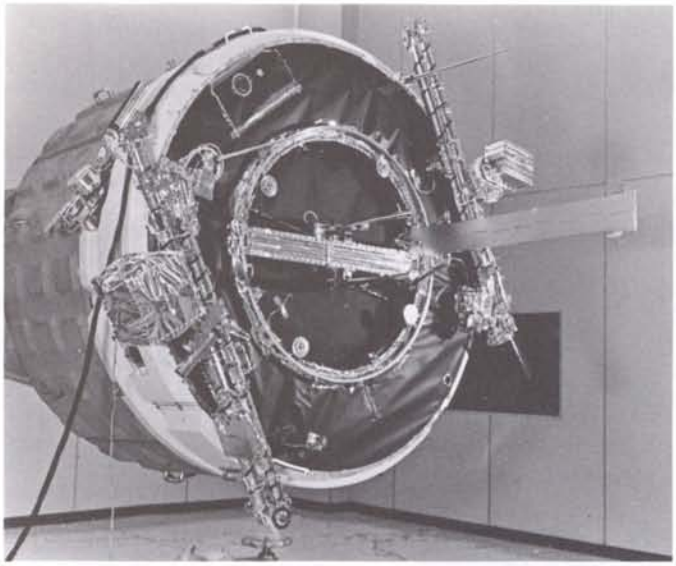
One valuable feature of the motor is that the case remains relatively cool during combustion (at less than 180°C). With the thermal insulation provided in the satellite, this limits the temperature rise of units inside the satellite body to only 3–4° after combustion

Full details of the motor and its development can be found in ESA Bulletin No. 8 (February 1977).

AUXILIARY PROPULSION SYSTEM

This system allows corrections to be made to the orbit, permits attitude manoeuvres and changes of spin rate, and allows the longitudinal position in orbit to be held or varied, to select the most interesting measurement base. It uses hydrazine, a monopropellent liquid similar to water in appearance but which, when passed through an iridium-bearing catalyst, decomposes at high temperature into its constituent gases of ammonia, nitrogen and hydrogen. Upon expansion through a thruster nozzle, a jet is formed which imparts an impulse to the satellite.

Geos carries about 30 kg of hydrazine in two teardrop tanks, and these are pressurised by helium, initially to about 30 atm. The hydrazine is conveyed by piping to six



UHF antenna

thrusters, which can be selected and operated by telecommand. There are two axial thrusters, one at the top and one at the bottom of the spacecraft body, which can be used to tilt and precess the satellite, two radial thrusters, which can be used to modify the orbit, and one spin-up and one spin-down thruster.

The thrusters are of entirely European manufacture. Their technology derives directly from development work carried out by Société Européenne de Propulsion (SEP, France) for both CNES and ESA. Using, the CNESRO catalyst, they develop a thrust of up to 15 N. Operation can be either continuous or pulsed over part of one spin revolution. The thrusters' development required the solution of many practical problems before fully acceptable performance could be achieved.

TELEMETRY

Earlier ESA satellites have transmitted information at low to medium rates (HEOS-2 32 bit/s and TD-1 700 bit/s). The experiments carried by Geos generate much more information and there are two major telemetry modes: low-speed scientific data at 11.91 kbit/s and high-speed data at 95.25 kbit/s. The total data stream of over 107 kbit/s can be transmitted only at high frequency, and Geos was then destined to be the first Agency satellite to work in the UHF region (S-band), the transmission frequency being 2.299 GHz (1 GHz = 1000 MHz). This represents a significant step forward in radio-frequency technology for ESA (VHF telemetry is used during transfer orbit and manoeuvres for spacecraft housekeeping data at 186 bit/s). The antenna used to beam the message to the ground is a slotted waveguide which is unfolded from beneath the satellite body. This antenna produces a toroidal beam, with maximum transmissivity in the direction of the ground station.

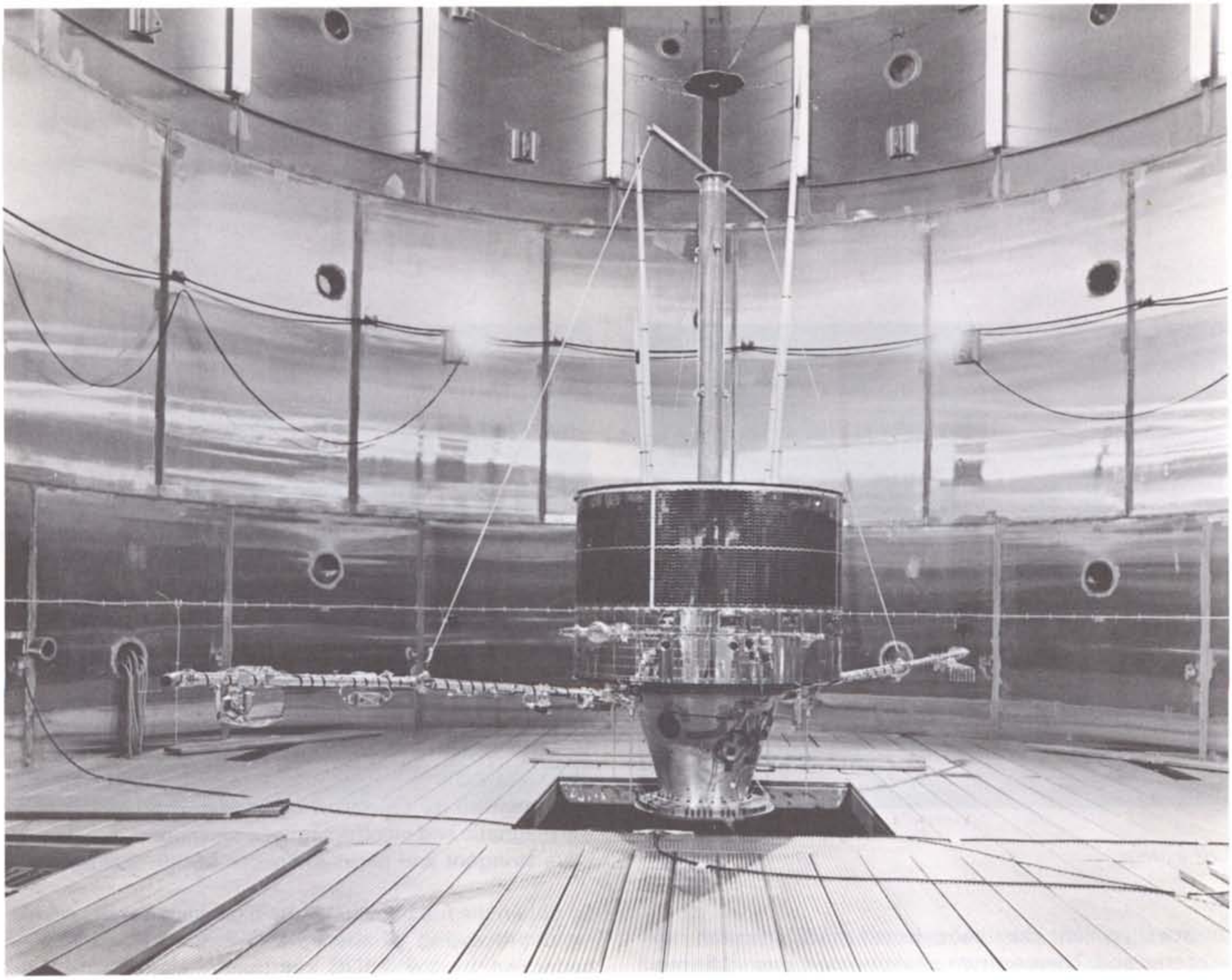
The UHF transmitters on board were developed by Thomson-CSF and the transistorised power stage is a novel feature for European flight hardware. In addition, the magnetic and electromagnetic cleanliness constraints were stringent and required special design features.

To obtain the full benefits of the high-capacity downlink, rapid processing of the data is essential and this is performed by the ESOC computers, as described elsewhere in this Bulletin.

Proper exploitation of the experiments demands a matching uplink, and this is provided by a PCM telecommand system the data rate of which (550 bit/s) is higher than that of many satellite telemetry systems.

BOOMS

At first glance, it is clear that Geos has an unusual collection of booms. They are needed to ensure the best possible operating conditions for the scientific instruments: the DC magnetometer is placed well away from any remaining magnetism in the satellite, the electron-beam guns are spaced at increasing distances from the central axis, and so on. The types of booms were not arrived at by chance; extensive studies and tests were made and all sorts of extending and unfolding structures were investigated to find the kind best suited for each purpose.



The requirement for accurately placing each S-300 'bird cage' field sensor in position led to the choice of the gas-driven telescopic booms (originated at RAE, Farnborough). The S-300 DC field experiment, on the other hand, was conceived for a cable-type boom, since this provides wide sensor separation (over 40 m tip-to-tip) with low mass and minimum perturbation of the environment. This cable must, however, have special properties: apart from carrying power and signal wires, it must be capable of transmitting a radio signal to the surrounding plasma for sounding purposes. It must also be easily coiled up and paid out, yet be strong enough to withstand the high tensile stress and the radiation environment. These requirements are satisfied by a miniature cable specially developed by Habia (Stockholm). Irradiation tests showed that the teflon base material can withstand up to 300 Mrad, which is several times the orbital dose.

The 3 m radial booms carry a variety of instruments and study showed that hinged element booms which unfold and lock into position under the influence of centrifugal force would be best for this function. Deployment is controlled by synchronising mechanisms which ensure that the satellite stays in a balanced configuration as the booms extend. More details are given on page 22 of this Bulletin.

The stability of Geos in orbit demanded much study during the design phase. The nightmare vision of those 20 m cables flailing uncontrolledly and ending up wrapped around the satellite body is obvious, but there are many possible types of instability. Evidently, it was not possible to test even a scale model in the zero-gravity, free-suspension conditions of orbit and so computer simulations of the dynamics were undertaken. It is difficult to obtain proper verification of such computational results, and groups at BAC, at ESTEC, and at Virginia Polytechnic Institute worked independently on the stability problem. Only when all three produced

Booms deployed

similar results was it accepted that Geos would be stable. However, to achieve this state of affairs it was found necessary not only to modify the original configuration, inclining the 3 m radials by 6° upwards and limiting the extension of the axial booms, but also to impose special requirements upon devices to damp out nutation.

To maintain the stability factor, strict computer control of the satellite moments of inertia budget was maintained throughout development. Finally, predictions were checked by measurements on a machine specially developed for Geos (another first). For maximum precision this machine was operated with the spacecraft in vacuum in ESTEC's Dynamic Test Chamber (see page 54, ESA Bulletin No. 8).

CLEANLINESS

Geos brings us into the era of the superclean satellite – it is magnetically, electrically and chemically clean in order to avoid interference with the scientific payload. Magnetic and electric fields in the magnetosphere at geostationary altitude are weak, and so great care has been taken to make the spacecraft as neutral as possible. Whilst it is easy to build a satellite structure from nonmagnetic material, it is not possible to eliminate all magnetic effects. Many semiconductor devices have nickel leads, for example, and the electric currents that flow in the satellite cables produce their own magnetic fields.

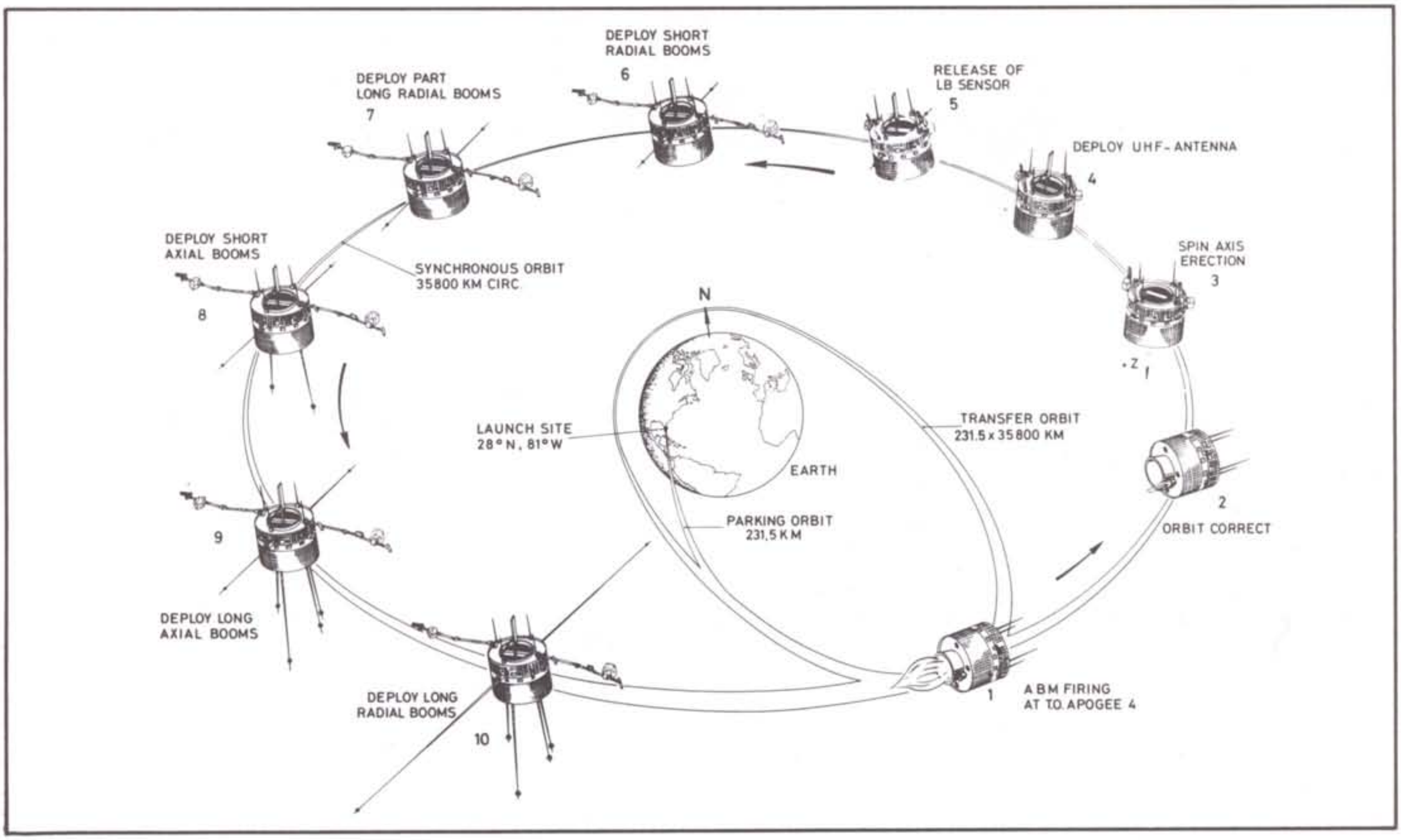
By careful design, verified by much testing of components and units, it has been possible to reduce the remnant magnetism, as seen by the on-board magnetometer, to only 0.3 gamma (less than 1/100 000 of the Earth's field), which is a small fraction of the 60 gamma measuring range of the instrument.

The solar array produces an electric field when illuminated; this has been neutralised by balanced design of the modules. Similarly, the magnetic effects have been reduced by using a self-compensating layout for the connecting leads.

The wave-field experiments operate over a very wide spectrum and require a vehicle which is 'quiet', i.e. does not generate electromagnetic interference. The 'noisiest' elements on board are the power converters and the spacecraft 'clock' (encoder standard frequency generator). The effect of these has been minimised by choosing a signal transfer clock frequency (47 kHz) well above the region of major scientific interest and by synchronising all converters at a still higher frequency (63 kHz). With other special measures, such as the provision of separate power and signal cable harnesses, the result is a satellite that more than meets the 'quietness' specification.

TABLE 1
Characteristics of the Geos Satellite

Total mass in launch configuration:	573 kg
Propellant mass	
– apogee motor:	269.4 kg
– hydrazine:	30.6 kg
Body size:	1645 mm dia × 1321 mm high
Maximum dimensions:	4766 mm from UHF antenna tip to S-300 long axial boom tip, 42.6 m from tip-to-tip of long radial booms.
Thermal environment:	−6° to +41° for units within body; minimum hydrazine temperature 3° at end of long eclipse with no battery power
Power:	more than 110 W at beginning of life, from 7200 solar cells
Telecommunications	
– downlinks:	186 bit/s and 744 bit/s at 137.2 MHz. 11.91 + 95.25 kbit/s at 2299.5 MHz.
– uplinks:	550 bit/s or 650 bit/s at 149.48 MHz, memory load or on/off command, or range tone
Attitude measurement:	X-beam Sun sensor, dual-beam infrared Earth sensor, accelerometer
Attitude control:	hydrazine reaction control, six 15 N thrusters, two fluid nutation dampers



A strict material selection and control programme was enforced to avoid any problems from long-term materials outgassing in space. Inevitably, the apogee motor produces most outgassing, but this will die away rapidly after combustion and acceptable conditions will be established by the time the experiments are switched on.

Finally, special measures have been adopted to give the satellite a conductive 'skin', in order to avoid the build-up of electric charges on insulating surfaces, which would have disturbed the local electric field (see page 17 of this Bulletin). This has meant that solar-cell cover slips have had to be provided with a transparent coating of indium, and likewise the solar reflectors on the body (small mirrors to reject heat). The technology of connecting to these microscopically thin films needed much painstaking development. Moreover, all metallic tapes and foils used for thermal control had to be grounded to structure, and this demanded a completely new process which had to be qualified for space application.

The result of all these techniques has been most satisfactory; more details are given in the article on page 28 of this Bulletin.

MANOEUVRES IN ORBIT

After separation from the Thor Delta launcher, a long and complex procedure is to be followed before the satellite is precisely stationed in the geostationary orbit. First, the accuracy of the elliptical transfer orbit, which reaches out to synchronous altitude, is to be checked using Sun and Earth attitude data from the satellite and tracking data from ground stations. Coarse and then fine attitude manoeuvres are to be performed, so that the apogee motor will be correctly oriented for ignition.

The motor will be ignited at the fourth apogee and will burn for about 50 s. The velocity increment of some 1780 m/s will place the satellite into an orbit very close to a true synchronous orbit. After the properties of this orbit have been measured, the satellite's spin axis will be aligned exactly with the orbital plane, and the axial thrusters will be used to set Geos on a drift course towards the first operating station. The spin-axis direction will then be changed until it is perpendicular to the orbital plane, which is the normal operating orientation. As the operating station is approached, the radial thrusters will be used to achieve synchronism with the Earth and to correct any small errors in the orbit.

It is expected that at least 10 days will be required after apogee-motor firing to reach the first station. The satellite will then be spun down from about 90 rpm to about 60 rpm, and the UHF antenna and the booms will be deployed. As the radial booms are extended, the increase in spin inertia will reduce Geos's spin rate naturally until

TABLE 2
Mission Characteristics

Mission duration:	2 years
Geoststationary orbit inclination: eccentricity:	 less than 1.6° less than 0.0013
Attitude:	spin axis normal to orbital plane; inversion at equinoxes planned to avoid shadowing of solar array
Spin rate:	90 rpm in transfer orbit, 10 rpm in geostationary orbit.

the operating rate of 10 rpm is reached. The sequence of releasing and deploying the booms is illustrated opposite. The experiments will be brought into operation progressively during the deployment cycle.

The fully operating satellite is scheduled to undergo two further types of manoeuvres. It can be moved around the orbit (longitudinal shift) to achieve the best correlation with ground-based observations and several such movements are foreseen during the two-year lifetime. The most dramatic manoeuvre, however, is a complete inversion with all booms deployed. This is planned to take place near the equinoxes (September and March) to avoid shadowing of the solar array by the radial booms, which would severely reduce the power available. Clearly, the trajectory must be carefully designed to comply with dynamic constraints, to maintain electrical power, and to ensure continuity of the communications links.

The procedures and computer software developed at ESOC to carry out these manoeuvres have broken new ground and will be of great use for later geostationary satellites.

RELIABILITY

To ensure continuing operation throughout the mission, most subsystems embody redundancy, in that components, units or even complete subsystems are duplicated.

For example:

- the complete UHF communications electronics are duplicated, as are the VHF electronics
- the data-handling unit (encoder) is fully redundant
- the whole attitude-measuring system is duplicated
- the hydrazine system has double tanks and dual thrusters and the control electronics are duplicated
- two batteries provide power for the mission-critical pyrotechnic ignition, and pyrotechnic devices are redundant
- each power converter is fully redundant, and the power regulator has triple redundancy in its control electronics.

In a few cases, duplication has not been practicable. There is only one apogee motor on board (it accounts for over half the weight of the complete spacecraft), and so its inherent reliability has had to be demonstrated by extensive tests and ground firings. It would have overcomplicated the design, and so reduced the chances of good operation, if more than one antenna had been provided for each radio-frequency system. The functions of the subsystems are, however, carefully protected in all cases and it is almost as if two spacecraft had been squeezed into the skin of one.

Changeover from one set of units to the other is made by telecommand, but if this does not take place immediately, the satellite will remain in a safe state. Indeed, even if the data link from the special ground station in the Odenwald is cut, spacecraft control will still be assured via the Redu station and the VHF links. This generous provision of redundancy has allowed the chance of a critical failure to be reduced to an acceptable level.

CONCLUSION

Many people have contributed to the Geos project. To achieve its success they have worked enthusiastically over a long period, often in difficult or laborious circumstances, and they have frequently been called upon to do more than strict duty demanded. The international cooperation of scientists, industry, NASA and ESA engineers is not the least of the special features of the programme. □

Geos at the Centre of a World-wide Study of the Earth's Magnetosphere

K. Knott, Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands

The magnetosphere is that part of space permeated by the Earth's magnetic field. It has been studied intensively and successfully in the last two decades, so much so that scientists have begun thinking of the magnetosphere as their 'little backyard universe'. ESRO/ESA has played a major role in its exploration with the scientific satellite programme devoted primarily to this field. The results that have been achieved to date have provided us with a reasonably detailed picture of our immediate spatial environment. Nevertheless, we are still far from achieving even a rudimentary explanation of some of the basic mechanisms that create and maintain the charged-particle population trapped in the geomagnetic field.

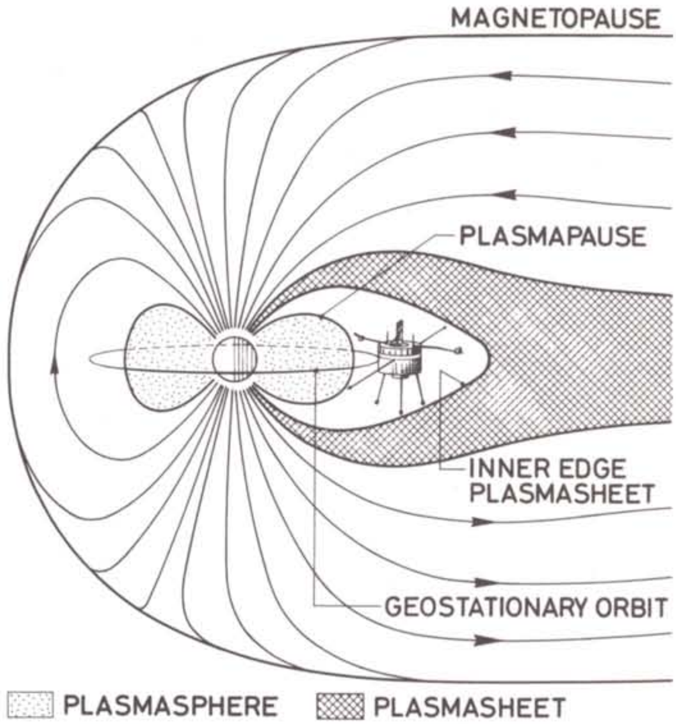


Figure 1 – Illustration of the geostationary orbit in the magnetospheric frame of reference.

Guided by the many phenomenological descriptions and observations that now exist, we are at last able to concentrate our measurements at points of particular interest and to devise and combine missions aimed at discovering processes thought to play a major role in the general behaviour of the magnetosphere. Fully realising these possibilities, scientists from all the countries involved in the exploration of near-earth space have joined forces in the common effort known as the 'International Magnetospheric Study' (IMS), to be conducted in the years 1976–79.

The IMS will be based on measurements carried out by satellites, sounding rockets, balloon payloads and ground-based instrumentation. Geos has been selected as the reference spacecraft and will play a major role during the study period.

THE MISSION

The scientific mission of Geos is to further advance our knowledge of the dynamics of the magnetosphere and in particular to study the response of the near-earth environment to varying conditions in interplanetary space. To achieve this goal, Geos will carry out integrated particle, wave, field and plasma measurements in the very centre of the magnetosphere, and it is essential that these measurements be correlated with data collected simultaneously in interplanetary space and at other points in the magnetosphere.

The satellite's geostationary orbit, shown in Figure 1, has distinct advantages from both a scientific and an operational point of view. It is situated between two boundaries of fundamental importance for magnetospheric dynamics, the 'plasmapause' and the 'inner edge of the plasma sheet'. The former terminates a near-earth reservoir of dense but cool particle population at a distance of some $4R_E$ from the Earth, while the latter marks the transition to a low-density but high-temperature population, at about $8–10R_E$. The two boundaries are not fixed and change their positions as a function of solar activity and solar-wind intensity. During very quiet periods, the whole magnetosphere expands and the plasmasphere may move past the geostationary orbit. During periods of disturbance, the magnetosphere is compressed, the plasmasphere shrinks, and the inner edge of the plasma sheet crosses the geostationary orbit. Geos will be in an ideal position to monitor these most important transitional processes.

The stationary character of the Geos orbit will make it possible to establish the average geophysical conditions in the equatorial plane at a geocentric distance of $6.6R_E$. Any deviations from this average will therefore be indicative of temporal variations, so that Geos will be able to discriminate to a certain degree between temporal and spatial variations. Such discrimination has proved difficult with previous satellite missions and can only be achieved completely if a suitable pair of satellites is employed.

Another attractive feature of the geostationary orbit is its magnetic conjugacy to the auroral zone. Geos will be positioned on magnetic field lines which connect with both the northern and southern auroral ovals. Because particles are guided along magnetic field lines, the particle population monitored by Geos should contain those particles that generate the well-known auroral displays. Co-ordinated ground-based experiments carried out at the footprints of the Geos field lines will therefore further our knowledge on the origin and acceleration of auroral particles.

Payload operation will also benefit greatly from the stationary character of the orbit and the satellite's resulting constant visibility from its ground station. Downlink (data) and uplink (telecommand) communication will be maintained for 24 hours per day throughout the mission, the experiment data, arriving at a rate of approximately 100 000 bit/s, being treated in real time by an online ground-based computer system. The optimum mode of payload operation will be determined automatically and the necessary telecommands can be sent at some 100 bit/s. These factors allow the operational flexibility of the payload to be fully exploited.

Considering the many advantages of the geostationary orbit for magnetospheric studies, it is interesting to note that Geos is the first geostationary satellite devoted exclusively to magnetospheric research. The American ATS series of geostationary communication satellites have however carried small scientific packages containing particle and magnetic-field experiments, experiments that have confirmed that the geostationary orbit is an ideal platform for magnetospheric studies. In fact, it can be said that the results from ATS have served to stimulate interest in the Geos mission, and the latter's simultaneous measurements of all relevant parameters are eagerly awaited.

THE PAYLOAD

The attractiveness of the Geos mission stems last but by no means least from the composition, sophistication and flexibility of its payload, which will conduct simultaneous wave and particle measurements whilst monitoring the basic background parameters like electric and magnetic fields, as well as the total plasma density. Waves are to be measured in six components with frequency coverage up to 80 kHz, while particle experiments will explore energies extending from the suprathermal to the MeV range with high spatial and temporal resolution. In the past experimental difficulties have prohibited the reliable measurement of electric fields and plasma densities in magnetospheric regions outside the plasmasphere. By applying the newly developed techniques and partly active experiments on Geos, it is hoped to arrive at reliable measurements of these until now inaccessible yet most important parameters.

The payload, summarised in Table 1, consists of seven experiments, of which four measure particles in various energy ranges, and three fields and waves in various frequency ranges. It is a well-balanced mixture of instruments relying on proven techniques, and novel experiments aimed at the determination of parameters not so far measured in the outer magnetosphere. Figure 2 shows how the various experiment sensors are accommodated on the spacecraft.

The prime purpose of experiment S-300 is to study magnetospheric wave phenomena in both the electric and

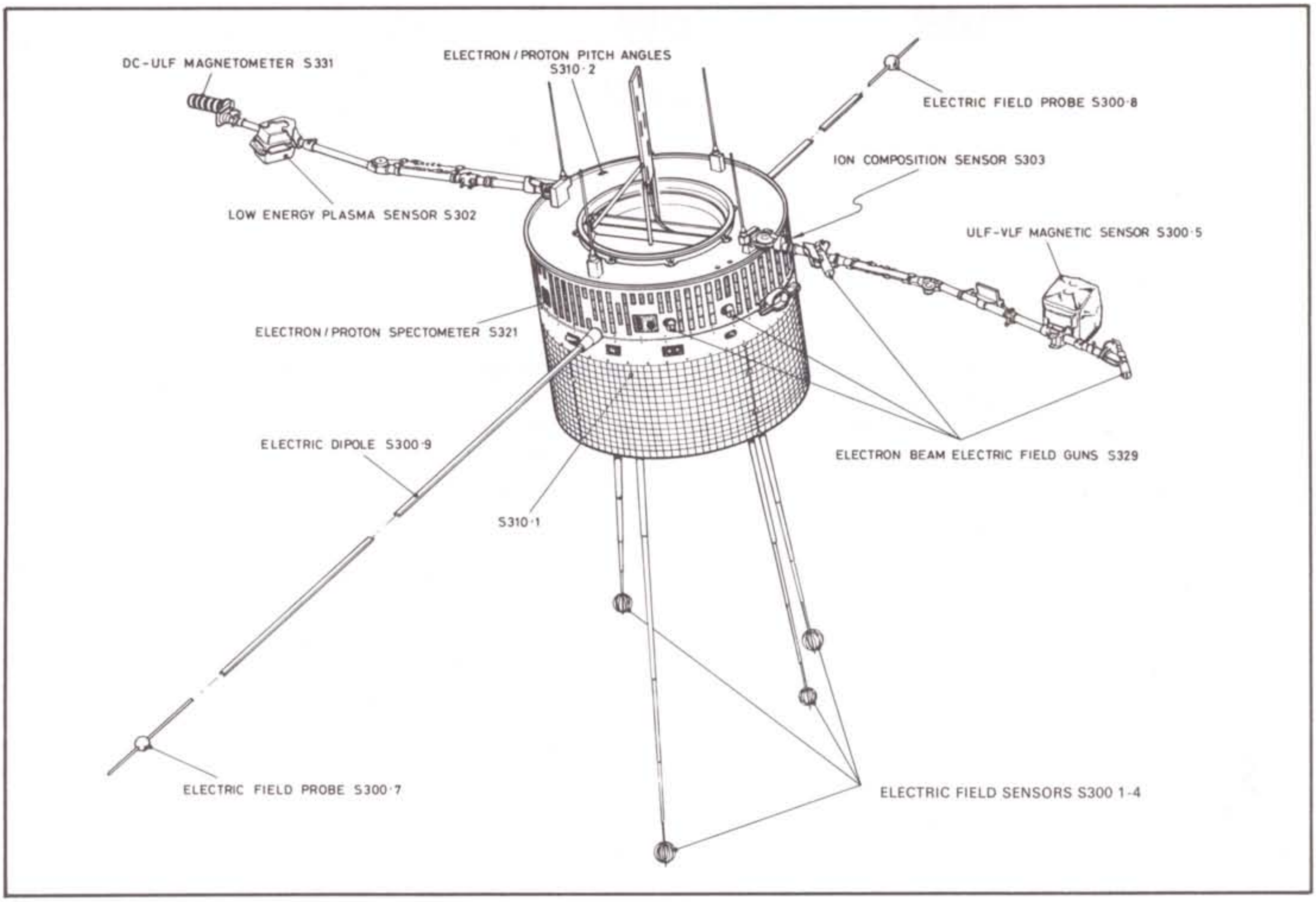


Figure 2 – Orbital configuration of Geos showing the accommodation of all experiment sensors.

TABLE 1

Exp. No.	Measurement	Technique	Experimenter from
S-300	AC magnetic fields up to 30 kHz DC/AC electric fields and plasma resonances up to 80 kHz Mutual and self-impedance	Search-coil magnetometer Electric aerials Emission and reception of VLF signals	CRPE, Issy-les-Moulineaux, France Space Science Dept., ESTEC, Holland Danish Space Research Institute, Lyngby
S-302	Study of thermal plasma	2 electrostatic analysers	Mullard Space Science Lab., Dorking, UK
S-303	Composition, energy spectra & angular distribution of ions	Combined electrostatic and magnetic analyser	University of Bern, Switzerland and Max-Planck-Institute, Garching, Germany
S-310	Pitch-angle distribution of electrons and protons in the 0.2–20 keV energy range	10 electrostatic analysers	Kiruna Geophysical Observatory, Kiruna, Sweden
S-321	Pitch-angle distribution for electrons (20-300 keV) and protons (20 keV-2 MeV)	Magnetic deflection system followed by solid-state detectors	Max-Planck-Institute, Lindau, Germany
S-329	DC electric field and grad $\|\mathbf{B}\|$	Tracing of electron beam over one or more gyrations	Max-Planck-Institute, Garching, Germany
S-331	DC and ULF magnetic field	Fluxgate magnetometer	CNR, Frascati, Italy

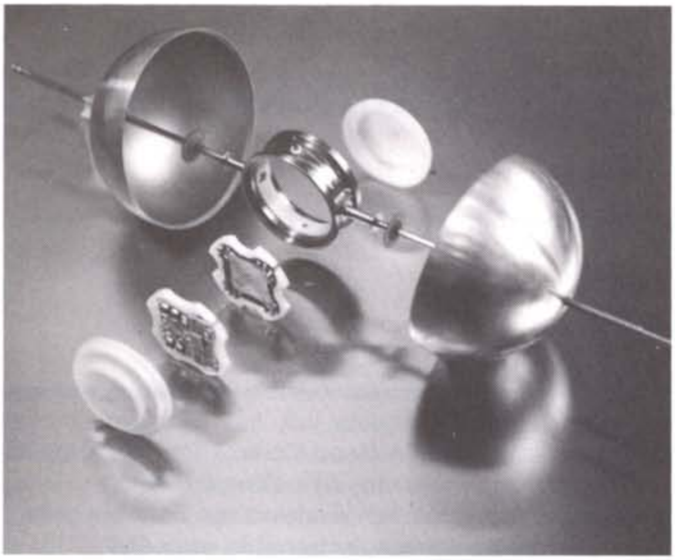


Figure 3 – This (dismantled) sensor for electric-field measurements forms part of experiment S-300 and is accommodated at the tip of the 20 m long cable boom.

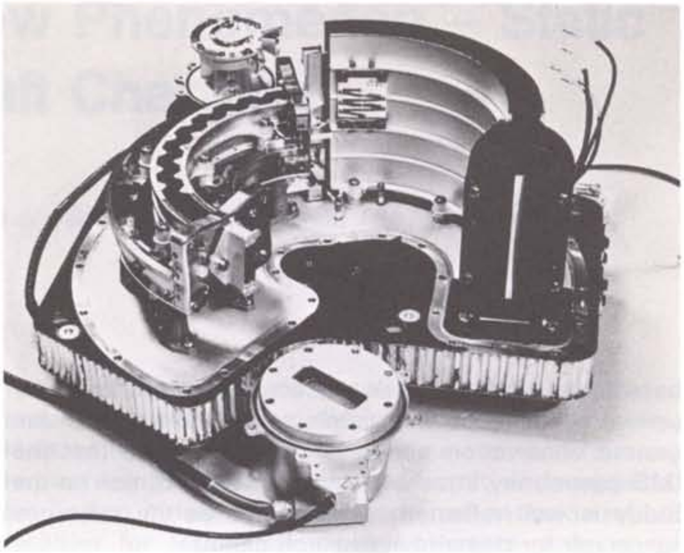


Figure 4 – Dismantled mass spectrometer (experiment S-303) flown on Geos. The instrument consists of an entrance slit (right), energy analyser, channeltron, mass analyser and electron multiplier.

magnetic domains. Frequency coverage extends up to 80 kHz for electric fields and up to 30 kHz for magnetic fields. In addition, local plasma diagnostics will be sought by transmitting and receiving in specified frequency ranges. S-300 is the most comprehensive wave experiment ever flown and the first on a geostationary satellite. Two of its sensors are carried by 20 m long cable booms, an arrangement that will make it possible to measure the DC electric field also. One of the sensors employed is shown in Figure 3.

The objective of experiment S-302 is to measure fluxes of electrons and protons in the energy range 0.5–500 eV in two orthogonal directions. The very low particle energies addressed by this experiment made it necessary to accommodate it on a boom, away from the main spacecraft body.

Experiment S-303 is a sophisticated mass spectrometer which will measure the energy, angular distribution and composition of ions. Energy coverage extends to 16 keV and mass up to 140 amu can be detected. The sensor employed by this experiment is shown in Figure 4.

Experiment S-310 employs an array of 10 particle detectors to measure electrons and protons in the energy range 0.5–20 keV with high spatial resolution. The experiment is intended to detect those particles that are thought to create auroral displays in the subpolar regions.

Particles with energies above 20 keV are studied by experiment S-321, which employs a total of 14 solid-state detectors, 4 for proton and 10 for electron detection. The electrostatic deflection technique used by all other particle experiments on Geos is no longer practical at these high energies.

Experiment S-329 measures the deflection of an electron beam to determine the DC electric field and the gradient of the magnetic field. The necessary information is obtained from the displacement of the beam after one gyration in the weak geomagnetic field at the geostationary orbit. Experiment S-331 employs a triaxial fluxgate magnetometer for the measurement of the latter. This experiment has an ambitious research programme of its own and provides magnetic-aspect data to all other experiments.

All the satellite's experiments have been designed for great operational flexibility, which not only allows the payload to be adapted to varying geophysical conditions but also makes it possible to carry out active experiments. Geos must therefore be seen as both a very flexible observatory and as a platform for active research in the magnetospheric-plasma environment.

GEOS AND THE INTERNATIONAL MAGNETOSPHERIC STUDY

On the basis of the information obtained by many individual satellite missions, the International Magnetospheric Study was proposed at the beginning of this decade as a concerted effort to acquire co-ordinated ground-based, balloon, rocket and satellite data. It was realised that only such an effort could significantly further our understanding of the behaviour of the plasma environment of the Earth. The IMS has since developed into a programme of international scientific co-operation based on a set of complex spacecraft missions flown by several agencies, to be complemented by an extensive ground observation network. The importance that the IMS community attaches to Geos's contribution to the Study is well reflected in its choice as the reference spacecraft for this global research period.

In the context of the IMS, the Geos mission must be seen as one major element in a wide network of spaceborne and ground-based observations. This network will consist of interplanetary probes such as Helios and ISEE-C, a satellite pair, ISEE-A and B, in a carefully chosen eccentric orbit, the Geos reference spacecraft, and magnetospheric satellites such as EXOS and Magik, as well as a large number of geophysical observatories and measuring chains on the ground. Additional data will be collected by sounding-rocket and balloon-borne instrumentation flown at selected times from selected launch sites. Well co-ordinated operation of this network and a common analysis of the data acquired is expected to bring new momentum to magnetospheric research and to lead to a better understanding of many of the phenomena which are as yet poorly understood.

The key role played by Geos stems from its combination of particular features. Its longitudinal position can be adjusted to place it in regions of the magnetosphere conjugated magnetically to special ground-based observatories or rocket and balloon launch sites. Observations on the ground and on the satellite will have two specific objectives: (i) to confirm experimentally that the predicted conjugacy is achieved, and (ii) to carry out research programmes at the conjugated points. During such studies, the Geos payload can be operated in many different modes and can be adapted to different ground research activities.

Geos's longitudinal position in geostationary orbit will be varied between 35°E (conjugated to Northern Scandinavia) and 0° (conjugated to Iceland in the Northern Hemisphere and to Syowa Base in the Southern Hemisphere). A very dense network of ground-based instrumentation, such as magnetometers, auroral photometers, all-sky cameras, ionosondes and riometers has been built up over the last few years in Northern Scandinavia. In addition there are two sounding-rocket ranges situated very near to the satellite's nominal magnetic footpoint. A data link has been established between the Agency's Geos Control Centre at ESOC (Darmstadt) and these ranges, making it possible to base a sounding-rocket launch decision not only on observations made at the range, but also on real-time data received from the satellite itself. A special Committee for the Co-ordination of Observations associated with Geos (CCOG) has been set up to co-ordinate all efforts in this field.

A final but nevertheless major objective of the IMS is the introduction of a new mode of team-oriented data analysis and interpretation at an international level. ESA will contribute to this goal by generating and distributing a well-defined set of Geos summary data to the IMS Community. These summaries from the IMS reference spacecraft are expected to serve as 'crystallisation points' for common data analysis and as selection criteria for periods of major scientific interest to be analysed in detail on a world-wide scale.

The co-ordination of IMS activities is the responsibility of the IMS Steering Committee, supported by two major institutions, the Satellite Situation Center (SSC) and the IMS Central Information Office (IMSCIE). The prime task of the SSC is to identify special intervals in which two or more satellites are simultaneously located in different, but geophysically related regions of space. The IMSCIE collects information on current and planned IMS projects on a world-wide basis and disseminates this data together with recommendations from the Steering Committee in a monthly IMS Newsletter. The Geos mission is to be carried out in very close liaison with the IMS Steering Committee, the SSC and the IMSCIE. □

An Old Discipline and a New Phenomenon – Static Electrification and Spacecraft Charging

R. Grard, K. Knott & A. Pedersen, Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands

The phenomenon of static electrification has been known for thousands of years. Thales, the wisest of the Seven Sages, who lived between about 640 and 550 BC, was already acquainted with the fact that amber could attract light objects when rubbed with cat fur. Static electrification, or electrostatic charging as it is sometimes known, is quite common in a dry atmosphere and the unpleasant shock that one gets from the door handle of a car is but one of its manifestations. It is due to the accretion of electric charges on a body causing its surface to develop an electric potential different from that of its environment. But charging is not only caused by friction; it can also occur when an object is immersed in an ionised gas, or plasma. Surface potentials of a fraction of a volt were measured on rockets and low orbiting satellites in the early days of space research, but it was not until 1970 when results became available from the USA's ATS series of satellites (Application Technology Satellites) that it was realised that spacecraft in geostationary orbits could charge up to potentials of several kilovolts. The anomalous behaviour of more than twenty spacecraft and at least one catastrophic failure have since been attributed to electrostatic charging.

Charging events can disturb the operation of the scientific experiments carried by spacecraft and may cause serious malfunctions of various subsystems. Electric discharges generate interferences which propagate along the spacecraft wiring causing spurious switching of logic circuitry and even permanent damage to electronic components. Arcing is also responsible for the erosion of material surfaces and the degradation of the properties of thermal blankets. Scientists and engineers, after a short period of scepticism, have now become so concerned about the troublesome consequences of surface charging that satellite electrostatic cleanliness is presently a new and fashionable space discipline. Experimenters interested in wave, field and particle measurements now request electrostatically clean spacecraft, and engineers are finding it necessary to develop new techniques and facilities for testing the ability of space systems to withstand static electrification.

THE SPACE ENVIRONMENT

Geos's environment, 35 600 km above the Earth's equator, will be a rarefied ionised gas of hydrogen atoms which have been split into their basic constituent electrons and protons. Such a mixture is macroscopically neutral, since every cubic centimetre contains an equal number of negatively charged electrons and positively charged protons. This number defines the plasma density and is of the order of 1 to 10 per cm^3 at geostationary satellite altitudes.

Surface charging depends more on the thermal energy of the plasma particles than on their volume density. Electrons and ions have approximately the same temperature; in other words, the kinetic energies carried by an electron and a proton are of the same order of magnitude and one can say that the two species are in thermal equilibrium. Their thermal energies are in the order of 1 electron volt* in the near-earth space environment, but in more distant regions, and particularly near the geostationary orbit, they can be a few hundred to a few thousand eV (Fig. 1).

We shall see in the following how a spacecraft can become electrostatically charged in a medium that is electrically neutral and in thermal equilibrium.

THE CHARGING MECHANISM

SURFACE IN SHADOW

Electrons have a much smaller mass than protons and consequently move with a much higher velocity, as otherwise the mean kinetic energy of the two species could not be comparable; in thermal equilibrium electrons are moving 43 times faster than protons.

* A mean kinetic energy of 1eV corresponds to a temperature of 11 600 K.

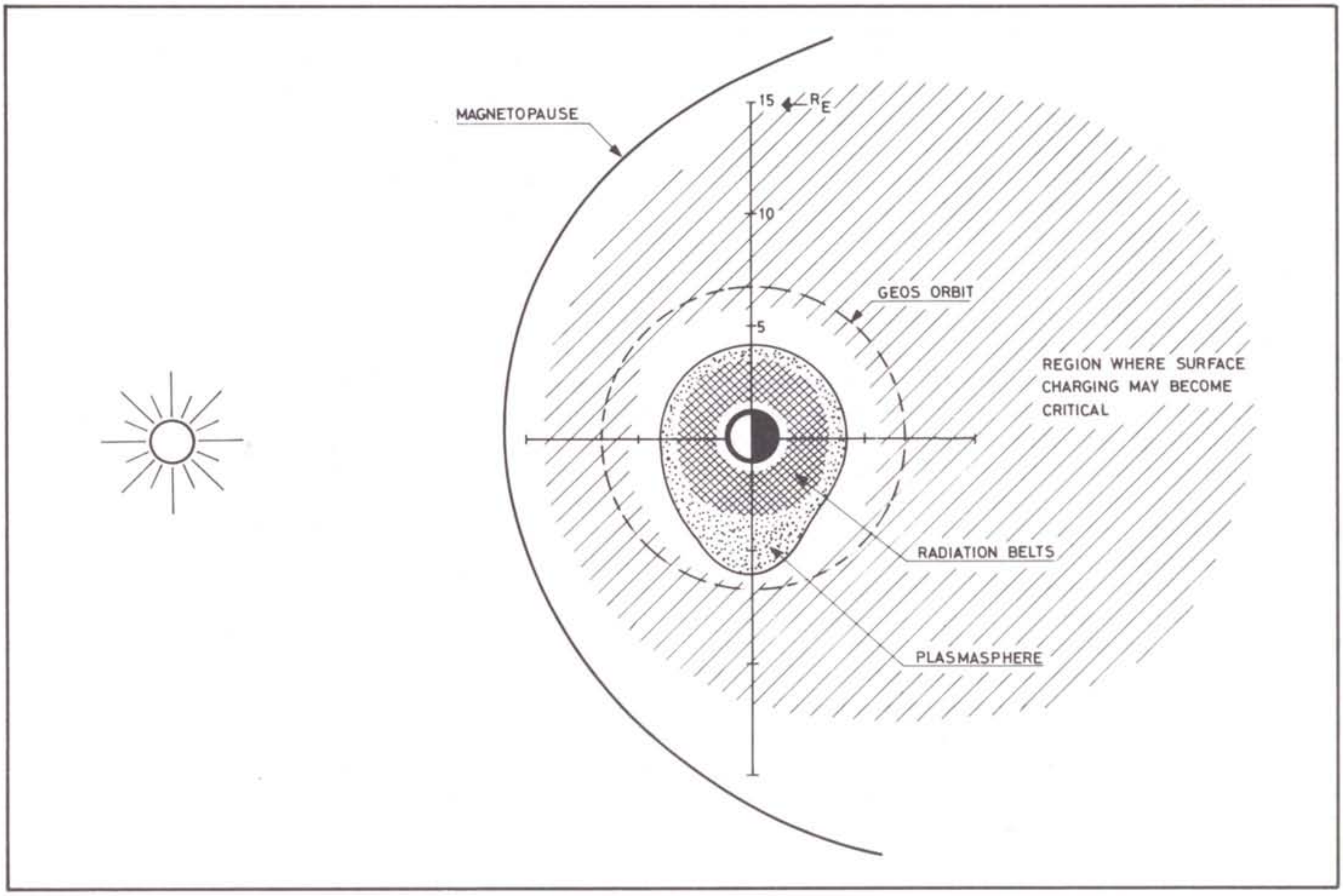


Figure 1 – Cross-section of the magnetosphere through the plane of the Earth's equator showing Geos's orbit (scale graduated in earth radii, 1 R_E = 6378 km; Sun on the left). The plasmasphere forms the inner part of the magnetosphere, the boundary of which is the magnetopause. The plasmasphere consists of a relatively cold plasma in which surface charging is very moderate. The plasmasphere also contains the radiation belts, which are characterised by the additional presence of very energetic charged particles. These particles are not sufficiently numerous to play any significant role in surface charging, but their high energy allows them to penetrate the spacecraft and cause what is called radiation damage. Charging events occur in the outer magnetosphere, and predominantly in its antisunward portion.

We first consider the case of a body completely in shadow, as a spacecraft is during eclipse. Let us assume that an initially uncharged satellite is suddenly immersed in a plasma. More electrons, because they are moving faster than the ions, initially impinge at random on this body, which starts accumulating electric charge. The resulting surface potential, which is negative, tends to slow down or even repel other approaching electrons and to accelerate incoming protons. An equilibrium is reached when the flows of electrons and ions become equal; the net current to the body is zero and the negative charge accumulated on its surface does not increase further (Fig. 2a).

The magnitude of the negative potential depends on the temperature of the plasma. The higher the mean kinetic

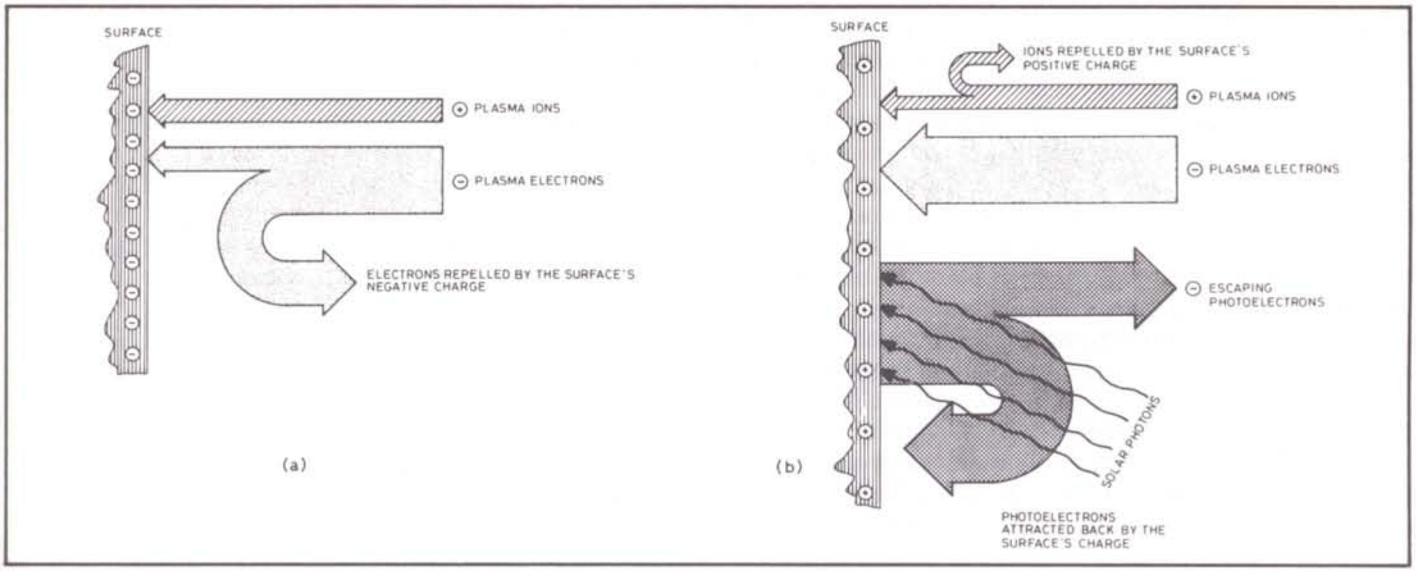


Figure 2 – Qualitative illustration of the charging of a surface by a plasma. The width of the arrows is proportional to the flux of each particle species; the equilibrium potential is reached when the sum of the currents collected and emitted by a surface element is zero:
(a) Surface in shadow: the current balance requires equality between the flow of the plasma ions and that of the plasma electrons impinging on the surface.
(b) Surface in sunlight: equilibrium is achieved when the flow of escaping photoelectrons is equal to the difference between the incoming flows of plasma electrons and ions.

energy of the electrons, the more negative the surface must become before it can control the flow of these particles and finally reach its equilibrium potential. Spacecraft charging is moderate in the comparatively cold ionised medium of the near-earth environment, but it can be anticipated that the more energetic plasma to be found at geostationary altitude will give rise to greater surface potentials.

SURFACE IN SUNLIGHT

When a body is illuminated by sunlight, the photoelectric effect causes its surface to emit electrons, knocked out by incoming photons. These particles are, of course, identical in nature to the plasma electrons. Every photoelectron extracted from the body is removed from an initially neutral atom which then becomes positively charged. The photoelectrons themselves are emitted with a relatively low energy (a few eV), but at a rate which generally exceeds that of the incoming plasma electrons. When a surface is illuminated, it tends therefore to lose electrons in the first instance. The resulting positive charge on the body forces a fraction of the photoelectrons to return to the surface. An equilibrium is reached when the rate at which photoelectrons escape exactly balances the difference between the incoming flows of electrons and ions (Fig. 2b).

THE SPACECRAFT SURFACE POTENTIAL

SPACECRAFT IN ECLIPSE

A spacecraft in eclipse is subject to the charging mechanism shown in Figure 2a. Its entire surface is then floating at a negative potential which is a function of the plasma temperature. This situation will not, however, be encountered very often by Geos, as eclipses at the geostationary orbit last for less than 72 min and can only occur during periods of approximately 48 days centred around the vernal and autumnal equinoxes, on 20 March and 23 September.

In an isotropic medium, each surface element should normally be charged to the same potential irrespective of the surface being an insulator or conductor. In practice, this simple argument must be modified to take into account variations in secondary electron emission from different surface materials. These cause nonuniformity in potential distribution over the surface of insulators and differences between the potentials of insulated conductors. As we shall see, the problem of differential charging is more serious in sunlight than in eclipse, but it can be avoided altogether by covering the spacecraft with a conductive layer that gives it an equipotential surface.

SPACECRAFT IN SUNLIGHT, CONDUCTIVE SURFACE
We first consider a body with a conductive surface because this case is the easiest to describe. The spacecraft collects plasma particles over its whole surface, but emits photoelectrons only from its sunlit side (Fig. 3a). The surface is equipotential and currents can easily flow from one side to the other; the charging mechanism is therefore identical to that already illustrated in Figure 2b, the only difference being that the area for photoemission is smaller than the area for collection of plasma particles. However, since the photoelectron current is generally larger than the plasma current, the spacecraft is floating at a positive potential of the order of a few volts.

SPACECRAFT IN SUNLIGHT, INSULATING SURFACE
When the spacecraft is not conductive, every surface element will charge up independently to various potentials by the mechanisms already illustrated in Figure 2. One is then presented with a configuration in which the sunlit side of the satellite is positively charged and the shadowed side carries a negative electrostatic charge

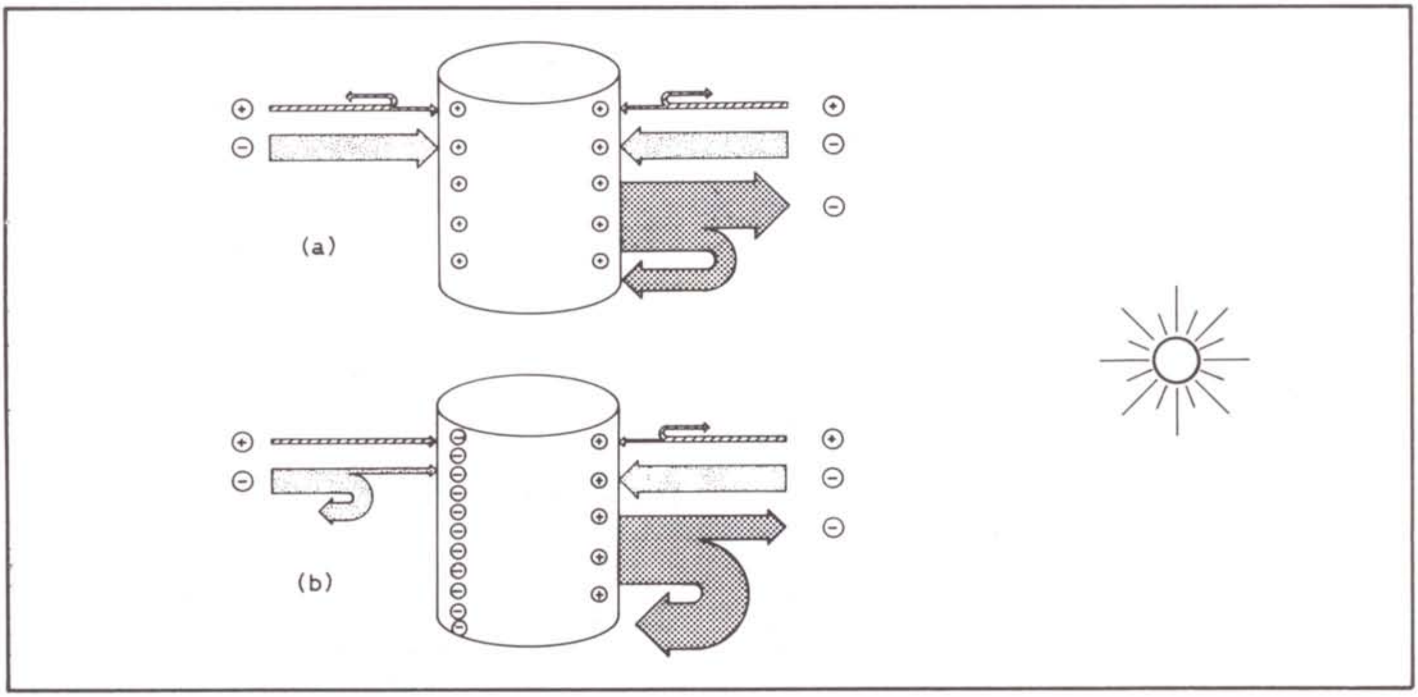


Figure 3 – Charge distribution over the surface of a spacecraft in sunlight. (Code for arrow shading same as Fig. 2):
(a) Conductive surface: the spacecraft surface is equipotential and the dominant role of photoemission is responsible for the positive charge that it carries.
(b) Insulating surface: each surface element charges up independently to a different potential; arcing occurs when the breakdown voltage is exceeded at any point.

(Fig. 3b). This differential charging is conducive to arcing, because adjacent elements develop electrostatic potentials that can differ by thousands of volts.

AVOIDANCE OF SPACECRAFT CHARGING

The surfaces of conventional spacecraft are normally partly insulating, as solar arrays and thermal blankets are nonconductive. Shadowed insulated surfaces will therefore acquire potentials of several kilovolts – the reported world record stands at 19 kV – whereas the illuminated elements, which carry positive charges, are at potentials considerably closer to zero.

Differential charging can, in principle, be easily avoided by making every surface element conductive and by establishing electrical contact between them. The technical implementation of this solution is not trivial, and moreover it is very costly. Thanks to the dominating role of photoemission on the sunward side of the satellite, a conductive spacecraft can be expected to have a floating potential near to zero. Only during very rare events of abnormally high geomagnetic disturbance or during eclipses will photoemission be unable to balance the flow of plasma particles, in which case the conductive spacecraft will acquire a highly negative but uniform potential. These negative charging events are not critical for satellite instrumentation, since no arcing can occur whilst the surface is equipotential but, as in the case of Geos, the scientific experiments may still require their elimination. This can be achieved by attaching an electron source (heated filament) to the spacecraft which returns the charge accumulated on the surface to the plasma, thus replacing or supplementing photoemission.

GEOS, A FIRST STEP

It was realised when the Geos project was entering its development phase that spacecraft charging could be detrimental to several experiments, and to those measuring low-energy particles and DC electric fields in particular. The following precautions have therefore been taken:

- the solar-cell covers are coated with a conductive but transparent layer of indium oxide
- the optical solar reflectors used for thermal control are also covered with indium oxide
- thermal blankets have an aluminised surface exposed to space
- only metallised tape has been used for surface finishing
- conductive paints have been specially developed
- each individual conductive surface element is connected to the satellite structure.

Geos is the first spacecraft ever developed to have a surface that is more than 96% conductive, and it will offer a remarkably clean platform, from an electrostatic point of view, for the sensitive plasma experiments that constitute its payload. Nevertheless, Geos is only a first step and it is already to be followed by a number of other researches in the field of electrostatic charging:

(i) Following Geos's example, it has been decided that all three ISEE spacecraft should also have conductive surfaces. In addition, an attempt will be made to control the potential of the ISEE-A satellite using an 'electron gun' developed by ESA's Space Science Department.

(ii) The American Scatha (Spacecraft Charging at High Altitude) satellite to be launched in 1978 is dedicated to the study of static electrification of surfaces in space.

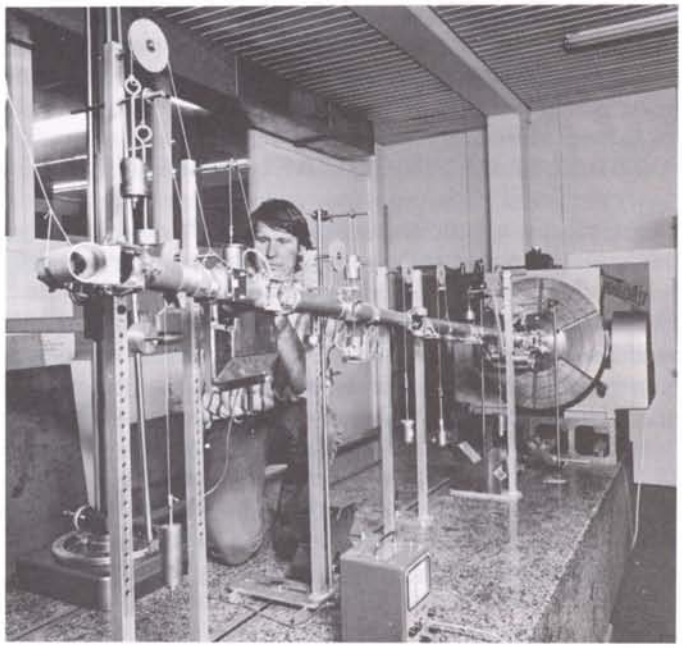
(iii) It is now well established that surface charging also occurs in the environment of other planets, such as Jupiter. Future planetary missions, such as the Jupiter Orbiter and Probe, and the Out of Ecliptic mission will certainly be influenced by the findings made in the Earth's magnetosphere.

(iv) Application satellites will also benefit from the technological progress that has been achieved with Geos; new materials have been developed and tested, and grounding techniques have been improved, in order to minimise the risk of arcing between satellite elements charged at different potentials. It is even foreseen that entire systems might be tested in large vacuum chambers by bombarding them with photons and energetic electrons in order to assess the spacecraft's susceptibility to interactions between their surfaces and the space environment. □

The Booms and Mechanisms of Geos

G. Schmidt, Dornier System, Friedrichshafen, Germany
M. Newns, British Aircraft Corporation, Bristol, UK
B. Henson, Geos Division, ESTEC, Noordwijk, The Netherlands

The four particle and three field experiments that make up the payload of the Geos spacecraft rely on a total of 31 experiment units. Because of the susceptibility of the majority of the experiments to satellite-generated electrostatic, electromagnetic, and magnetostatic interference, their sensors have had to be mounted on booms, away from the main body of the spacecraft. Experiment requirements have led to the development of three different boom systems (long radial, short radial, and axial) for these sensors, while satellite requirements have been responsible for the incorporation of further deployment mechanism for Geos's UHF antenna. A sophisticated ground-test programme has been necessary to demonstrate the reliability of these systems, in terms of both deployment and alignment under space flight conditions.



Short-radial-boom alignment and balancing tests at Dornier System.

MAIN CHARACTERISTICS

SHORT RADIAL BOOMS

Geos carries two 3 m radial booms which have alignment accuracy and stiffness as their basic mechanical requirements. They are double-hinged, deployable structures which are folded horizontally and stowed below the thermal shield of the spacecraft, beside the spacecraft/launcher adapter cone. Offset hinges and tubes with a high moment of inertia but low weight ensure accurate linear and angular alignment to satisfy the positioning requirements of the experiments carried. The dry-lubricated hinges are playfree and were specially developed. The booms' split-axis design provides high torsional and bending stiffness and allows free movement of the electrical harness routed through them.

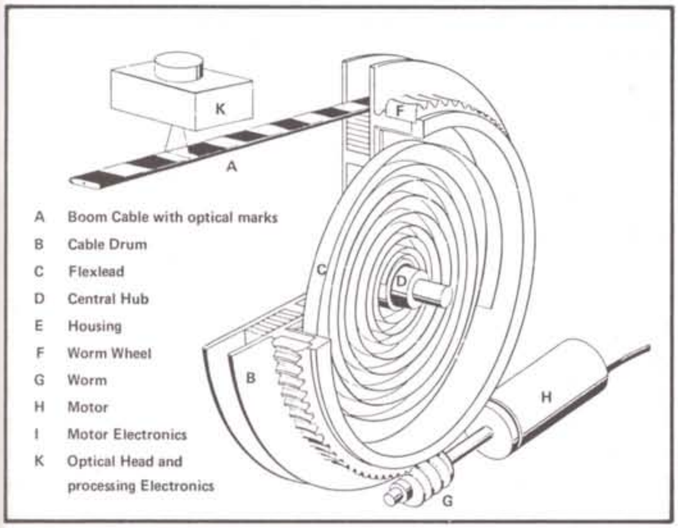
The two booms are held in stowed position by tie-down cords, which are cut pyrotechnically for release. Simultaneous and correlated deployment is achieved by a pulley-wire synchronisation system, the tension in which is relieved automatically at the end of deployment to avoid additional bending forces. The deployment motion generated by centrifugal force is controlled by two hermetically sealed linear hydraulic dampers acting on the inner hinges.

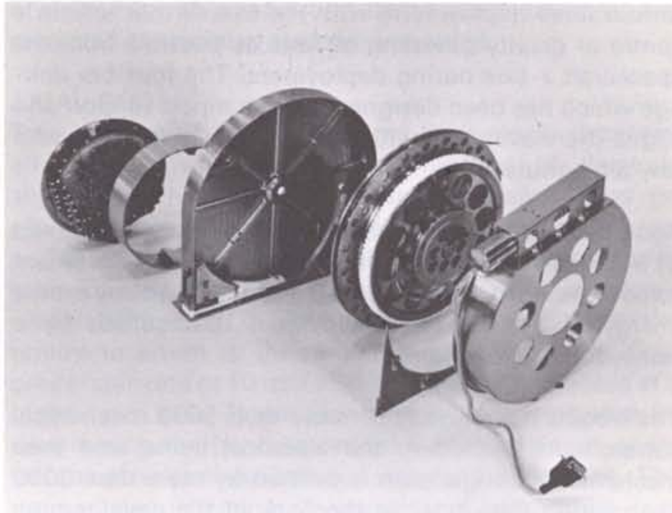
LONG RADIAL BOOMS

The long radial booms consist of two cable-boom mechanisms mounted below the lower spacecraft platform and two experiment release mechanisms positioned outside the spacecraft which support the S-300 vitreous carbon spheres at the cable tips.

The cable-boom mechanism allows the controlled deployment of a 20 m long cable in the centrifugal force field. In launch configuration, the flat part of the cable (first 19 m) is reeled on a 240 mm diameter rotating drum, which is connected electrically to the stationary central housing by a 'flexlead'.

The experiment spheres are protected by covers held in place by wires which are cut pyrotechnically for release. The round (in section) experiment cable (± 1 m) is





Long-radial-boom deployment mechanism (cable booms).

stowed in a U-shaped groove around the spacecraft between the upper and lower skirts. This groove has an 'elasticated' exit slit which acts as a tear-out device during sensor release and serves to absorb the cable's pendulum energy. Deployment of the cable is monitored by an optical sensor which reads black bars marked on its surface.

Special development effort was necessary for:

- the long radial-boom cable and the flexlead
- the dry-lubricated worm-gear drive for the cable drum
- the high-torque stepper motor for the cable drum, and
- the 'root dampers' at the bases of the booms, which serve to damp out oscillations in the 20 m long cables.

AXIAL BOOMS

The four axial booms – two 2.5 m and two 1 m long – deploy and support Geos's four wire-sphere electric-field sensors. During launch these experiment spheres are retracted into cannister-like housings in the base of the spacecraft, which are closed by thin aluminium-foil membranes. The spheres are served electrically by helically-wound triaxial cables running inside the telescopic booms. By using aluminium-alloy tubes with a large outer diameter, sufficient stiffness can be achieved despite the very thin walls to withstand the bending loads due to centrifugal forces caused by the maximum deployment spin rate of 30 rpm. Torsional orientation is provided by a keyway. The axial booms are locked by a three-ball mechanism during launch and are released and deployed by pressurised nitrogen, stored in pyrotechnically activated tank valve assemblies at 110 bar. Gas flow during deployment is controlled by orifices at the base of each boom (0.13 mmϕ for the short and 0.22 mmϕ for the long booms), resulting in a deployment time of 1 to 4 s. The gas system maintains a constant flow for 15 to 20 s to provide a safety margin in case of unforeseen stiction. Many deployment tests in vacuum have been necessary to define the optimum operational parameters for this pressure system.

UHF ANTENNA

In addition to the boom mechanisms for the experiments, a further mechanism is needed to deploy the 1 m long waveguide blade of the satellite's UHF antenna. In launch configuration this blade is stowed horizontally within the spacecraft/launcher adapter cone, but for transmission it has to be raised to a vertical position, in line with the spacecraft's z-axis. The forces involved in its erection have to be as small as possible to allow unrestrained deployment, with the overall mechanism's centre of gravity deviating as little as possible from the spacecraft z-axis during deployment. The four-bar linkage which has been designed forms a tripod support and aligns the waveguide with a reproducible accuracy of a few arc minutes.

Again, during launch the delicate wave guide is secured by a wire tie which is cut pyrotechnically. The deployment force is provided by redundant leg springs, and any excess energy at the end of deployment is absorbed by a honeycomb crush damper.

The booms have a total of more than 5000 mechanical components, excluding the electrical items, and their mechanical configuration is defined by more than 3000 engineering drawings. At the peak of the development test phase, when model manufacture and pre-assembly were already in progress, more than 100 people were employed full time on boom-related work.

SUBSYSTEM TESTING

The basic requirements of subsystem testing on the Geos booms were to demonstrate the adequacy of their design and provide confidence early in the programme in the ability of the units to perform correctly in orbit. The approach adopted was to design and manufacture units using good engineering design practice coupled with acceptable safety margins. The test programme was defined to demonstrate the limits of that design, and in so doing to provide evidence of the safety margins available.

SHORT RADIAL BOOMS

The short radial booms are deployed into locked orbital configuration by the centrifugal forces created by the spinning spacecraft. The loading on the booms can be divided into two basic conditions: one at release and the other at the instant of locking. The one at release is a high-load condition giving rise to high stresses in the boom components, but because the spacecraft spin inertia increases significantly about the spin axis as the booms deploy and the spacecraft spin rate is substantially reduced, the one near locking is a low-load condition.

Deployment of the short radial booms was tested by releasing them vertically downwards under gravity and the two loading conditions were imposed by using additional masses to simulate orbital centrifugal loads. One set was attached for proving the high-stress-release case, and a second to simulate the loads in the locking configuration. The moment available for locking was so small that changes in hinge friction had a significant effect. The locking test was therefore repeated many times under varying load conditions and temperatures, to demonstrate the necessary safety margin for locking under all possible orbital conditions.

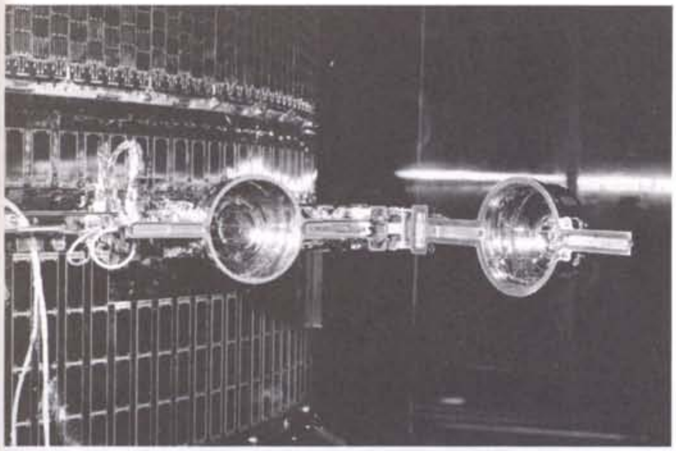
At the instant of release, one of the most highly stressed components is the hydraulic 'root damper' at the base of the short radial boom. Consequently, it was seen as a critical item and underwent extensive testing. With an oil-filled unit operating at high transient pressures, it was essential to demonstrate not only that it could withstand the imposition of the high operational loads, but also that under those conditions there would be no leakage.

Two aspects of the short-radial-boom design which needed accurate definition were the alignment requirements for the experiments and the static and dynamic balance requirements imposed by the system. These two requirements became linked and necessitated sophisticated gravity compensation and an iterative measurement-calculation process. Each boom was fixed on a rigid mounting plane, for example, and a complex system of masses and pulleys attached at the significant mass points to provide a loading system equivalent to the final orbital spin rate of 10 rpm.

On the basis of such measurements, the necessary final balance masses and their positions were determined, respecting the requirement that any static and dynamic imbalances resulting from the short radial booms had to remain the same from the stowed to the deployed states. This was to ensure that their deployment would have no adverse effect on the overall balance of the spacecraft.

LONG RADIAL BOOMS

Deployment of the long radial booms may be considered in two stages:



Housing on the spacecraft body for one of the S-300 experiment's vitreous-carbon spheres.

(i) release of the sensors from their housings on the side of the spacecraft, and
(ii) deployment of the flat cable to its full 20 m length.

The trajectory of the sensors during release was one of the more controversial mathematical modelling arguments of the design phase. To demonstrate conclusively the effect of the root damper and round-cable pull-out forces on the release motion, a special test rig was designed and built at ESTEC. A 'zero-gravity' environment was provided for the simulated sensors by using a low-friction plastic-surfaced table to support them in the plane of release. The effect of air drag on the trajectory was essentially removed by providing a helium-filled environment.

The complete rig was designed to rotate in the predicted orbital spin range at boom release and cameras attached to the rig allowed slow-motion studies to be made of the trajectory of the 'sensor'. The results of this test were both conclusive and in agreement with the mathematical analysis; moreover they were instrumental in effecting a design modification in that it was decided to retain the sensor covers, rather than jettison them after sensor release and risk a collision between a sensor and the opposite cover.

During deployment, the tensile load in the cable varies continuously over its 20 m length and the profile of load against deployed length can be accurately predicted. A special deployment rig was constructed using a reel and a torque motor programmed to simulate the variable cable load. This rig was used to establish both the deployment and retraction capabilities of the long-boom mechanism.

When the flat cable is deployed, the tubular polyurethane root damper provides a damping component for spacecraft moment. To establish the damping available, component-level tests were performed on each flight-standard damper by measuring the damping characteristic of each unit with a pendulum-decay method over the full predicted operational temperature range.

AXIAL BOOMS

Two aspects of the axial booms have received special attention at subsystem level. The first of these is alignment. The multitube telescopic design relies on plastic rings and guides both to provide gas-tight seals and to transfer bending loads along the boom from tube to tube. This led to some speculation concerning alignment repeatability after deployment and the ability of the booms to return to their nominal positions at the final orbital spin rate of 10 rpm after being initially released at a higher spin rate. These problems were investigated by determining the bending line of each boom unit under various simulated orbital spin-rate load conditions. The residual tip deflection (hysteresis) of each boom was measured after being subjected to the full spin-rate loading range.

The second design criterion which was extensively investigated was optimisation of the deployment times for each boom. The booms should deploy sufficiently quickly that, in the event of a single gas-bottle failure, both booms of any pair fully deploy before the available gas escapes via the numerous seals. On the other hand, they should not deploy so fast as to become damaged.

Extensive tests have been performed at subsystem and system level to demonstrate that the throttle sizes finally selected will give acceptable deployment times for all four booms, both at the extremes of operational temperature (using one or two gas bottles) and over the operational spin range.

UHF ANTENNA

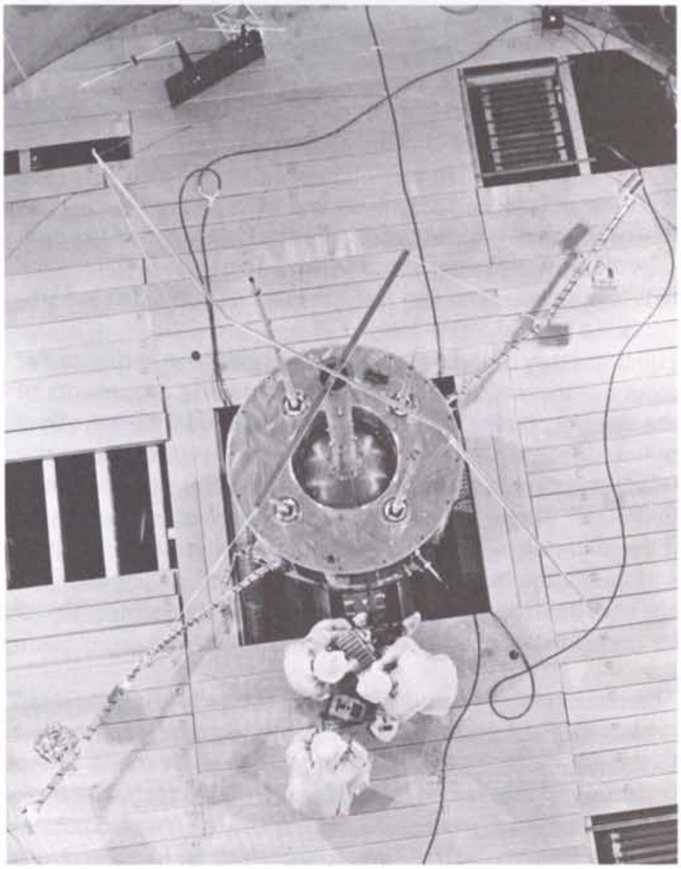
Deployment tests were performed with gravity compensation to optimise the deployment spring tension needed to erect the antenna over the full spin-rate range. Tests were also performed with only one deployment spring attached. Static gravity-compensated deployment tests in thermal vacuum were also conducted to verify the effect of temperature extremes on bearing friction. These showed that even with the increased stiffness of antenna cables caused by the low temperatures, the mechanism could still operate successfully and meet the alignment requirements.

The balance requirements for the UHF antenna mechanism proved to be similar to those for the short radial booms. The mechanism had therefore to be balanced statically and dynamically in both its stowed and deployed configurations by attaching an offset balance mass to the tip of the waveguide.

SYSTEM TESTING

All basic performance parameters were successfully tested and demonstrated at unit level, but with such complex assemblies it was also necessary to test at system level to demonstrate that the integrated components, including the telecommand and the pyrotechnic processing unit, would function correctly. Because of the nature of the design, this presented a unique challenge in order to ensure that the test was representative, realistic, and did not endanger any of the boom systems or the spacecraft itself.

All the system-level deployment tests were made in ESTEC's Dynamic Test Chamber which has been specially designed and built to perform dynamic tests on Geos and similar spacecraft. It readily provides a vacuum of less than 1 torr, a reference pressure accepted as eliminating all the effects of aerodynamic drag. The boom tests made use of a spin machine with variable speed control and variable acceleration and deceleration characteristics. The main points of interest in the system test can be discussed boom by boom.



Geos's boom systems deployed (long radials only partially) in the Dynamic Test Chamber at ESTEC.

SHORT RADIAL BOOMS

As has already been mentioned, deployment of the short radial booms significantly alters the moment of inertia of the spacecraft, causing a spin down of approximately 20 rpm. It was not wise to artificially maintain the release spin rate because of the high stresses that would be imparted to the booms, and therefore the tests were made by firing the pyrotechnic cable cutter and decoupling the spin machine's drive simultaneously. For greater realism, gravity compensation was applied at the outer hinges.

The system testing of the short radial booms had to be divided into two parts to fully demonstrate the two most important criteria, namely release of the boom from the stowed position and locking of the hinges at the end of deployment. This was necessary because the booms are not designed to lock under 1 g conditions, where considerable hinge friction (about ten times that in orbit) is introduced. A zero-gravity suspension rig was designed at ESTEC to support each boom at a single point and thereby eliminate friction moments at the outer hinges and reduce inner hinge moments to noncritical levels. The difficulties of applying such accurate compensation over the full deployment cycle dictated that the locking test be started with the booms only 5° from their final position.

The test was made by spinning up the spacecraft slowly, as the angular acceleration had to be less than 0.02 rad/s^2 to ensure that locking resulted entirely from centrifugal forces. A typical spin-up time from 0 to 20 rpm was about 10 min.

The locking test highlighted two problems associated with the integration of the short radial booms which were subsequently overcome:
(i) the procedure for setting the synchronisation cord had to take into account the effects of gravity
(ii) the restraining effects of the synchronisation cord guides across the spacecraft had to be considered.

LONG RADIAL BOOMS
Due to test-facility limitations, it was necessary to devise a suspension system that would not interfere with sensor release, with the locking of the hinged root dampers, or with any other boom systems, but would still provide adequate support to ensure that the sensors would not hit the floor as the flexible booms dropped when stopping the spin machine. The events in the deployment sequence were:
(i) initiation of the pyrotechnic cable cutters
(ii) opening of the experiment housing, release of the sensors, and microswitch operation
(iii) locking of the hinged root dampers and oscillation of the sensors relative to the spacecraft until their excess energy has been dissipated
(iv) a short deployment of the flat cables.

As the flat cables are 19 m long, it was not possible to make a full deployment under spinning conditions. The long radial booms were, however, deployed completely at system level at BAC. A tension equivalent to the centrifugal force was applied and the deployed length was measured by built-in optical-sensor electronics accurate to within 1 cm in 19 m for each boom.

AXIAL BOOMS
The axial booms are deployed by gas pressure and there is therefore a major difference between testing in air and in vacuum; the differential pressure determines the deployment dynamics, whereas the absolute pressure determines the gas-bottle charge required. The system tests in ESTEC's Dynamic Test Chamber were the first occasion on which the axial booms had been deployed in vacuum with the spacecraft rotating at the nominal deployment speed.

The initial tests performed in air identified an orifice in the short-axial-boom gas line as a single-point failure. This was subsequently eliminated from the design. One of the early tests in vacuum caused some surprise because the booms deployed quicker than anticipated, by approximately 0.5 s. This resulted in some damage to the tube guides due to a rebound effect at the end of deployment. Consequently, the gas flow rate to all booms was lowered by reducing the diameter of the control orifice at the base of each boom. In all subsequent tests the pump-down time was extended to give a stabilisation period of 5 h at 0.5 torr to ensure that residual gas pressure within the booms did not affect the deployment profile.

UHF ANTENNA
The positioning of this antenna at the separation plane interface made it impossible to make a completely realistic system test whilst spinning the spacecraft. The deployment tests were performed with the spacecraft's z-axis horizontal, such that the antenna blade deployed sideways, with the disadvantage that unrealistic side forces were applied to the four-bar link system. This caused a slight problem with the housekeeping microswitch, which actuates in a range of some hundredths of a millimetre. This malfunction disappeared when the gravity bending forces were eliminated by positioning the antenna vertically.

CONCLUSION

This article has hopefully served to illustrate that the Geos boom systems are a very sophisticated and complex set of mechanisms which have required an extensive programme of testing and adjustment to guarantee successful in-flight performance. The numerous anomalies that were brought to light during subsystem and system level tests and were subsequently designed out have served to emphasise how necessary detailed control procedures and rigid disciplines are to the achievement of consistently good satellite performance. □

Electromagnetic Cleanliness – An Important Characteristic of the Geos Satellite

C. Kalweit, Geos Division, ESTEC, Noordwijk, The Netherlands
A. Pitt, Electronics & Space Systems Group, British Aircraft Corporation, Bristol, UK

To avoid disturbing Geos's measurements of weak electromagnetic fields and low-energy particles, the spacecraft has had to be provided with an unusual degree of electromagnetic cleanliness (EMC). A comprehensive cleanliness development programme has therefore been pursued and the final design includes a variety of novel features. New test facilities were built to verify EMC performance and the satellite that has finally been produced is fully compatible with the experimenters' requirements, with interference levels decades below the ambient noise level on Earth.

Geos has had to meet the most severe electromagnetic-cleanliness requirements of any European satellite built so far. The problem has been to achieve extremely low interference levels over a wide range of frequencies, including DC (zero frequency) fields. The field amplitudes involved are close to the resolution threshold of present-day sensors and far below ambient field levels at the Earth's surface.

The need for this high degree of electromagnetic cleanliness stems from the spacecraft's experiments, which measure fields and particles in geostationary orbit. Both electric and magnetic fields are to be studied, covering the frequency range from zero to several 10^4 Hz. The particle experiments measure electrons and protons in the range 0.5 eV to several MeV. The physical

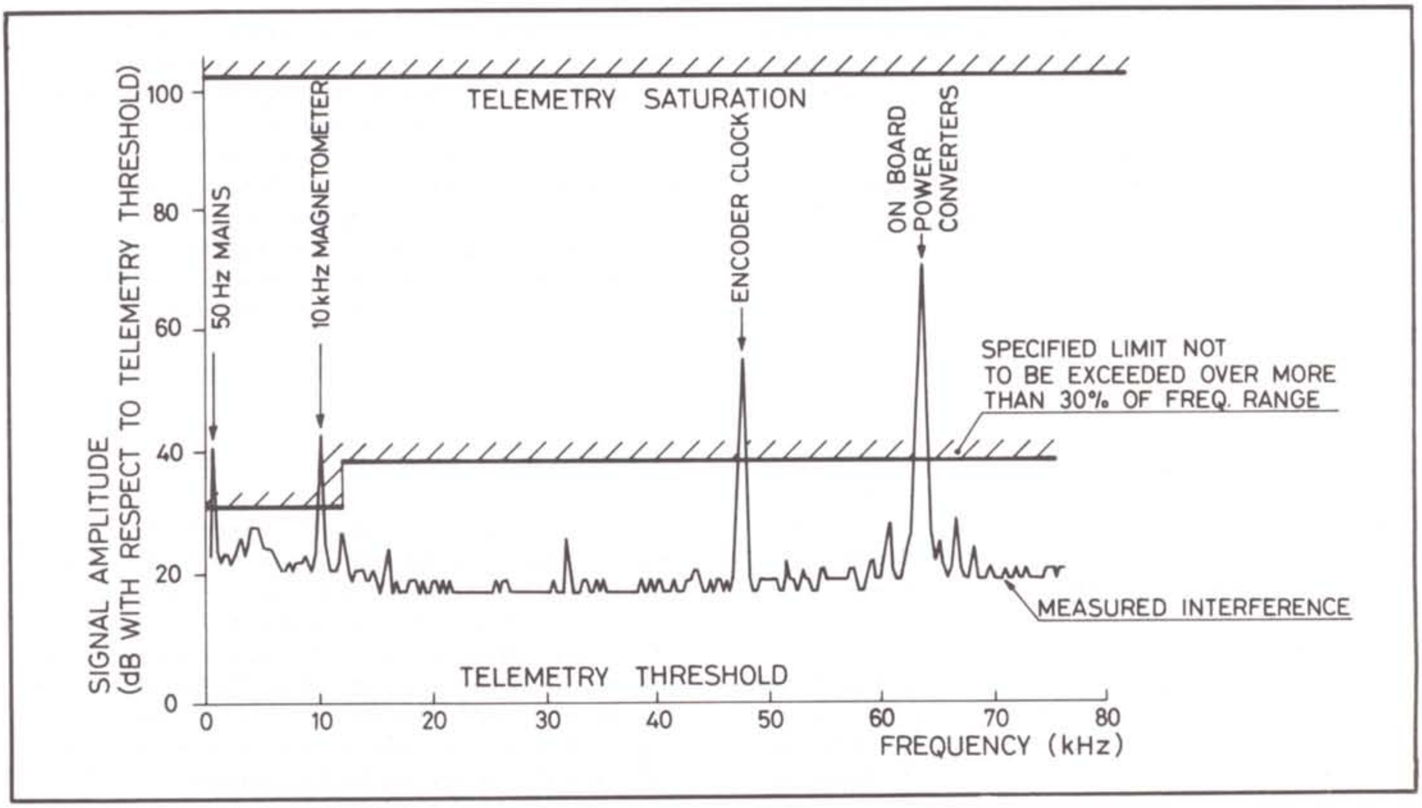


Figure 1 — Comparison of specified and typically achieved electromagnetic cleanliness.

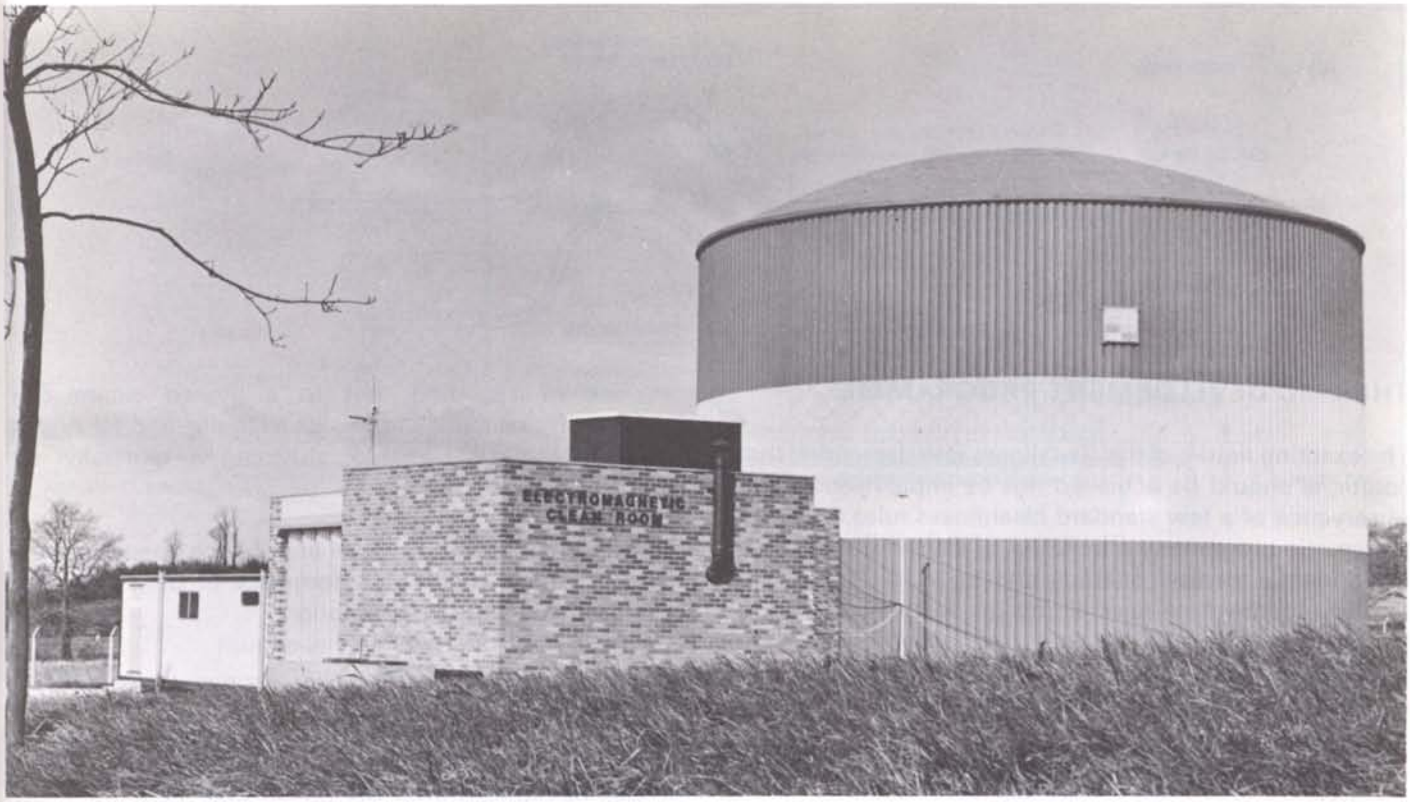


Figure 2 – Electromagnetic clean room at BAC, Bristol.

phenomena can only be studied if the electromagnetic interference generated by the spacecraft is small compared with the field levels expected in orbit and if the satellite fields do not disturb the particles (the low-energy particles are, of course, the most easily disturbed).

ELECTROMAGNETIC CLEANLINESS REQUIREMENTS

The cleanliness requirements of the particle experiments to be flown on Geos are fairly normal by satellite standards, and the requirements for the magnetic-field measurements (experiment S-331) are briefly discussed later, in the section on 'magnetostatic cleanliness'. The most demanding experiment as far as EMC is concerned is the S-300 wave-field experiment which consists of five groups of field sensors.

The magnetic field is measured by two sets of three-axis search-coil magnetometers, one set for the ULF/ELF range (0.1–450 Hz) and one for the VLF range (450 Hz – 30 kHz). The sensors are mounted 2.9 m from the satellite's central axis on a radial boom. Their tolerable interference level is shown in Figure 1 as a function of frequency.

The alternating electric field is measured by a set of four small spherical wire cages not unlike small bird cages. They are mounted at the ends of two pairs of axial booms, which extend 1.0 m and 2.5 m, respectively, above the upper face of the cylindrical spacecraft. Three components of the electric fields are measured, in the frequency range 50 Hz – 77 kHz.

The frequency range of the electric measurements is extended down to 0.1 Hz by two vitreous-carbon-sphere sensors mounted at the tips of two radial cable booms, each 20 m long.

It is difficult to visualise the very low field levels that we are dealing with for Geos. An idea of their order of magnitude can perhaps be gained from a comparison with the radio signals received from a typical broadcasting station. If we take a station transmitting with a power of 400 kW on a frequency of 200 kHz, a combination that fits BBC Radio-2 at Droitwich, then an antenna 100 km away would receive a radio signal with an approximate magnetic-field amplitude of 0.33 nT and an electric-field amplitude of 0.1 V/m. These levels are no less than 20 000 times stronger than the magnetic-field tolerance and 300 000 times stronger than the electric-field tolerance of the Geos S-300 experiment at its most sensitive operating points.

A further difficult requirement originates from the long-radial-boom sensors, in that the electrostatic field generated by the spacecraft must not exceed 10^{-4} V/m.

THE EMC DEVELOPMENT PROGRAMME

The exacting nature of the cleanliness task demanded that solutions should be achieved not by improvisation and observance of a few standard cleanliness rules, but by a systematic programme consisting of several phases:

- an initial theoretical study phase (1970–71)
- development of special design features involving computer modelling and (simplified) hardware models (1971–73)
- establishment of detailed subsystem specifications (1972)
- elaboration of system and subsystem designs (1971–73)
- study, design and manufacture of special test facilities (1971–74)
- EMC tests on engineering-model units, followed by modification and improvement of unit cleanliness, and integration of these units into the development-model satellite (1974)
- unit testing of the next two generations of units: prototypes for the qualification-model satellite, and flight units (1975–76) incorporating improvements from earlier tests
- EMC system-level testing of the development-model satellite (January-February 1975), followed by diagnostic investigation of EMC problems and improvements at unit and system level
- EMC system-level testing of the satellite qualification model, i.e. measurement of the final design cleanliness characteristics (April 1976)
- EMC system-level testing of the flight-model satellite to confirm the qualification-model results and to verify repeatability (1976).

THE CLEANLINESS DESIGN

The design measures taken to minimise electromagnetic interference are too numerous to be described in detail here. The most important general principles employed were:

- minimisation of current loops by careful cable-harness routing and internal unit wiring
- careful filtering of power lines (filtering was improved following the first system-level test results)
- use of shielding, but to a limited extent (for transformers and cables, for example, and for higher frequencies); ULF/ELF shielding is generally not practicable.

Three further design features are of such special importance to the cleanliness performance of Geos that they merit at least a brief presentation:

- the use of the frequency spectrum
- the grounding scheme, and
- the solar-array design.

FREQUENCY SPECTRUM

It was recognised from the outset that there are a few 'interference generators' on board the spacecraft whose field levels could not possibly be kept below the tolerance levels just discussed. To minimise their effect, their frequencies have been chosen so as to create minimum annoyance, and all are rigidly synchronised to ensure that the interference frequencies are stable, easily recognisable, and do not produce beat frequencies.

The main interference generators are, of course, the power supply converters, which are synchronised by a 127 kHz signal derived from the encoder clock. There are nine (main) power converters on board Geos and, as a special feature of the EMC design, they are grouped into four sets, each set synchronised by a train of pulses phase-shifted by 90° with respect to the next to give partial compensation of the interference signals.

The other major interference generator is the telemetry encoder, which generates digital signals over a frequency range of 0.09 Hz to several MHz, dictated by the satellite's data-transmission requirements. The main precautions taken against such interference from the data-handling subsystem have been to minimise the areas of the current loops traversed by the signal currents and to keep the amplitudes low by using high-impedance interfaces.

GROUNDING SCHEME

A crucial and somewhat controversial aspect of EMC design is the question of grounding, i.e. connection to a common electrical reference. Some designers argue in favour of a decentralised grounding system, in which every circuit is grounded directly, by the shortest possible

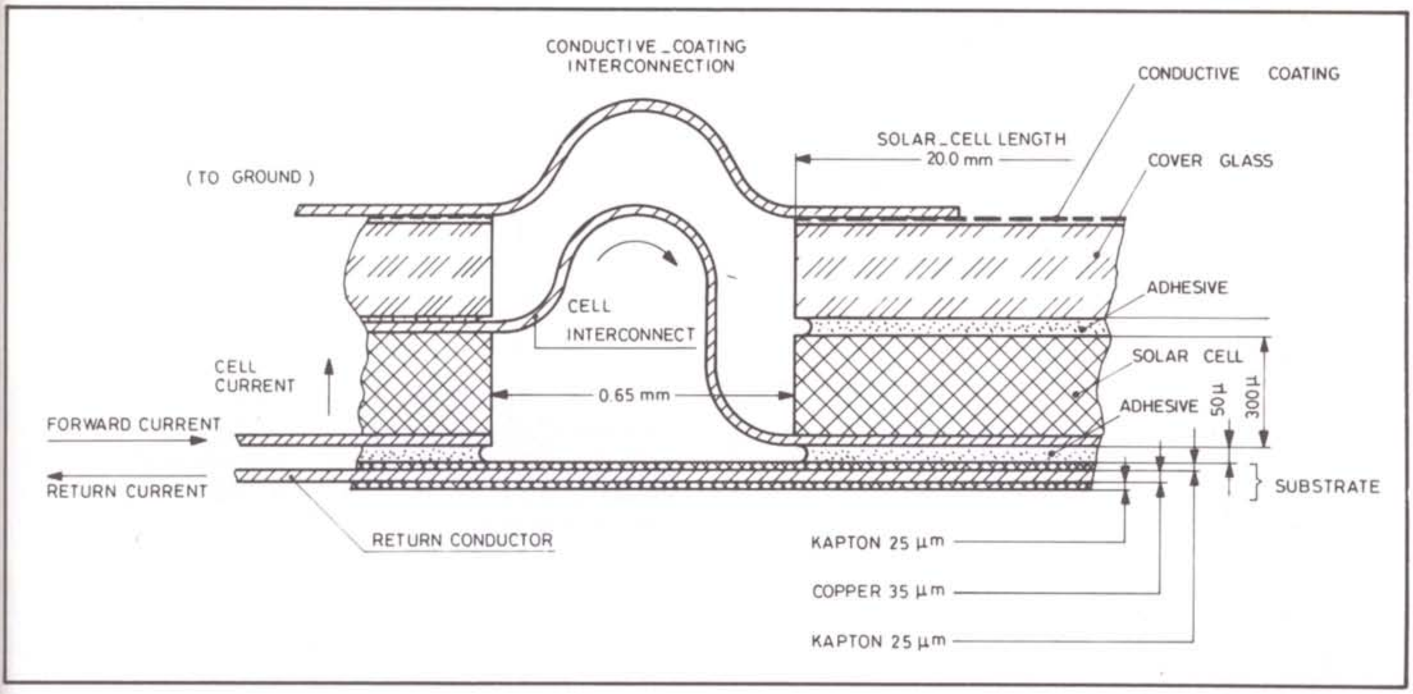


Figure 3 – Cross-section through the Geos solar array.

route, to the metal structure. This has the advantage that grounding impedances are extremely small and thus cross-coupling of signal return currents is minimised.

In the Geos design, we have opted for a centralised grounding system. Almost all the electrical ground connections are brought to one 'Central Ground Point', where they are connected to the metal structure of the satellite. The exceptions are the high-frequency circuits of the telecommunications subsystem, which are grounded close to each unit, and a few experiment sensor circuits which are linked to the remainder of the electronic system only by high-impedance paths.

The main argument in favour of central grounding is that all ground signal paths are known and well defined. There can be no cross-coupling of different subsystems by vagrant ground currents flowing through the same parts of the structure. This scheme proved its merits during the Geos hardware development phase, when it was possible to trace certain interference phenomena to the subsystem grounding and hence to improve matters by altering the ground connections.

To achieve a true single-point grounding system, a decentralised power supply is required, otherwise the return lines for the various supply voltages would provide an interconnection between the individual subsystems and so create ground loops. Geos therefore employs nine separate DC-DC power converters which provide transformer isolation between inputs and outputs.

SOLAR ARRAY

Of the satellite's electrical subsystems, the solar array deserves special comment by reason of its particular EMC features. It is certainly one of the most critical items in this respect, for two reasons: (i) it carries the heaviest current of all subsystems and could therefore generate strong magnetic fields, and (ii) its electrodes and surfaces cover a large part of the spacecraft's outer skin and could therefore, if unshielded, produce important electric fields.

The solar cells are arranged in 240 vertical strings on four panels, with a 19 mm gap between panels. As the satellite rotates in sunlight, the satellite's own shadow sweeps over the solar array and causes modulation of cell currents and voltages. As the array produces a current of approximately 4A and a potential of 25 V, the interference generated would be prohibitive if no special measures had been taken to reduce it. It is these measures which have made development of the Geos solar array one of the most interesting tasks in the cleanliness programme.

The first step towards reducing magnetic fields was to minimise the current-loop area (Fig. 3). Each string consists of 30 solar cells, connected in series and mounted on a thin substrate. The string current flows via welded interconnections from one cell to the next, and the return conductor runs back beneath the same string. Each string current is therefore constrained to a very narrow loop, about 0.24 mm across.

The next step was to adopt the novel layout for the solar-

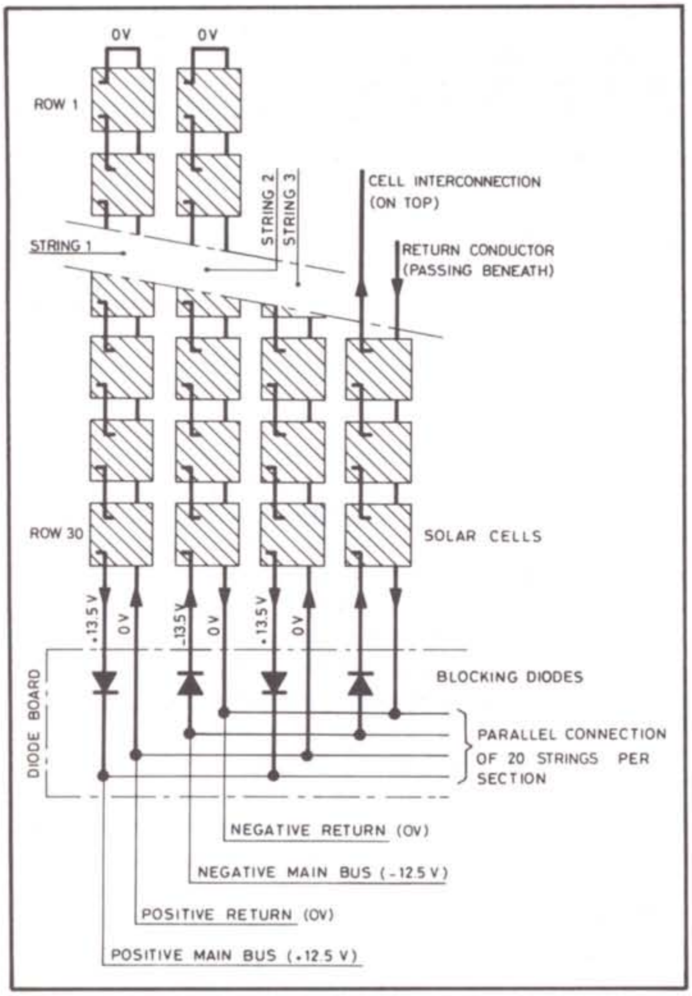


Figure 4 – Layout of the solar-array strings.

cell strings shown schematically in Figure 4. This has two purposes: mutual compensation of current loops of individual strings, and optimised distribution of surface potentials.

Another benefit of the solar-cell layout that has been used is that the electric field generated by the cells' surface potential is much reduced because the contributions from the adjacent cells are of opposite polarity and are to a large extent mutually compensating. Furthermore the maximum cell voltage to ground (structure) has been limited to half the total array voltage (13.5 V) by dividing the array into a negative and a positive half (each half having strings of 30 cells) which are connected in series and grounded at the centre point.

To the fields originating from the complete solar array, one has, of course, to add those fields generated by the wiring between diode boards and between diode boards and connectors, which are actually somewhat more difficult to compensate.

A major task in the cleanliness programme was the development of an *electrostatically* clean satellite, with a minimum of electrical spacecraft-surface charging. This aspect will not be discussed in detail here as it is covered elsewhere in this Bulletin, but for the solar array it involved the application of the transparent conductive coating to the cell cover glasses (see Fig. 3).

THE EMC TEST PROGRAMME

The main problem in preparing the EMC tests was to find a suitable electromagnetically 'quiet' test facility in which the ambient noise would not swamp the faint interference signals from the satellite.

Two approaches were pursued. The first was to seek a 'naturally quiet site', sufficiently far removed from electrical machinery, railway lines, densely populated areas etc., to have a low residual electromagnetic noise level. Systematic surveys in remote areas of France, Germany, Britain and the Netherlands failed to locate a suitable site. The results varied from place to place, but the ambient noise level always exceeded the tolerable levels for Geos by factors of up to several hundred, and at best by a factor of about 20. These surveys did, however, serve to provide an impressive illustration of the severity of Geos's requirements.

The other approach pursued was to devise a 'screened test room' in which the ambient noise could be reduced by metallic (preferably ferromagnetic) shielding. There were already many shielded EMC test rooms in use in Europe, but they are all intended for kHz/MHz frequencies and

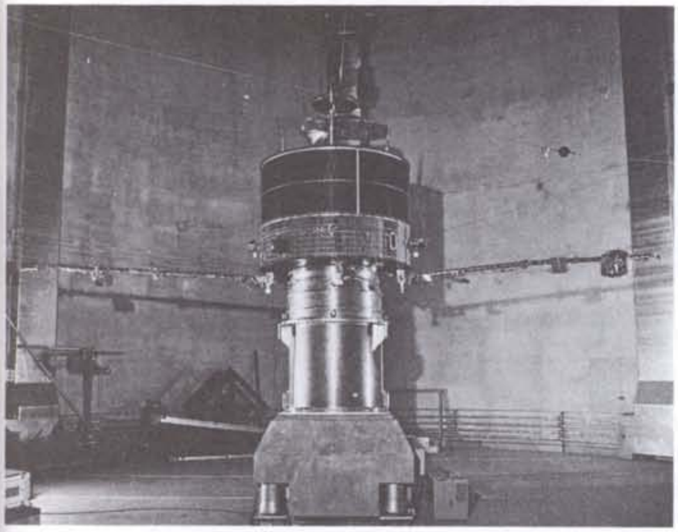


Figure 5 – Geos qualification model in the BAC chamber.

none provided the requisite attenuation at lower frequencies. Finally, a solution was proposed by BAC which combines very good shielding characteristics with relatively low cost. The main structure, erected in 1974 at BAC's Filton premises, is a cylindrical tank 12 m high and 14 m in diameter made, rather like a gas or petroleum storage tank, from continuously seam-welded mild-steel plates (Fig. 2).

Extensive system-level EMC tests were conducted successfully in this chamber at Filton for all three Geos satellite models. Figure 5 shows the satellite during such a test, mounted on a seismic block to reduce mechanical vibrations, which in conjunction with the static geomagnetic field would induce error voltages in the sensors.

These system level tests were made with the satellite powered by its own battery. Separate EMC tests were performed with a complete solar array mounted on a special, simplified spacecraft model. A collimated light beam about 2 m in diameter and having approximately the same intensity as natural sunlight was used to illuminate the array. Artificial light sources were precluded because they would have produced too much electromagnetic noise. The scheme adopted used the natural sunlight reflected by a set of mirrors mounted on rotating stands, as shown in Figure 6. Although the chamber doors had to be open during this test, the electromagnetic noise inside was increased only slightly, due to the waveguide-type attenuation provided by the entrance tunnel (Fig. 7).

Radio-frequency interference tests were made at unit and system level. As expected, the Filton chamber suffered from strong reflections. Lining of its wall with anechoic material would have improved matters, but this was not done because of the high costs involved. Instead, the preliminary satellite radio-frequency tests at Filton were supplemented by tests in the anechoic test facility at MBB, Ottobrunn and the magnetic facility at IABG, Munich.

MAGNETOSTATIC CLEANLINESS

The achievement of satellite magnetostatic cleanliness is a more conventional task and need not be described here but for a few salient features that distinguish Geos from earlier projects.

The tolerable field level of 0.5 nT (in the *z*-direction at the S-331 experiment sensor) is about 10^{-5} times the geomagnetic field at the Earth's surface. This is one of the most severe requirements encountered to date by the Agency, and to achieve this degree of cleanliness in the Geos development programme the following principal problems had to be resolved:

- the fields generated by current loops had to be made small in comparison with the disturbing effects of ferrous materials by applying the standard classical rules, such as minimisation of loop areas (e.g. twisting of power cables), avoidance of strong solenoids (relays, motors), etc.
- the inverse cubic law for the fall-off of a dipole field led to an emphasis on extreme cleanliness in the immediate vicinity of the Geos magnetometer
- small disturbances (in the order of fractions of a nano-tesla) arose from unexpected sources. For example, the short radial Geos boom was plagued for a while by a disturbance that was finally traced to contamination on a fibreglass washer
- materials and components that are normally classified

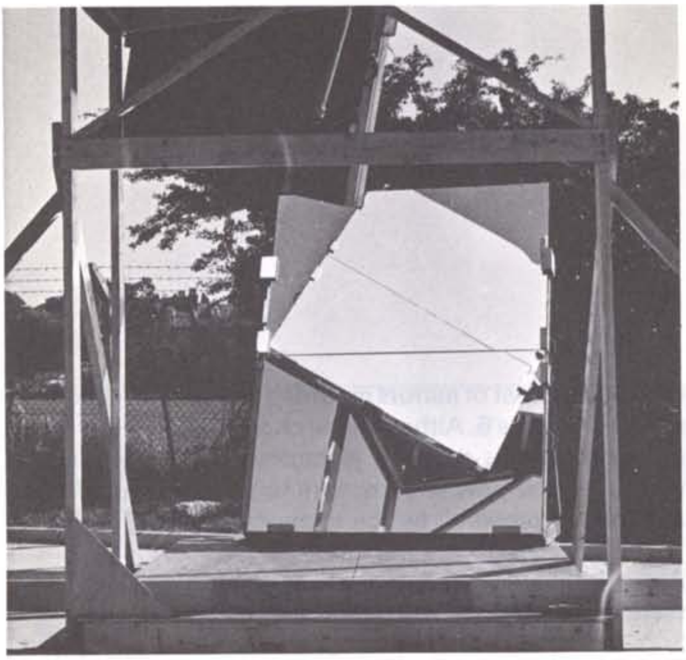


Figure 6 – Mirror system seen from inside the EMC facility.

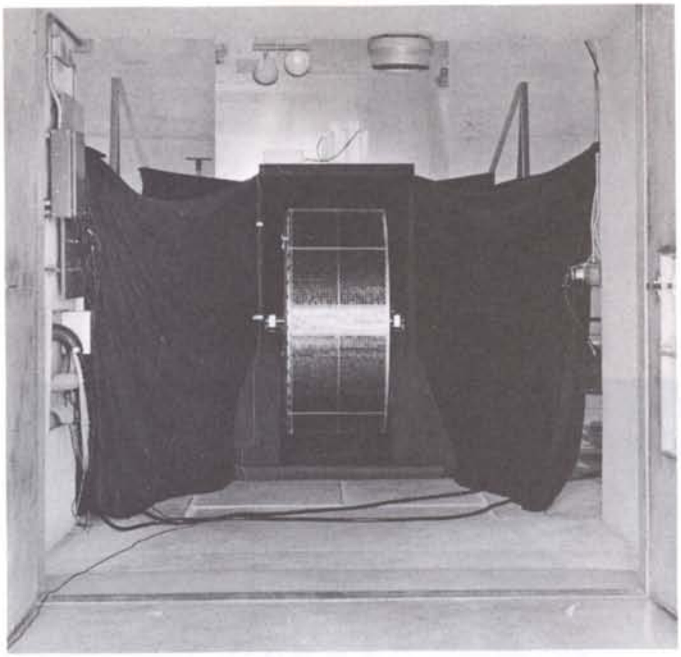


Figure 7 – Solar-array-generated noise test in progress. Viewed through open doors of facility.

as 'nonmagnetic' do not merit this descriptor when requirements below 1 nT are involved. For instance, a great many rivet nuts had to be changed from stainless steel to titanium for magnetic reasons.

The testing of a satellite for magnetic cleanliness to an accuracy of fractions of a nano-tesla is a problem even in the best magnetic test facilities, for which the measurement resolution is in the order of 0.2 nT. Adding to this other measurement errors in alignment, instrument drift, temperatures, etc., the need to develop special test techniques soon became apparent.

Geos was tested in the IABG magnetic test facility at Ottobrunn. The special test technique developed involved mounting an array of five test magnetometers on a probe frame as shown in Figure 8. The satellite was moved back

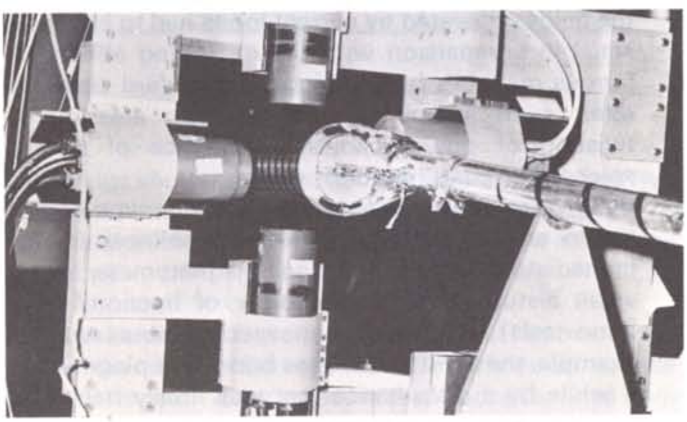


Figure 8 – Test magnetometers on travelling probe frame.

and forth on rails, so that the boom carrying the S-331 experiment moved through the window in the test-probe frame. The magnetometers measured the magnetic-field envelope around the boom as a function of radial distance from the spacecraft. The data obtained were analysed with a specially developed computer program to identify the disturbance sources and to extrapolate the fields at the critical sites.

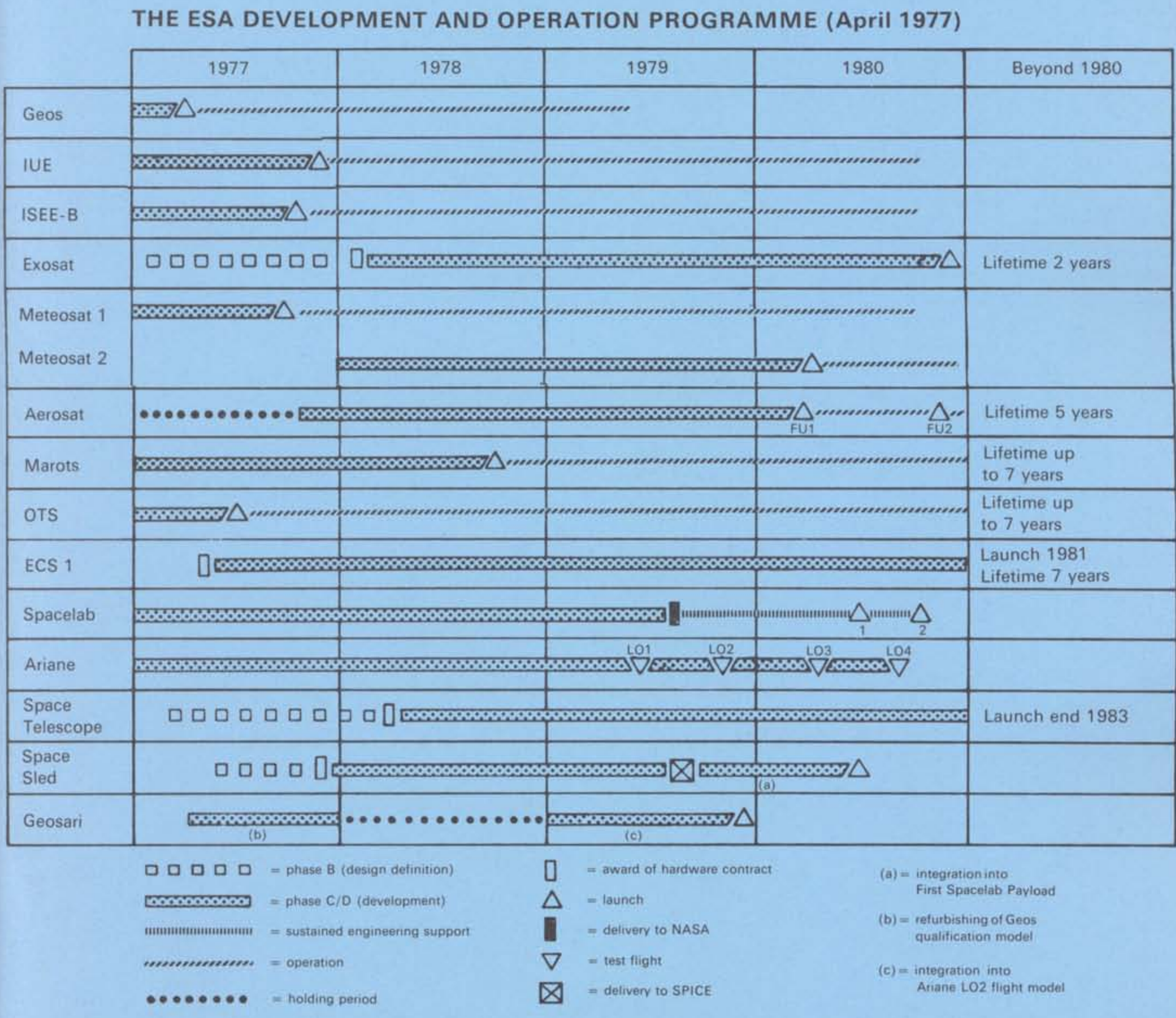
The results of these tests showed that the disturbance field is 32% below the specified tolerance in the critical satellite *z*-axis direction.

Apart from ensuring magnetic cleanliness under space conditions, the satellite's design also had to ensure that its inevitable exposure to higher magnetic fields during pre-launch transport and testing, for example, would not produce residual magnetisation. The tests showed that such a remnant effect would only occur at field levels well above those to be encountered by Geos in its ground environment.

THE EMC RESULTS

The very considerable effort invested in the Geos cleanliness programme has resulted in a satellite performance that meets, and in most respects surpasses, the specifications. Generally speaking, satellite cleanliness is at least a factor two better than the minimum S-300 acceptance criteria. A comparison between S-300 requirements and actual interference measured was shown in Figure 1 for a typical case (*z*-axis electric component, all subsystems and experiments switched on). □

Projects under Development
Projets en cours de réalisation



GEOS

The Geos Flight-Readiness Review was conducted on 9 and 10 February 1977. Clearance for shipment to Eastern Test Range was given and the launch campaign was started in early March to meet the launch date of 20 April. Launch operations are proceeding satisfactorily, including ground simulations with the ground network and the Operations Centre at ESOC in Darmstadt.

IUE

The flight-quality cameras have been delivered to NASA by the UK Science Research Council and four more are being prepared for delivery before June, lending confidence that the scheduled launch date for IUE of 15 December 1977 will be maintained.

The flight scientific instrument is at present undergoing tests in the vacuum optical bench facility at Goddard Space Flight Center. The flight spacecraft and the engineering model of the scientific instrument are being readied for a first series of integrated tests.

At a recent three-Agencies meeting at GSFC, the detailed plans for the scientific commissioning of IUE were discussed, and a basis was established for setting up an IUE Commissioning Team, composed mainly of project personnel but supported by a few external scientists.

Present plans for ESA's IUE ground station require it to be fully operational by 1 December 1977. As regards the contract for integration of the station, there are indications that the planning schedule can only be respected with exceptional effort on the part of the contractor. All hardware to be delivered under this contract is expected to be available on site by mid-April and installation activities are now proceeding.

Construction of the VHF antenna platform is progressing and it is planned that this antenna, which has already been delivered to Madrid, will be installed, with NASA's assistance, in July/August 1977.

Usage of the Sigma 9 computer system is nominal and integration of the software continues following the receipt of the second release of the Observatory Control Centre (OCC) software in March.

Twenty-nine staff have now been provided by the contractor for the operation and maintenance of the station. The microwave link with Madrid has been completed and will be used shortly for telephone, telex and data traffic. Preparatory work for the improvement of the access road has started, but as yet the road is still in very bad condition.

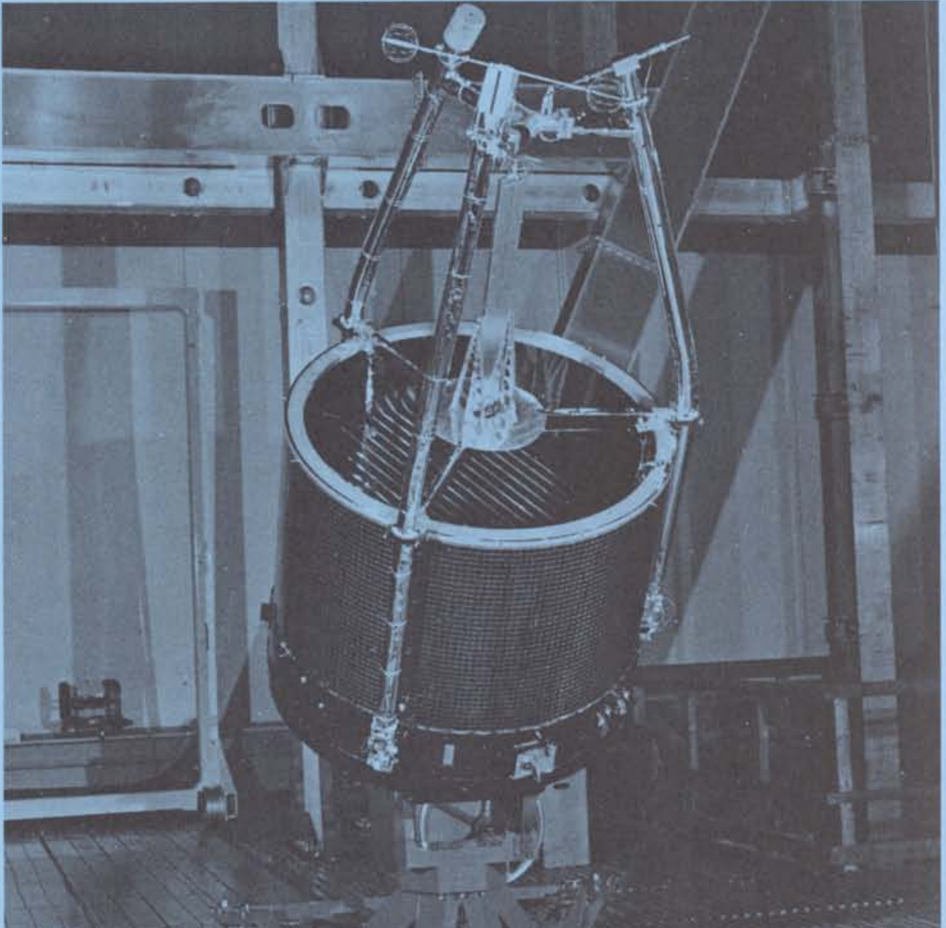
ISEE

ISEE-B Spacecraft

The general progress of the ISEE project continues to be satisfactory and, unless a major catastrophe occurs, there should be no difficulty in meeting the launch date, which has now been advanced to 13 October

ISEE-B satellite in launch configuration

Satellite ISEE-B en configuration de lancement.



GEOS

A l'issue de l'examen d'aptitude au vol de Geos qui a eu lieu les 9 et 10 février, le feu vert a été donné pour l'expédition du satellite à l'Eastern Test Range où la campagne de lancement a aussitôt commencé, début mars, afin de respecter la date du 20 avril fixée pour le lancement. Les opérations de lancement se déroulent normalement, notamment les simulations qui sont faites au sol avec le réseau de stations et le Centre des Opérations à Darmstadt.

IUE

Le Conseil de la Recherche scientifique (SRC) du Royaume-Uni a déjà livré à la NASA plusieurs systèmes de tubes-images aux normes de vol et en prépare actuellement quatre autres en vue de leur livraison avant juin. On peut donc se montrer très optimiste sur la possibilité de tenir la date du 15 décembre 1977 prévue pour le lancement d'IUE.

L'instrumentation scientifique de vol subit actuellement des épreuves au banc d'essais optiques sous vide du GSFC. On prépare actuellement, pour une première série d'essais d'intégration, le modèle de vol du véhicule spatial et le modèle d'identification de l'instrumentation scientifique.

Lors d'une récente réunion entre les trois Agences responsables qui s'est tenue au GSFC, les plans détaillés de mise en oeuvre scientifique de l'IUE ont été débattus et les bases de la constitution d'une Equipe de mise en oeuvre du satellite ont été arrêtées. Cette équipe sera essentiellement composée de personnel de projet auquel se joindront également quelques chercheurs extérieurs.

En ce qui concerne la station au sol fournie par l'Agence, les plans actuels imposent qu'elle soit entièrement opérationnelle au 1er décembre 1977. Pour ce qui est du contrat d'intégration de la station, certaines informations donnent à penser que le planning ne pourra être remanié qu'au prix d'un effort exceptionnel du contractant. Tous les matériels qui sont à livrer dans le cadre de ce contrat devraient être disponibles sur le site à la mi-avril et les travaux d'installation ont d'ores et déjà commencé.

La construction de la plate-forme de l'antenne VHF avance et l'on prévoit que cette antenne, qui a maintenant été livrée à Madrid, sera installée avec l'aide de la NASA dans la période juillet-août 1977.

Le système de calculateur Sigma 9 fonctionne normalement et l'intégration du logiciel se poursuit après la réception de la seconde version du logiciel du Centre de contrôle de l'Observatoire (OCC) en mars.

Le contractant a affecté, à ce jour, 29 personnes à l'exploitation et à l'entretien de la station. La liaison hyperfréquences entre la station et Madrid est achevée et doit être prochainement mise en service pour les communications téléphoniques, les transmissions telex et de données. Les travaux préparatoires pour l'amélioration de la route d'accès ont commencé mais, en l'état actuel des choses, cette route est toujours en très mauvais état.

ISEE

Véhicule spatial ISEE-B

Dans l'ensemble, le projet ISEE continue à progresser de façon satisfaisante et, à moins de catastrophe, la date de lancement qui a maintenant été avancée au 13 octobre de cette année devrait pouvoir être tenue. Les essais du modèle d'intégration du véhicule spatial ont été achevés dans les temps et les unités de ce modèle qui doivent servir de rechange de vol ont été renvoyées aux différents sous-traitants pour être remises en état, ce qui a été fait pour une grande partie d'entre elles.

L'intégration du modèle de vol du véhicule spatial s'est déroulée dans des conditions exceptionnelles chez le contractant principal, sans dépassement excessif des horaires normaux de travail. Actuellement le véhicule spatial est entièrement assemblé et le premier essai du système intégré est partiellement achevé.

Charge utile expérimentale

Toutes les expériences destinées à l'unité de vol ont été livrées et à un ou deux incidents près, aucun problème sérieux ne s'est posé à ce jour. On met au point les plans de remise en état des unités du modèle d'intégration qui serviront, lorsque ce sera possible, de rechanges pour l'unité de vol.

Véhicule spatial ISEE-A

L'équipe du Centre des vols spatiaux Goddard a rencontré un certain nombre de difficultés en ce qui concerne d'une part, la livraison des expériences de l'unité de vol et d'autre part, le logiciel de vérification du véhicule spatial. Les membres de l'équipe ont toutefois pu régler la plupart des problèmes en fournissant un effort supplémentaire important et ils ont bon espoir d'être prêts pour le lancement au jour fixé. Une inversion de séquence entre les essais de vide thermique et les essais en vibration s'est révélée nécessaire pour éviter d'éventuels chevauchements avec le programme IUE dans l'utilisation des installations d'essais.

this year. Testing of the integration-model spacecraft was concluded on schedule and the units from it which are intended as flight spares have been returned to the various subcontractors for refurbishment. Many of these have already been completed.

Flight-spacecraft integration has been progressing remarkably smoothly at the prime contractor without need for undue overtime or weekend work. Current status is that the spacecraft has been completely assembled and the first integrated system test has been partially completed.

Experimental payload
All experiments for the flight unit have been delivered and, although there have been one or two incidents, no major problems have been encountered to date. Planning is under way for refurbishment of integration-model units as flight spares where this is practicable.

ISEE-A spacecraft
The team at Goddard Space Flight Center has experienced a number of difficulties with delivery of flight-unit experiments and also with the software for checking-out the spacecraft. However, by working considerable overtime, most of these problems have been solved and GSFC confidently expects to be ready for launch on the appointed day. A reversal of sequence between the thermal-vacuum and vibration testing has been found necessary to avoid possible conflict with the IUE programme in the test facilities.

ESA has been manufacturing an accurate mass model of the ISEE-B spacecraft to be used in joint vibration testing of the A and B spacecraft. This has now been completed and sent to NASA.

The Pre-Environmental Test Review for the ISEE-A spacecraft took place successfully in January, with ESA providing part of the Review Panel.

Launch and operations
Work in this area is now increasing and a pre-launch schedule of work at Eastern Test Range has been evolved and agreed with the contractor. This period is more complex than for a normal satellite in view of the many interfaces with the ISEE-A spacecraft.

The writing of the Spacecraft Operating Procedures (SCOP) is now well under way, as is the preparation of the in-orbit software. It is planned to hold a training period for the NASA spacecraft operators in May/June.

EXOSAT

Satellite
The contract for Phase B (Project Definition Phase), was signed on 10 January.

Messerschmitt-Bölkow-Blohm (MBB), the Main Contractor, has subsequently spent a great deal of effort in negotiations with co- and subcontractors, and while agreement has been reached in the majority of cases there still remain two or three unresolved difficulties.

In the meantime, technical definition work continued, leading up to the System Concept Review (SCR) on 22/23 March. The Review served to clarify a number of misconceptions and also clearly identified two problem areas concerning the steps to be taken in order to meet the stringent requirements for both cleanliness and alignment of payload units. Payload options were also discussed, in general terms, during the SCR.

In parallel with the foregoing, a contract was signed on 15 February enabling MBB to study the financial and technical implications of modifying their baseline concept (Thor-Delta 2914 launcher) to make the satellite compatible with the Ariane launch vehicle. This study is due to be completed by 23 May. It is imperative that a decision be taken by the Agency within four weeks of this date whether to continue with the Thor-Delta baseline concept, or go for the Ariane concept.

The next important milestone for the satellite is the Subsystem Concept Review (SSCR) scheduled for early May.

Payload
Testing of the scientific model elements of the experiments continues satisfactorily. At present, the individual mirror shells and the channel multiplier array detectors are being tested at the University of Utrecht's X-ray facility. The complete low-energy telescope will be integrated for testing at a special facility in the United States within the next few months. Development work on the medium-energy and position-sensitive detectors continues satisfactorily.

At its meeting on 31 March, the Agency's Industrial Policy Committee approved the placing of contracts with LABEN/MATRA (experiment electronics), MATRA/SNIAS/SIRA/LABEN (focal plane) and CIT/ISA/Fichou (mirrors) for flight hardware. Award of the contract for the medium-energy detector is still pending.

ESOC activities
Mission-analysis work currently being undertaken at ESOC includes the

L'ESA a établi un modèle de masse très précis du véhicule spatial ISEE-B qui sera utilisé dans les essais en vibration communs des véhicules spatiaux A et B. Ce modèle est maintenant achevé et a été envoyé à la NASA.

L'examen préliminaire des résultats des essais d'ambiance du véhicule spatial ISEE-A s'est déroulé avec succès en janvier, une partie des membres du Groupe d'examen venant de l'ESA.

Lancement et opérations
Le volume des travaux augmente désormais dans ce secteur et un calendrier des tâches à effectuer avant lancement à l'Eastern Test Range a été élaboré en accord avec le contractant. Les problèmes qui se posent sont plus complexes que pour un satellite normal compte tenu des nombreux interfaces avec le véhicule spatial ISEE-A.

La rédaction des procédures d'exploitation des véhicules spatiaux (SCOP) est en bonne voie, tout comme la préparation du logiciel orbital. On prévoit d'organiser en mai ou juin un stage de formation pour les opérateurs de la NASA affectés au contrôle du satellite ISEE-B.

EXOSAT

Satellite
Le contrat relatif à la phase de définition du projet (phase B) a été signé le 10 janvier. Le maître d'oeuvre (MBB) s'est livré ensuite à un important travail de négociation avec les co-contractants et les sous-traitants, et bien que ces efforts aient abouti dans la majorité des cas, deux ou trois difficultés restent encore à résoudre.

Entre-temps, le travail de définition technique se poursuivait, aboutissant à l'examen de la conception au niveau système (SCR) les 22 et 23 mars. Cet examen a permis d'opérer un certain nombre de redressements et a fait apparaître deux secteurs critiques en ce qui concerne les mesures à prendre pour satisfaire aux impératifs de propreté et d'alignement des unités de la charge utile. Les options de charge utile ont également été discutées en termes généraux au cours de cet examen.

Parallèlement à ces activités, un contrat signé le 15 février permettait à MBB d'entamer l'étude des implications financières et techniques d'une modification de la conception de référence (avec lanceur Thor-Delta 2914) pour rendre Exosat compatible avec le lanceur Ariane. Cette étude doit être terminée pour le 23 mai. L'Agence doit impérativement décider dans les quatre semaines qui suivront si les travaux doivent se poursuivre sur la base de la conception de référence, avec lanceur Thor-Delta, ou s'il convient d'adopter la conception 'Ariane'.

La prochaine étape importante pour le satellite sera l'examen de la conception au niveau sous-système (SSCR) prévu pour début mai.

Charge utile
Les essais des éléments des expériences destinés au modèle scientifique progressent de façon satisfaisante. A l'heure actuelle, les coquilles réfléchissantes et le détecteur à galette de micro-canaux subissent des essais dans l'installation de rayonnement X de l'Université d'Utrecht. L'ensemble du télescope 'faible énergie' sera intégré pour des essais en installation spéciale aux Etats-Unis dans le courant des prochains mois. Les travaux de développement relatifs aux détecteurs 'moyenne énergie' et aux compteurs proportionnels à détection de position progressent de façon satisfaisante.

A sa réunion du 31 mars, l'IPC a approuvé la passation de contrats avec LABEN/MATRA (électronique des expériences), MATRA/SNIAS/SIRA/LABEN (plan focal) et CIT/ISA/Fichou (miroirs) pour des matériels de vol. La passation du contrat relatif au détecteur 'moyenne énergie' est toujours en attente.

Activités de l'ESOC
L'ESOC procède actuellement à un travail d'analyse de la mission, portant notamment sur la mise au point d'une stratégie d'occultation et sur l'établissement d'un modèle de mission. Ce dernier permettra une simulation réaliste pour l'évaluation du sous-système triaxal de commande d'orientation et de contrôle d'orbite (AOCS).

L'une des possibilités d'utilisation de la station de Weilheim en remplacement de celle de Villafranca initialement envisagée se poursuit.

Les négociations avec les autorités allemandes pour l'utilisation des fréquences en bande S ont abouti. Dans l'intervalle, il a été demandé à la DFVLR d'étudier l'importance des modifications qu'il faudra apporter à la station de Weilheim pour satisfaire aux impératifs de mission d'Exosat. Une réponse détaillée devrait être disponible pour la mi-août.

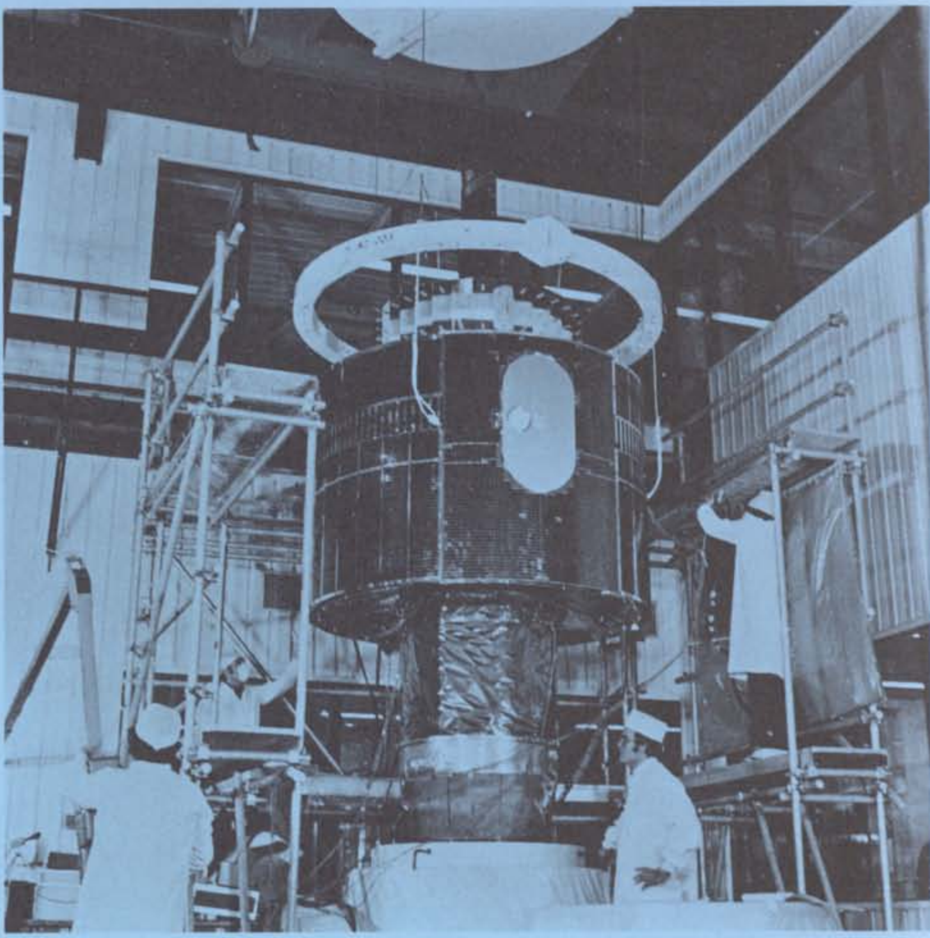
METEOSAT

Secteur spatial
Comme l'avait annoncé le dernier Bulletin, le modèle d'identification (P1) de Météosat a été envoyé en

development of an occultation strategy and the preparation of a mission model. The latter will be used as a realistic test simulator for evaluating the three-axis Attitude and Orbit Control Subsystem (AOCS).

Investigation of the Weilheim ground station as a possible alternative to Villafranca is continuing.

Agreement on the use of S-band frequencies has been reached with the German authorities. In the meantime, DFVLR has been requested to study the implications of modifying the Weilheim station to meet the Exosat mission requirements. A detailed response should be available by mid-August.



Meteosat prototype undergoing vibration tests at Centre Spatial de Toulouse.

Prototype de Météosat aux essais de vibration au Centre spatial de Toulouse.

METEOSAT

Space segment
As was foreseen in the last Bulletin, the Meteosat engineering model (P1) was sent in January to Odenwald for compatibility tests with the Data Acquisition Telecommand and Tracking Station (DATTS). The prototype model (P2) arrived in Toulouse in January, and it has successfully undergone vibration and other system tests. It is now being prepared for solar-simulation tests, which could start in mid-April, provided OTS can vacate the chamber by 20 March. Integration of the flight model has been completed and subsequent performance tests have been executed successfully. It arrived in Toulouse in mid-March and is now being prepared for vibration tests in early April. The intention is to launch this flight model on 31 August 1977.

The Meteorological Programme Board at its meeting on 11 March 1977 unanimously approved (France and Germany *ad referendum*) the launch of one Meteosat flight unit as principal passenger on Ariane flight LO3. Through the approved modifications to Annexes A and B of the Meteosat Arrangement, this project has become part of the Meteosat Programme.

Ground segment
The compatibility tests with the DATTS have so far revealed no major problems, except for the down-converters which will have to be repaired or replaced. The land-based transponder is now being prepared for compatibility tests with the satellite. Copies of the technical documentation for the Data Collection Platform (DCP) have been sent to users and development of the Primary and Secondary Data Users Stations (PDUS and SDUS) is on schedule. As far as the data-processing system is concerned, progress has been made with the availability of the computer (an average of 12 hours per day), but confidence in the planning is so far not very high.

As far as applications software is concerned, spacecraft and mission-control software packages have now been completed and are to be tested very soon.

Operations
The Meteosat Protocol, which covers a two and a half year exploitation phase starting six months after the launch of Meteosat 1, has so far been signed by Belgium, Germany, the United Kingdom and Switzerland. Denmark, France and Italy have stated their intention to sign by 30 April 1977, the date to which the period for signature has been extended.

The first members of the Meteosat Operations Division (MOD) took up duty on 1 March and recruitment of further staff is in progress.

janvier à la station de l'Odenwald (Allemagne) où ont commencé les essais de compatibilité avec la DATTS (Station d'acquisition des données, de télécommande et de poursuite). Le modèle prototype (P2) est arrivé en janvier à Toulouse où il a subi avec succès les essais de vibration et autres au niveau système. On le prépare actuellement pour les essais de simulation solaire qui pourraient débuter vers la mi-avril sous réserve que l'OTS libère la chambre d'essais pour le 20 mars. L'intégration du modèle de vol est maintenant terminée et les essais de performances qui ont suivi ont donné satisfaction. Le modèle de vol est arrivé à la mi-mars à Toulouse, où il subit actuellement les préparatifs nécessaires pour les essais de vibration qui doivent commencer début avril. L'objectif visé est le lancement du modèle F1 le 31 août.

Le Conseil directeur du programme, à sa réunion du 11 mars, a approuvé à l'unanimité (la France et l'Allemagne ad referendum) le lancement d'une unité de vol Météosat sur le vol Ariane LO3 en qualité de passager principal. Avec les modifications des annexes A et B de l'Arrangement Météosat qui ont été approuvées, ce projet fait désormais partie intégrante du Programme Météosat.

Secteur terrien

Les essais de compatibilité avec la DATTS n'ont fait apparaître jusqu'ici aucun problème majeur, sauf en ce qui concerne les convertisseurs abaisseurs de fréquence qui devront être réparés ou remplacés. Le transpondeur terrestre est en cours de préparation pour les essais de compatibilité avec le satellite. Des exemplaires de la documentation technique relative aux plates-formes de collecte de données (DCP) ont été envoyés aux utilisateurs. Le développement des stations d'utilisateurs de données primaires et secondaires (PDUS et SDUS) avance conformément aux plans. En ce qui concerne le système de traitement des données, des progrès ont été enregistrés quant au temps machine disponible (12 heures par jour en moyenne). On ne doit toutefois pas trop compter actuellement sur la tenue du planning.

Pour ce qui est du logiciel d'application, les lots relatifs au contrôle du véhicule spatial et de la mission sont achevés et seront mis à l'essai très prochainement.

Opérations

A ce jour, le Protocole Météosat, qui couvre deux ans et demi d'exploitation après les six premiers mois dans l'espace de Météosat 1, a été signé par l'Allemagne, la Belgique, le Royaume-Uni et la Suisse. Le Danemark, la France et l'Italie ont exprimé l'intention de le signer d'ici le 30 avril 1977, date à laquelle a été reportée l'expiration de la période d'ouverture du Protocole à la signature.

Les premiers membres de la Division des Opérations de Météosat (MOD) ont pris leurs fonctions le 1er mars dernier. Le recrutement de personnel complémentaire est en cours.

AEROSAT

Une option pour le contrat couvrant la fourniture du véhicule spatial Aérosat a été signée en février par la General Electric Company et la COMSAT General Corporation, agissant au nom des trois copropriétaires du secteur spatial. Cependant la General Electric n'est pas en mesure d'entreprendre les travaux en raison des problèmes de financement rencontrés par l'Administration fédérale de l'Aviation (FAA). Il faudra attendre l'issue des débats qui se déroulent actuellement au Congrès des Etats-Unis pour savoir si ces difficultés peuvent être résolues.

MAROTS

L'intégration du modèle d'identification de la charge utile de Marots se poursuit chez MSDS à Portsmouth et tous les matériels sont maintenant disponibles. La livraison de ce modèle est actuellement prévue pour juillet 1977 et il sera alors couplé au modèle de qualification du module de service OTS pour subir des essais au niveau du système pendant le reste de l'année. Entre temps, la fabrication du modèle de vol de la charge utile et de la plate-forme se poursuit.

Le Conseil, au cours de sa réunion au niveau ministériel en février, a décidé l'extension du programme Marots dans le cadre d'un nouveau programme d'ensemble en matière de satellites de communications, ce qui permettra le lancement d'un deuxième véhicule spatial.

Un projet d'accord a été négocié avec les Administrations européennes des PTT pour couvrir l'utilisation opérationnelle de Marots, au-dessus de l'Est atlantique et de l'Océan Indien pour une période de cinq ans (1979–1983); ce projet va maintenant être examiné à un niveau supérieur par le Conseil directeur commun des programmes de satellites de communications.

Enfin, des échanges de vues exploratoires ont eu lieu entre le Consortium MARISAT, les Administrations européennes des PTT et l'ASE concernant le remplacement des satellites Marisat par des satellites Marots pour assurer une couverture mondiale à partir de 1981. Une première réunion s'est tenue à Oslo début mars et les conversations doivent se poursuivre en avril.

AEROSAT

In February, an option was signed for the Aerosat spacecraft contract by General Electric Company and COMSAT General Corporation acting for the three co-owners of the space segment. However, General Electric cannot be authorised to start the work because of the Federal Aviation Administration (FAA) funding problems. It is necessary to wait for the outcome of the discussions taking place at present in the United States Congress to know if these difficulties can be resolved.

MAROTS

Integration of the Marots payload engineering model is continuing at MSDS, Portsmouth, with all hardware now available. Delivery of the engineering model payload is now scheduled for July 1977, after which it will be mated with the qualification model of the OTS service module for tests at system level during the remainder of the year.

In the meantime, manufacture of the flight model of the payload and of the platform is in progress.

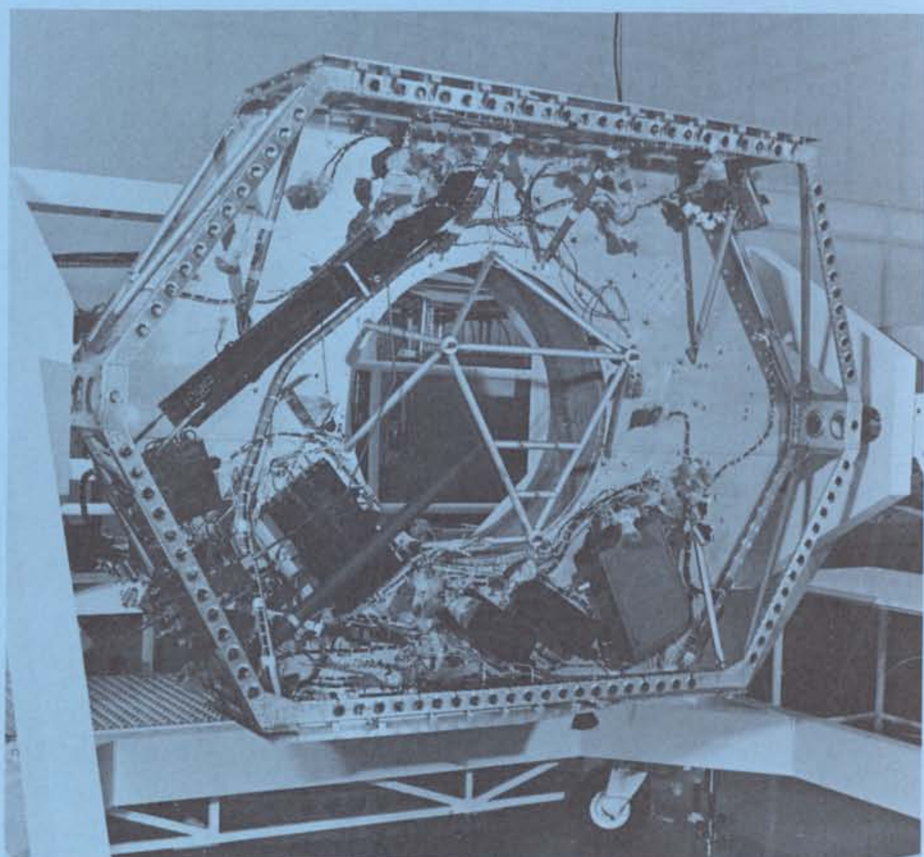
At the February Council Meeting at Ministerial level, it was decided to extend the Marots programme as part of a new overall satellite communications programme, to permit the launch of a second spacecraft.

A Draft Agreement has been negotiated with the European PTT's, to cover the operational use of Marots over the Eastern Atlantic and Indian Ocean for a period of five years (1979–1983), and this will now be reviewed at higher level by the Agency's Joint Board on Communication Satellite Programmes and the PTT's.

Finally, exploratory talks have been held between the MARISAT Consortium, the European PTT's and ESA concerning the possibility of using Marots satellites to replace Marisats in providing world-wide coverage from 1981 onwards. A first meeting was held in Oslo in early March and talks are due to continue in April.

OTS

Space segment
During the first quarter of 1977 the qualification model successfully underwent vibration testing before being subjected to on-station solar-simulation testing in the SIMLES facility at Toulouse. During this simulation, it became evident that parts of the communication module equipment were running hotter than predicted and that the satellite as a whole was running colder than predicted. Intensive analysis of the causes was carried out by the Agency and the contractors in order to be able to introduce modifications to the



Marots engineering-model payload in the course of integration.

Modèle d'identification de la charge utile de Marots en cours d'intégration.

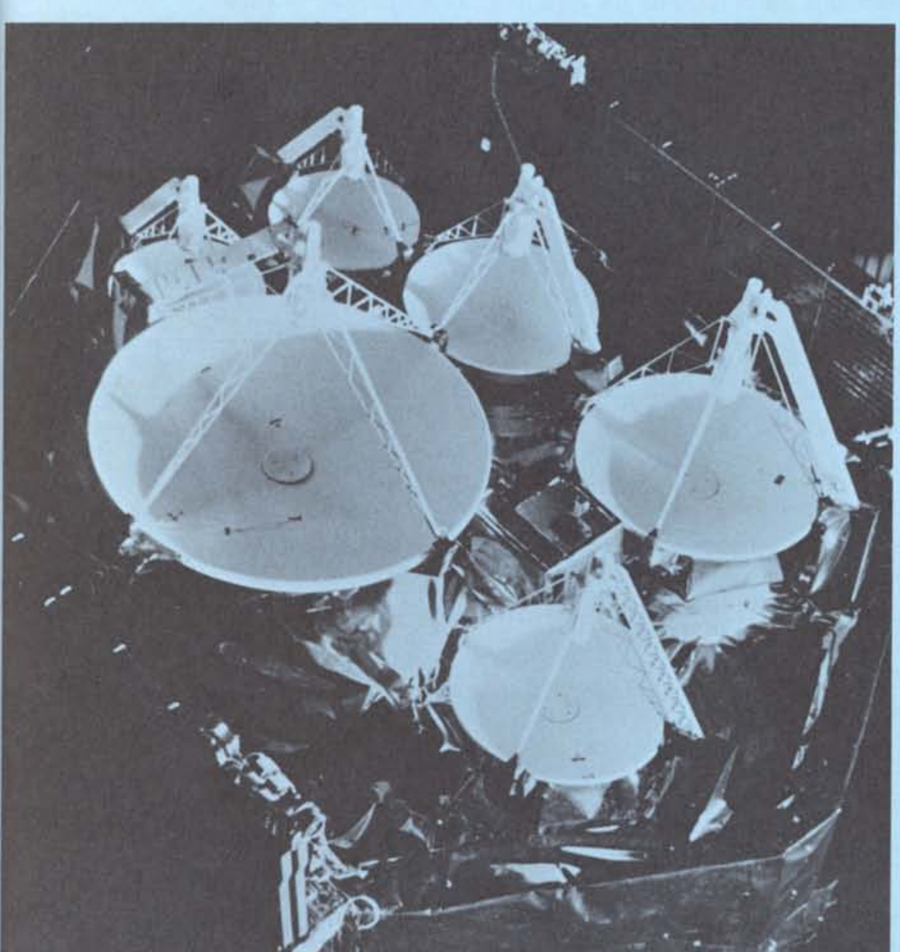
OTS

Secteur spatial

Au cours du premier trimestre, le modèle de qualification à subi avec succès des essais en vibration avant d'être soumis à des essais de simulation solaire à poste à l'installation SIMLES de Toulouse. Au cours de cette simulation, il est apparu que les températures de fonctionnement de certains éléments des équipements du module de communications étaient plus élevées que prévu tandis que les températures de fonctionnement de l'ensemble du satellite étaient plus basses que prévu. Une analyse approfondie a été effectuée par l'Agence et par les contractants de façon à pouvoir apporter des modifications au modèle de vol avant qu'il ne subisse les essais de simulation solaire dans la deuxième quinzaine de mars. Le mauvais fonctionnement d'amplificateurs à tubes à ondes progressives a également été constaté mais on ne pense pas qu'il s'agisse d'un problème de système et des mesures correctives sont en cours.

La préparation du modèle de vol à la phase d'essais d'ambiance s'est poursuivie en février et ce modèle a subi début mars les essais acoustiques au niveau de la recette à l'IABG (Munich). Il a ensuite été renvoyé à Toulouse pour les préparatifs de la simulation solaire, y compris les modifications thermiques qui se sont révélées nécessaires au cours des essais du modèle de qualification. Des instruments de mesure thermique supplémentaires ont en outre été installés pour contrôler les résultats des modifications. Les essais de simulation solaire se sont achevés le lundi 28 mars et l'installation a été évacuée pour permettre le démarrage des essais de Météosat. Une collaboration très étroite s'est poursuivie entre les deux équipes de projet tout au long des essais du modèle de qualification et du modèle de vol de façon à réduire le plus possible les retards causés par des conditions incompatibles d'utilisation de l'installation SIMLES.

C'est en avril que se dérouleront les phases finales des programmes d'essais des modèles de qualification et de vol parmi lesquelles se situent les réunions des diverses commissions d'examens des résultats d'essais qui précèderont l'examen avant embar-



Modèle de qualification d'OTS dans la chambre d'essais à vide du CNES à Toulouse.

OTS qualification model in the vacuum test chamber at CNES, Toulouse.

flight model prior to its solar-simulation testing in the second half of March. Problems were also encountered with malfunctioning travelling-wave-tube amplifiers, but the cause is not thought to be a system problem and remedial action is being taken.

Preparation of the flight model for its environmental test phase continued throughout February, and in early March it successfully underwent acoustic testing at IABG, Munich. It was then returned to Toulouse for preparation for solar simulation, including the thermal modifications shown to be necessary during qualification-model testing. In addition, extra thermal instrumentation was installed to monitor the results of the modifications. Solar-simulation testing was completed on 28 March and the facility evacuated in order to allow Meteosat tests to commence. Throughout the qualification- and flight-model testing, very close collaboration has been maintained between the two project teams in order to minimise schedule delays due to conflicting requirements for the SIMLES facility.

During April, the final phases of the qualification- and flight-model testing programmes will take place, including various test review boards prior to the 'Pre-Ship Review' at the beginning of May. Subject to satisfactory conclusion of these reviews, OTS will be launched in June as scheduled.

Ground segment
The compatibility tests between the OTS engineering model, located on Monte Magnola, and the Satellite Control Test Station (SCTS) at Fucino, Italy, will be carried out during April. The programme has had to be rearranged due to a delay in completion of the SCTS as a result of problems that have arisen during station integration.

Detailed planning of pre-launch procedures at ESOC and training of staff is in progress. Flight-operations plans are also being finalised.

SPACELAB

Spacelab development is approaching the integration and test phase. Preparations are in hand for the ESI (Electrical Systems Integration) model tests. Hardware for the integration of the engineering model is beginning to be delivered to ERNO from the co-contractors. The Critical Design Reviews at co-contractor level will take place during the next few months, to be completed by a Final Critical Design Review at system level early next year.

A major cost reduction exercise in the Spacelab programme has yielded savings in the order of 30 MAU. The principal measures agreed are the deletion of the second configuration of the engineering model, a reduction in the logistics and maintenance documentation, and the deletion of the third set of ground-support equipment intended to remain in Europe.

First Spacelab Mission
A total of 77 scientific and technological experiments – 61 European, 15 American and 1 Japanese – have been selected by ESA and NASA for flight aboard Spacelab on its first mission in the second half of 1980.

The European experiments selected can be summarised by discipline as follows:

Discipline	No. of Experiments	Countries participating
Life Sciences	9	France, Germany, Italy, Sweden, Switzerland, UK, USA
Atmospheric Physics	5	Belgium, France, Germany
Solar Physics	1	Belgium (and ESA investigators)
Plasma Physics	2	Austria, France, Germany, Norway (and ESA investigators)
Astronomy	3	France, Germany, Italy, UK (and ESA investigators)
Earth Observations	2 instruments	Germany (resulting data to be supplied to other European experimenters)
Spacelab Environment	2	Germany
Material Sciences	39	Austria, Belgium, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, UK

quement prévu début mai. Si les conclusions de ces examens sont satisfaisantes, l'OTS sera lancé en juin comme prévu.

Secteur terrien
Les essais de compatibilité entre le modèle d'identification de l'OTS situé à Monte Magnola et la station de contrôle et d'essais de satellite (SCTS) de Fucino (Italie) seront effectués courant avril. Il a fallu réorganiser le programme en raison d'un retard dans l'achèvement de la SCTS dû à des difficultés survenues pendant l'intégration de la station.

Le planning détaillé des procédures avant lancement à l'ESOC et la formation du personnel se poursuivent. Les plans d'opérations en vol sont également en cours de mise au point.

SPACELAB

Le développement du Spacelab approche de la phase d'intégration et d'essais. Les préparatifs sont en cours pour les essais de la maquette électrique (ESI-Intégration des systèmes électriques). Les matériels destinés à l'intégration du modèle d'identification, en provenance des co-contractants, commencent à être livrés à ERNO. Les examens critiques de la conception au niveau co-contractant qui doivent avoir lieu au cours des mois qui viennent seront complétés au début de l'année prochaine par un dernier examen critique de la conception au niveau système.

Un important travail de réduction des coûts, tendant à élaguer tout ce qui n'était pas essentiel, a permis de dégager environ 30 MUC d'économies. Au nombre des principales mesures retenues figurent la suppression de la deuxième configuration du modèle d'identification, une réduction de la documentation logistique et de maintenance et la suppression du troisième jeu d'équipements de soutien au sol qui devait rester en Europe.

Première Mission Spacelab
Ce sont au total 77 expériences scientifiques et technologiques 61 européennes, 15 américaines et une japonaise – qui ont été retenues par l'ESA et la NASA pour la première mission du Spacelab, prévue dans le courant du second semestre de 1980.

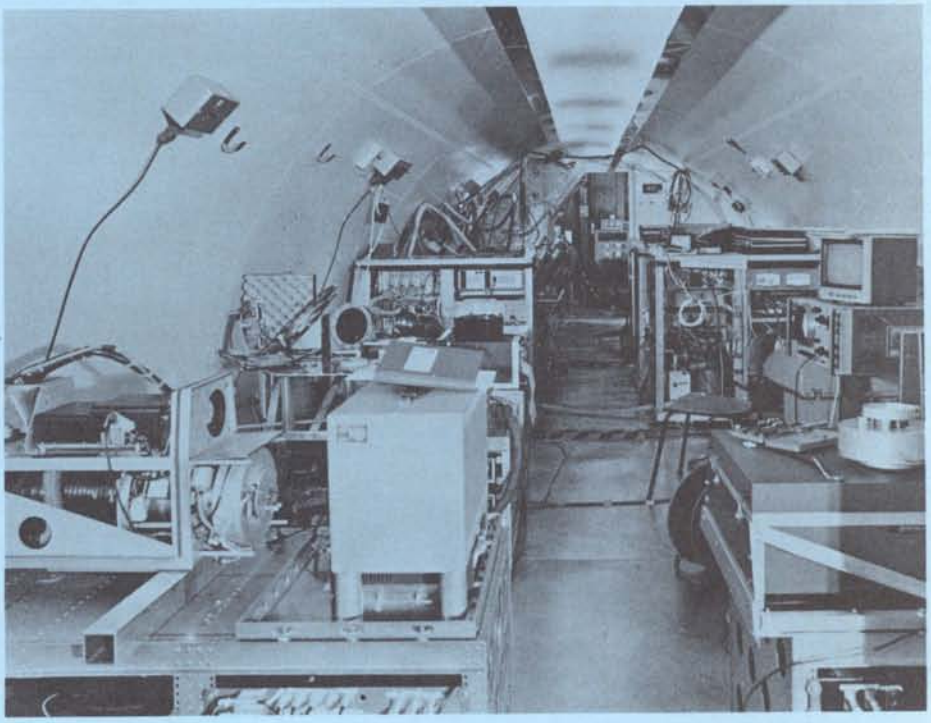
Le tableau ci-dessus récapitule les expériences européennes choisies, par discipline.

Discipline	*Nombre d'expériences*	*Pays participants*
Sciences de la Vie	*9*	*Allemagne, France, Italie, Royaume-Uni, Suède, Suisse, Etats-Unis*
Physique de l'Atmosphère	*5*	*Allemagne, Belgique, France*
Physique Solaire	*1*	*Belgique (et expérimentateurs de l'ESA)*
Physique des Plasmas	*2*	*Allemagne, Autriche, France, Norvège (et expérimentateurs de l'ESA)*
Astronomie	*3*	*Allemagne, France, Italie, Royaume-Uni, (et expérimentateurs de l'ESA)*
Observation de la Terre	*2 instruments*	*Allemagne (les données seront fournies à d'autres expérimentateurs européens)*
Environnement du Spacelab	*2*	*Allemagne*
Science des Matériaux	*39*	*Allemagne, Autriche, Belgique, Danemark, Espagne, France, Italie, Norvège, Pays-Bas, Royaume-Uni, Suède.*

La composition de la première charge utile du Spacelab ayant été arrêtée, l'ESA s'attaque désormais au processus de sélection qui mènera au choix de deux 'spécialistes Charge utile' européens. L'un d'eux sera finalement retenu pour la première mission et deviendra ainsi le premier Européen à tourner autour de la Terre; le second sera prêt à le suppléer dans l'exécution de la mission. L'ESA a lancé un appel de candidatures auprès des Etats membres pour ces deux spécialistes européens, qui seront vraisemblablement choisis à la mi-1978.

Integrated European experiments in the Convair 990 mock-up ready for 'mission simulation' at ESA/SPICE.

Expériences européennes intégrées dans la maquette du Convair 990 en vue de la simulation de la mission au SPICE.



Now that the composition of the first Spacelab payload has been determined, ESA has also started the selection process for choosing two European payload specialists, one of whom will finally be selected for the first mission and thus become the first European to travel in earth orbit. The other will act as back-up specialist for the mission. Through its Member States, the Agency has issued an Announcement of Opportunity for European payload specialist candidates. The two will probably be chosen in mid-1978.

SPACE TELESCOPE

To recap on the scope of this new project in the Agency's scientific programme, ESA's contribution to the NASA Space Telescope falls into three main parts:

- the Space Telescope's solar array, with associated drive and orientation mechanisms to provide 4 kW of electrical subsystem power;
- the Faint Object Camera, one of the focal-plane instruments, to fully exploit the full light-collecting and spatial resolving power of the Space Telescope for recording images of very faint objects at the limits of diffraction;
- participation in the initial ten years of in-orbit operation of the Telescope and refurbishment and/or replacement of the two ESA-provided hardware components as necessary during this operational period.

Following the consultation procedure with the scientific working groups, the Science Advisory Committee and the Science Programme Committee, the Director General has appointed the members of the Instrument Science Team (IST) for the Faint Object Camera. The IST assisted in preparing the technical documents for the Invitation to Tender for the Photon Detection Assembly, a major element of the Faint Object Camera. The Invitations to Tender for the Photon Detection Assembly and the Solar Array have been submitted to industry.

Phase-B studies for the Solar Array and Faint Object Camera will start later in 1977 and Phases C/D will follow in 1978, with hardware delivery in early 1982. The first Space Telescope launch by Shuttle is scheduled for the last quarter of 1983.

SPACE SLED

The tender documentation, technical and contractual, has been finalised and will be issued at the beginning of April. Requirements for the experiments to be conducted on the facility and for the interface with Spacelab have been examined by the Sled Scientific Team and by SPICE.

TELESCOPE SPATIAL

La contribution de l'ESA à ce nouveau projet scientifique portera sur trois points principaux:

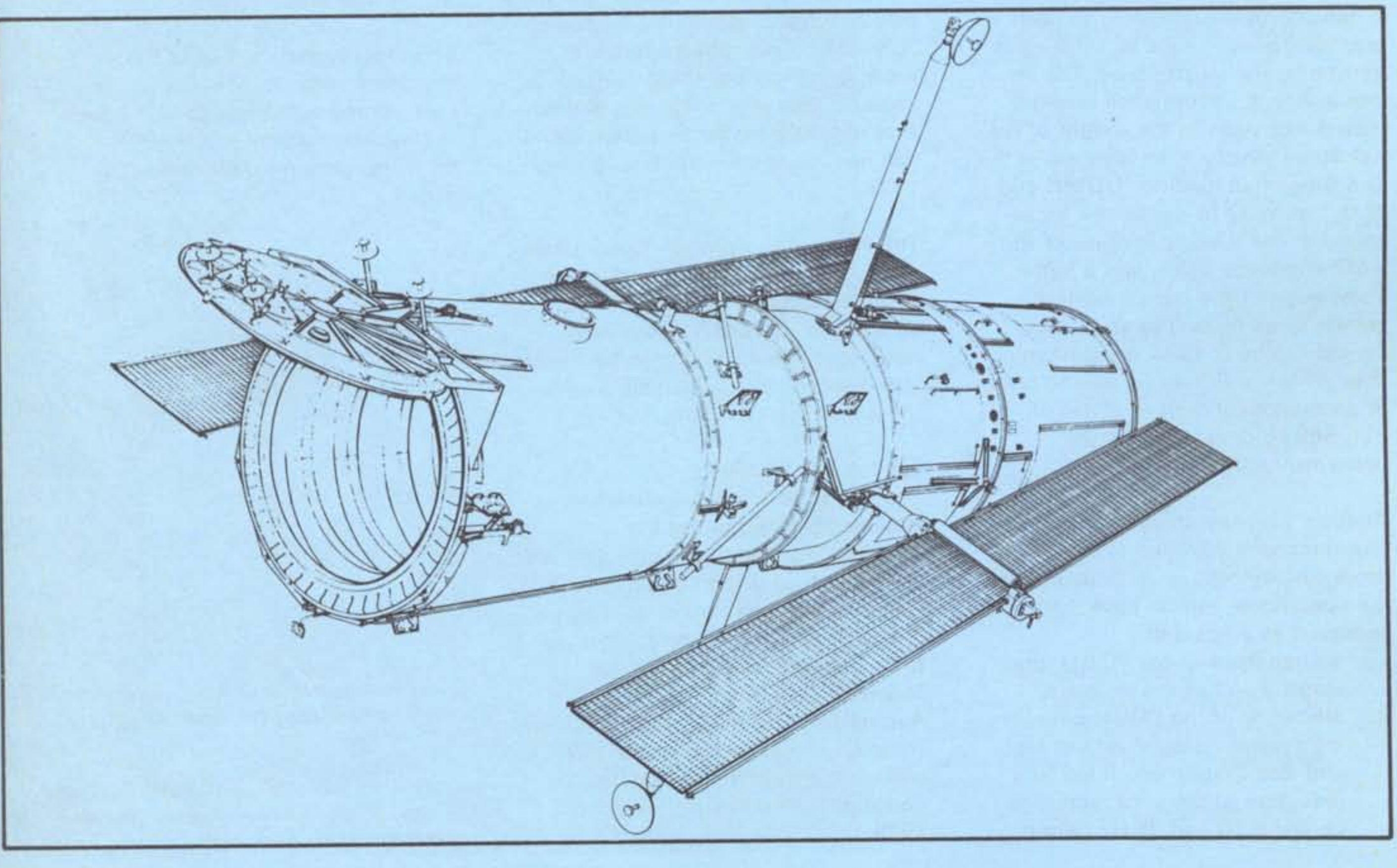
- *fourniture du réseau solaire du télescope spatial, avec ses mécanismes d'entraînement et d'orientation, qui devra fournir une puissance de 4 kW au télescope;*
- *fourniture de la chambre à objets de faible luminosité (FOC), l'un des instruments du plan focal, qui devra permettre d'exploiter à fond les capacités du télescope spatial dans le domaine du recueil de lumière et de la résolution spatiale pour la prise d'images d'objets de très faible luminosité à la limite de diffraction du télescope;*
- *participation aux dix premières années d'exploitation en orbite du télescope et remise en état et (ou) remplacement des deux éléments fournis par l'ESA, en fonction des besoins susceptibles de survenir au cours de cette période.*

Après avoir consulté les Groupes de travail scientifique, le Comité consultatif scientifique et le Comité du programme scientifique, le Directeur général a nommé les membres de l'Equipe de l'instrumentation scientifique (IST) de la FOC. L'IST s'est consacrée à la préparation de la documentation technique en vue de l'appel d'offres pour l'ensemble de détection de photons, un élément important de la FOC. Les appels d'offres couvrant ce dernier élément ainsi que le réseau solaire ont été envoyés à l'industrie.

Les études de phase B sur le réseau solaire et la FOC commenceront cette année, les phases C/D suivant en 1978 pour une livraison des équipements début 1982. Le premier vol du télescope spatial à bord de la Navette est prévu pour le dernier trimestre de 1983.

Le Télescope spatial en configuration orbitale.

The Space Telescope in orbital configuration.



ARIANE

Performance
Ariane's capacity for launch from Kourou into geostationary transfer orbit (200–36 000 km, inclination 10.5°) has been upgraded to 1700 kg. The previous guaranteed performance was 1600 kg – itself an improvement on the initial capability (1500 kg). This further improvement resulted from the latest assessment of the launcher characteristics which indicated an expected performance limit of 1763 kg. As a result of this assessment by CNES, based on reliable data (actual weights of structure and equipment and measured specific impulses of the engines) and making due allowance for contingencies, ESA is henceforth guaranteeing to users a minimum performance of 1700 kg in geostationary transfer orbit. The improvement in performance resulted from a reduction in the weight of the 3rd Stage structure, an increase in the 2nd Stage fuel loading (UDMH and N_2O_4) from 33 to 34 tonnes, an increase in the specific impulse of the HM7 engine to 435 s, and a better knowledge of the launch vehicle's aerodynamic properties after tests carried out by ONERA on scale models. Ariane will now be able to place in geostationary orbit satellites of 925-965 kg depending on the performance of the ABM used.

Ariane's vibratory characteristics
The sinusoidal vibration test standards for payloads to be launched by the operational vehicle have been improved as a result of:

- a re-analysis of the POGO loop stability and of the potential efficiency of the POGO correcting system installed on the 1st and 2nd Stages which led to a reduction of the excitation level between 10 and 35 Hz (along the longitudinal axis) from 4 *g* to 1.5 *g*.
- results from specific tests carried out on the 3rd Stage of the launcher's dynamic mockup which showed that the vibrational stresses to be applied to the payloads during sinusoidal vibration tests above 100 Hz could be suppressed along all three axes.

Interface Review
An Interface Review held from 20 January to 7 March with the participation of ESA and CNES representatives resulted in a critical analysis of the current version of the User's Manual and various recommendations for future issues, and it was decided to issue a new edition in July 1977. This new manual will incorporate most of the proposed changes. Some of the changes however require a longer preparation and will not be introduced until January 1978.

The Review also provided both users and launcher authorities with a better understanding of their respective constraints. Accordingly the next issue of the Manual should be a great improvement and a valuable tool for the promotion of Ariane.

Launch base facilities
The first of the three new tracking stations for reception of the launcher's S-band telemetry data was ready for acceptance in mid-March at Châteauroux (see opposite). These three telemetry receiving stations are to be installed, respectively, on Mount Galliot (near Kourou) in August 1977, on Mount Montabo (near Cayenne) in November 1977 and on the launch range at Barreira do Inferno, Natal (Brazil) in March 1978.

Each station is equipped with a 10-m antenna providing a 43 dB gain. Together with the Ascension Island facilities, they will ensure the reception of telemetry data throughout the launcher's trajectory from the launch pad at Kourou to the point of orbital injection.

Natal Down-range Station
Civil engineering work has been in progress since January on the Brazilian launch range at Barreira do Inferno (CLFB 1) for new facilities required both for Ariane use and the Brazilian programme.

This Natal station will be used for acquisition and distribution of all tracking and telemetry data transmitted by the launch vehicle.

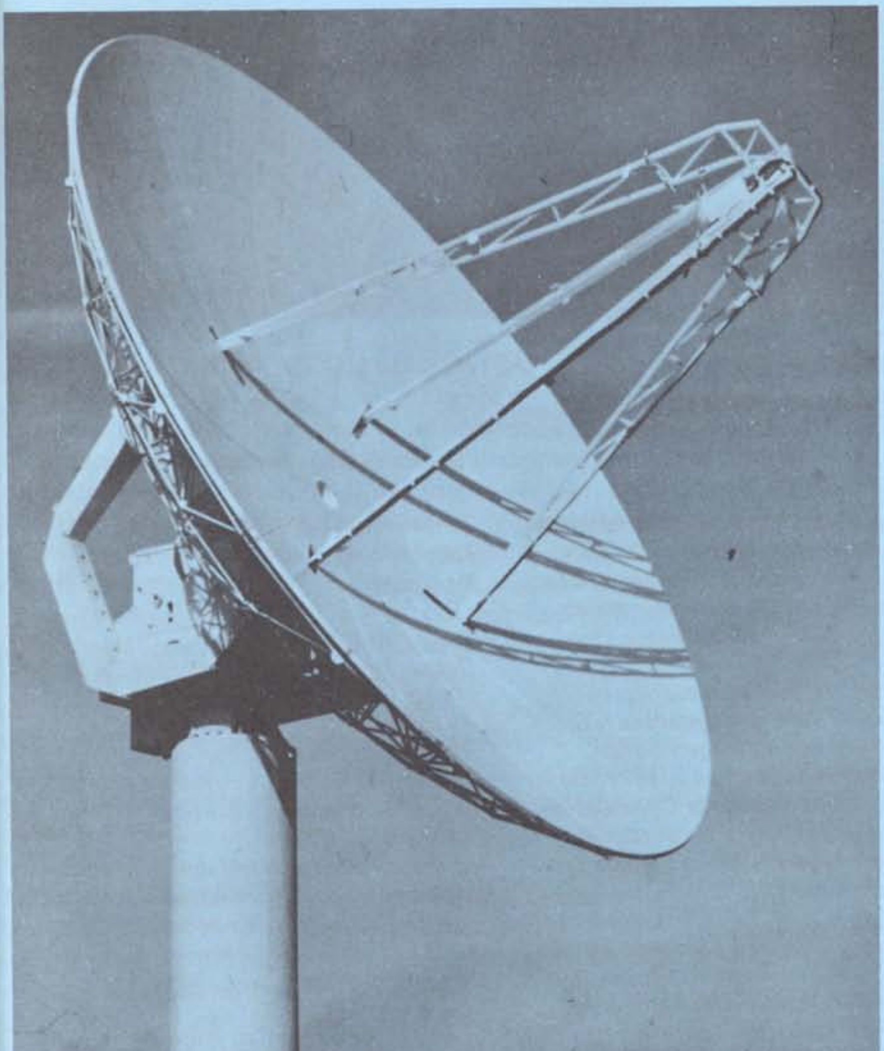
This will involve the use of the existing Bearn radar for tracking purposes (see photograph, page 50) and the setting-up of an entirely new receiving station for the telemetry data.

S-band telemetry station for Ariane launcher (antenna diameter: 10 m; gain: 43 dB).

Station de réception des télémesures en bande S du lanceur Ariane (diamètre d'antenne: 10 m; gain: 43 dB).

TRAINEAU SPATIAL

La dernière main a été mise à la documentation technique et contractuelle pour l'appel d'offres qui sera lancé début avril. Les impératifs à respecter en ce qui concerne d'une part les expériences à effectuer avec ce traîneau (Sled) et d'autre part les interfaces avec le Spacelab ont été examinés avec l'Equipe scientifique responsable du traîneau et avec le SPICE.



ARIANE

Performance

La capacité de lancement d'Ariane en orbite de transfert de satellite de type geostationnaire (200– 36 000 km; inclinaison: 10,5°) à partir de Kourou a été portée à 1700 kg. La précédente performance garantie aux utilisateurs se situait à 1600 kg, ce qui constituait déjà une amélioration de la performance initiale (1500 kg). Cette nouvelle amélioration a été rendue possible à la suite du dernier bilan du lanceur qui a fait ressortir une performance probable de 1763 kg. C'est à partir de cette dernière évaluation, effectuée par le CNES sur des données sûres (structure et équipements pesés, impulsions spécifiques des moteurs mesurées) et compte tenu des marges d'aléas, que l'ESA est désormais en mesure de garantir aux utilisateurs une performance minimale de 1700 kg de charge utile en orbite de transfert géostationnaire. Ce gain de performance a été rendu possible grâce à l'allègement des structures du 3ème étage, l'augmentation de la masse d'ergols (UDMH et N_2O_4) du 2ème étage de 33 t à 34 t, l'accroissement de l'impulsion spécifique du moteur HM7 du 3ème étage qui passe à 435 s, et une meilleure connaissance des caractéristiques aérodynamiques du lanceur suite aux essais de maquette effectués par l'ONERA. La nouvelle performance d'Ariane permettra de placer en orbite géostationnaire des satellites d'une masse de 925 à 965 kg selon la performance de l'ABM utilisé.

Environnement vibratoire d'Ariane

Les normes d'essais en vibration sinusoïdale pour les charges utiles du lanceur operationnel ont pu être améliorées:

- *à la suite d'un réexamen de la stabilité de la boucle POGO et de* l'efficacité potentielle du système correcteur POGO embarqué sur les 1er et 2ème étages, le niveau d'excitation entre 10 et 35 Hz (en direction longitudinale) a été réduit de 4 g à 1,5 g;

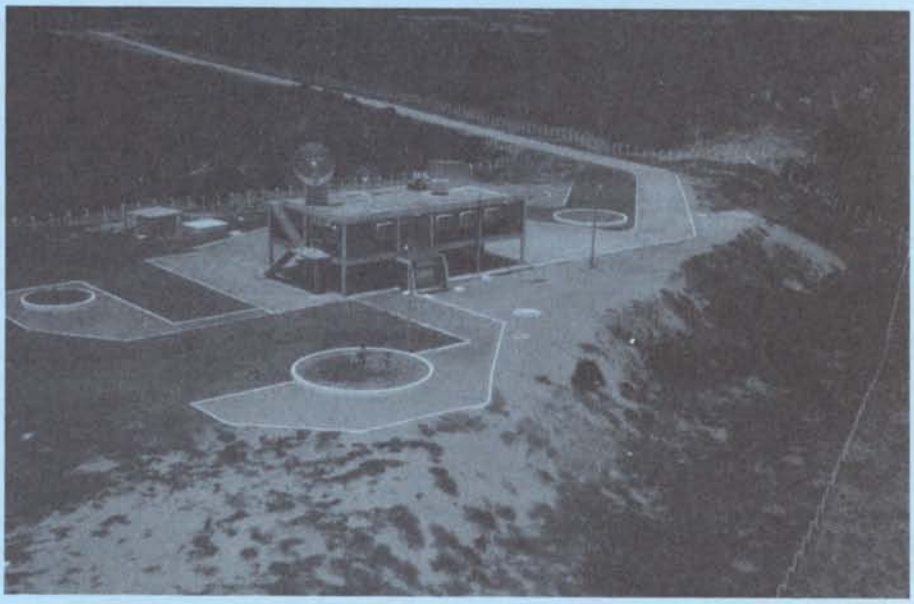
- les résultats obtenus des essais spécifiques effectués sur le 3ème étage de la maquette dynamique du lanceur ont permis de supprimer pour tous les axes l'excitation des charges utiles lors des essais en vibration sinusoïdale au-delà de 100 Hz.

Revue d'Interfaces

Une revue d'interfaces à laquelle participaient des représentants de l'ESA et du CNES s'est déroulée du 20 janvier au 7 mars. Elle a permis de faire une analyse critique de la version actuelle du manuel de l'utilisateur et d'établir de nombreuses recommandations pour les éditions futures.

A l'issue de cette revue, il a été décidé de disposer d'une nouvelle édition du manuel de l'utilisateur en juillet 1977. Cette édition incorporera la plus grande partie des modifications souhaitées par la revue. Cependant pour certaines demandes plus longues à satisfaire, les modifications ne seront introduites que dans l'édition de janvier 1978.

Cette revue a en outre permis aux utilisateurs et aux responsables lanceur de mieux appréhender leurs contraintes respectives; c'est pourquoi la prochaine édition du manuel de l'utilisateur devrait être grandement améliorée. Ariane disposera ainsi d'un bon outil indispensable à sa promotion.



Radar Béarn à la station aval de Natal.

Bearn radar at the Natal Down-range Station.

Installations sol de la Base de Lancement

La première des trois nouvelles stations terrestres de poursuite destinées à assurer la réception des télémesures en bande S du lanceur Ariane (voir Figure page 49) a été présentée en recette à la mi-mars à Chateauroux.

Ces trois stations de réception de télémesure vont être installées respectivement sur la montagne Galliot (près de Kourou) en août 1977, sur le mont Montabo (près de Cayenne) en novembre 1977, et à Natal (Brésil) sur le champ de tir de la Barreira do Inferno en mars 1978.

Les trois stations de réception en bande S sont équipées chacune d'une antenne de 10 m de diamètre et de 43 dB de gain: elles vont permettre avec les installations de l'île d'Ascension d'assurer la réception des télémesures du lanceur tout au long de sa trajectoire depuis l'Ensemble de Lancement Ariane à Kourou jusqu'à l'injection en orbite des charges utiles.

Station aval de Natal

Depuis janvier sont commencés sur le champ de tir brésilien de la Barreira do Inferno (CLFB1) les travaux d'infrastructure des nouvelles installations nécessaires pour le programme Ariane et pour le programme brésilien.

La station aval de Natal doit permettre l'acquisition et la restitution de l'ensemble de données de localisation et de l'ensemble des données de télémesure émises par le lanceur.

Il est prévu, à cet effet, d'utiliser pour la localisation le radar Béarn existant (voir Figure ci-dessus) et pour la télémesure de créer entièrement une nouvelle station de réception. □

The Geos Ground System

P.B. Lemke, Office for Co-ordination and Management, ESOC, Darmstadt, Germany

The development of ESA's third generation of scientific satellites, of which Geos is the first, has prompted the development of a second generation of ground systems for the Agency. To support the Geos mission, a new high-frequency receiving station has had to be built, and the Control Centre's data-processing systems have had to be expanded to allow the handling of what are unprecedented data rates for a scientific satellite. To fully exploit this wealth of information, a ground system has been developed which will allow experimenters to participate in the operations and to readily select the optimum operational mode for their instruments in space.

THE TASKS OF THE GROUND SYSTEM

The ground system for a satellite in geostationary orbit must consist to a large extent of facilities dedicated to this one satellite for the duration of its mission (Fig. 1). Time sharing of facilities with other users, as is normally the practice for low orbiters, is only feasible to a limited extent. The stationary satellite is always in view of the ground station, and in the case of Geos this requires that communications between space and ground be maintained continuously. The ground system's tasks are defined by the needs of the specific mission: the complexity of the ground system for a geosynchronous satellite is the result of a trade-off between the technical feasibility and costs of providing specific functions on board the satellite or within the ground system.

For Geos, the trade-off has led to the design of a satellite that is sufficiently reliable to reach its two-year lifetime design goal, by providing redundancy for the essential systems. At the same time, on-board automation has been minimised and control has, as far as possible, been transferred to the ground facilities. This is particularly true for the experiments flown on this satellite. All the instruments needed to conduct the scientific research are carried on-board, but it is left to a data-processing system on the ground to acquire the telemetry data from the individual experiments, to carry out a first analysis of the results, and to respond to these results by adjusting the operational mode of the experiments to enable them to 'focus' on the physical phenomena under investigation, some of which vary in time. An article on the scientific data processing for Geos can be found elsewhere in this Bulletin (p. 56).

THE GROUND STATIONS

The ground stations are an extension of the control and data-processing centre via which direct communication with the satellite in orbit is achieved. The high data rates to be transmitted from the satellite to ground made it necessary to depart from the previous Agency practice of using VHF (at around 137 MHz) and to move to a higher, UHF frequency (2299.5 MHz). This was, for ESA, a completely new frequency range and there were no suitable existing ground stations at the time of Geos's conception. Consequently, a new station had to be built and its location became a problem of paramount importance. It was already planned that the Control Centre and data-processing system would be located at ESOC, in Germany. Extension of the existing VHF station at Redu, in Belgium, was ruled out as the intervening distance would have been too great for the transmission of the high Geos data rates via terrestrial communication links. Technically there would not have been any insurmountable difficulties, but it could hardly be considered economically. At approximately the same time, another Agency satellite project, Meteosat, which will produce even higher data rates, also required a ground station. Consequently, it was decided to build a dual-purpose station near Michelstadt, a small town in the Odenwald about 30 km southeast of ESOC.

For Geos, it was decided to install only the data-reception facilities there. These include a 15 m parabolic antenna and the receiving and signal-conditioning equipment. No data treatment or data recording is to be carried out at the station: instead, a data-transmission system, connecting the station to ESOC by a 1.2 MHz wideband coaxial cable (backed up by a microwave link), will reformat the telemetry data at the ground station and send it on the

Control Centre, where it will be fed into the MSSS (Multi-Satellite Support System) data-processing system.

There are good reasons for omitting data recording at the ground station in the event of a data-link failure: firstly, the data generated by the experiments are only of full use as long as commands can be sent to switch into the appropriate experimental mode. This is, however, not possible without scientific data processing. Secondly, control of the satellite must be maintained, if only to switch it into a safe mode, even if the data flow from the main ground station is interrupted. Upon loss of the Michelstadt station, therefore, back-up VHF telemetry from the satellite will have to be transmitted (resulting in a much reduced data rate) and received at ESOC via the Redu ground station.

There is a special feature to the Geos mission, in that commands to the satellite are routed not through the Michelstadt station, which receives UHF data, but are transmitted on VHF through Redu. This is the result of the satellite design, which required that it carry a VHF telemetry and command system to operate it in its transfer-orbit phase before acquisition of the the geostationary orbit.

As the command facility must be maintained throughout the mission, ESOC found that it would not be economically viable to provide a UHF ground station with a VHF telecommand capability, especially as such dual-frequency operations were unlikely to recur in any future missions. The VHF command facility, which must be dedicated to Geos in order to send commands on a continuous basis, has therefore been sited at the existing Redu ground station, where it complements an existing system such that the station now has two complete up- and downlinks.

Commanding from Redu is conducted via a separate command computer which interfaces through a narrow-band data link (only 1/200th the capacity of the Michelstadt wideband link) with the MSSS data-processing system, by which all commands are generated. All operator intervention for normal operations is concentrated at ESOC, and the command facility at Redu can be regarded as a remote peripheral of ESOC's computer

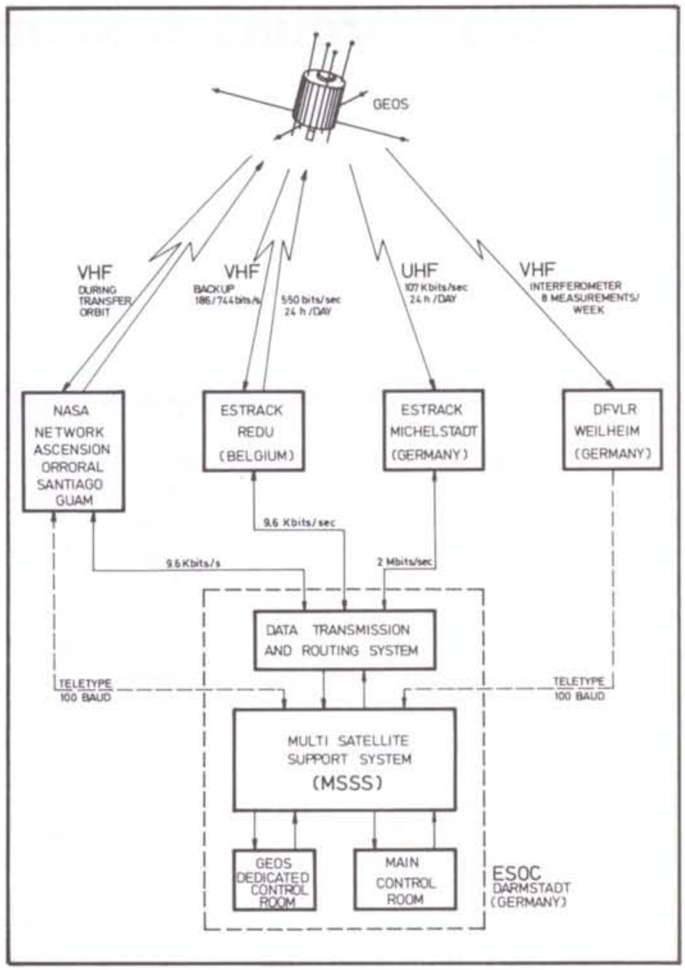


Figure 1 – The Geos Ground System.

system. The same raison d'être applies, but to a much greater extent, to the Michelstadt station. While Redu must still be staffed around the clock to set up equipment and operate it, Michelstadt is remotely controlled from ESOC and requires only routine preventive equipment maintenance. The two ground stations are described in more detail in ESA Bulletin No. 7, November 1976.

THE CONTROL CENTRE

The Control Centre with its Multi-Satellite Support System for on-line data processing is the hub of the ground system. It is here that all data transmitted by the satellite are to be received and analysed, and all responses to the satellite, in the form of telecommands, generated. Once Geos has completed its early orbit phase and has arrived at its geostationary location, operational control of the satellite will be transferred from the large general-purpose Main Control Room (Fig. 2) to a smaller Dedicated Control Room (Fig. 3) where the spacecraft engineer (a position manned 24 hours per day) and visiting Geos experimenters will have all the facilities

Figure 2 – Main Control Room (ESOC) for launch and early orbit operations.

needed to operate the satellite on a routine basis. They will have five control consoles at their disposal, with the following features:

- alphanumeric displays on which all spacecraft and experiment parameters can be called up from the real-time data-processing system
- stripchart recorders to display and record telemetry data as a function of time
- graphical displays on which spacecraft and experiment data can be presented in processed form to aid evaluation of the performance of satellite and payload
- keyboards to interact with the computer system for the selection of a multitude of different display formats, and to compose and send telecommands to the satellite.

These consoles will put the scientists in direct contact with their experiments. Whereas in the past experimenter participation has been essentially off-line, they can now assume full control fo their experiment to optimise their scientific results and to test new command strategies, which can subsequently be introduced into automatic command programs to be executed by the data-processing system.

Commanding of the satellite is carried out on three levels (Fig. 4):

- the manual mode from the consoles, based on information available on the displays
- the scheduled mode in which command sequences for recurring and predetermined operations are stored in advance in command files in the computer
- the automatic mode in which real-time experiment data analysis is performed in the data-processing system, resulting in commands to switch the experiments into an optimum observation mode to follow the observed physical phenomena.

The automatic command facility based on real-time telemetry data processing is one of the keys to the Geos mission. It is the first time that such a feature has been used on a scientific satellite mission and a hitherto unknown versatility of adaptation to actual, rather than expected, physical phenomena will be available to the payload scientists.

Figure 3 – Dedicated Control Room (ESOC) for Geos experiment operations.

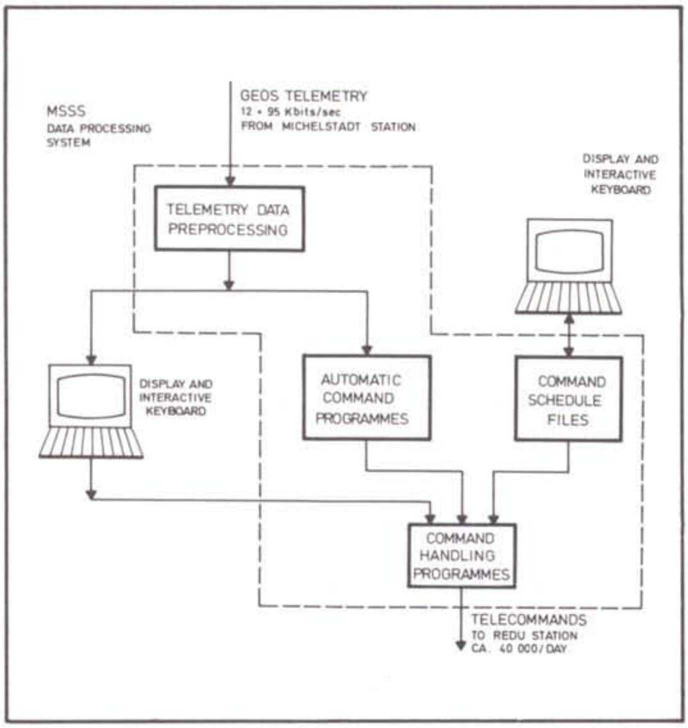


Figure 4 – Principle of the three telecommand modes.

TESTING BEFORE LAUNCH

The testing of a ground system before launching a new satellite is standard practice, to finally confirm that all specifications have been met and that the system is ready to support the satellite in orbit. Mission-specific testing, which follows the general subsystem acceptance tests, covers compatibility tests, software-validation tests, and finally simulations.

The compatibility tests must verify that the satellite signals (telemetry) can be received and processed by the ground station, and that ground-station signals (telecommands) can in turn be received and correctly interpreted by the satellite. Instead of transporting a complete satellite to the different ground facilities, a 'suitcase' model containing only the satellite hardware relevant to these tests, e.g. transmitters, modulators, encoders, and receivers and decoders, is usually used. The term 'suitcase' has long since lost its original meaning; in the case of Geos it is a small rack of equipment weighing about 100 kg which can easily be transported by car. It has been demonstrated that both the Michelstadt UHF and Redu VHF stations are compatible with Geos. These tests were preceded by similar tests with Nasa's ground stations, which will support the transfer-orbit phase, and with DFVLR's steerable interferometer at Weilheim (Germany), which will be used for satellite tracking during the synchronous orbit.

Software-validation testing has played an especially important role in Geos launch preparations. It has involved tests to show that the data-processing software on the ground is able to handle the data transmitted from the satellite correctly. For previous satellite missions, recordings on magnetic tape of spacecraft telemetry were used for this purpose. This was also the first step for Geos, but the essential command functions could not be tested realistically in this way because satellite response cannot be derived from tape recordings. The use of a software simulator, which provides limited simulation of the satellite functions and can also be used for launch preparations, has a serious shortcoming: apart from being limited in its functions, it is based on the same documentation used to develop the data-processing software. Consequently, any errors in or any misinterpretation of this documentation would go unnoticed as it would also be present in the testing tool!

To establish the necessary confidence in the Geos software, the satellite itself had to be used, and as the flight model was already undergoing extensive testing the satellite qualification model was moved to Michelstadt. As this station does not have a VHF command facility, as explained earlier, the command system procured for Redu was first installed at Michelstadt to make these tests possible. The satellite was operated there for six weeks during the autumn of 1976. UHF telemetry was received at the station and the data were then routed to the MSSS data-processing system and displayed on consoles in the Geos control room. There, telecommands were issued through interactive keyboards, processed by the computer system, and transmitted to the ground station, where they entered the satellite. The missing parts of the operational situation were, of course, the space environment for the satellite and the radio-frequency links between satellite and ground station; for the latter, a hard-wire connection was used.

The tests achieved their aim within the limited time scale, in that the majority of the spacecraft control software could be tested and corrections or improvements made where necessary.

Between 1 February and the launch date, final tests were carried out by conducting simulations on two days each week in which selected parts of later operations were rehearsed to ensure that the ground stations, data-processing facilities, and operating staff could function successfully as a unit.

THE COSTS OF THE GROUND SYSTEM

The Geos ground system consists almost entirely of new facilities required by this novel and complex mission. The costs that can be readily identified as attributable to the Geos mission, including the two years of operation, are estimated at 12.6 Million Accounting Units (1 AU = 1.1 US$). About 5.3 MAU of this has gone into the procurement of new facilities, including the Michelstadt ground station, the Geos control room, the new telecommand system at Redu, and some specific software development. This constitutes a basic investment which will remain valid for future missions beyond the end of Geos's operational lifetime. (One obvious candidate for the future use of these facilities will be Geosari, the mission of which is described elsewhere in this Bulletin.) The remaining 7.3 MAU covers the manpower expended on the development of the ground system and the operations, the costs for operating and maintaining the ground system and the Control Centre, a share of the development costs of the MSSS data-processing software, and the use of batch computer time to produce the data tapes to be sent to experimenters.

CONCLUSIONS

A ground system has been developed to match the capabilities and complexity of the Agency's third generation of scientific satellites. For the first time, ground-based observers will be able to operate their experiments 36 000 km out in space in similar manner to conventional experiments. They will not have to be content with passive observation, but will be able to participate actively, so closing the gap between the satellite and the ground system. □

The Scientific Data Processing for Geos

J. Anscombe & G. Kluge, Data Processing Division, ESOC, Darmstadt, Germany

The Geos payload generates scientific data at a rate of more than 100 000 bit/s and must be controlled by telecommands transmitted to the satellite at over 500 bit/s. In view of the continuous high-bit-rate coverage that is therefore needed for data reception and experiment commanding, a decision was taken early in the programme to concentrate data treatment on the ground rather than use an on-board computer. The complexity of the ground data-handling system that has subsequently been developed stems from this decision.

The Geos ground system's major tasks can be summarised as follows:

(i) A major part of the scientific data must be scanned in real time to allow a ground-based computer to generate appropriate telecommands sufficiently rapidly to secure optimum experiment operation.

(ii) The data are so voluminous that a preselection must be made prior to final processing. This makes it necessary to generate summary data in which gross features can be recognised more easily.

(iii) The classical ESA data-handling task, namely the decommutation and distribution of untreated experiment data and ancillary data (time, orbit parameters, etc.) to experimenter institutes is considerably greater for Geos than for previous ESA (ESRO) spacecraft.

THE DATA STREAM

Geos carries four particle experiments, two field experiments and one wave experiment, but the last of these uses more than 90% of the total spacecraft telemetry capacity. Wave experiments are by definition highly demanding in terms of telemetry as they have to transmit analogue signals with bandwidths of several tens of kilohertz. Previous wave experiments on satellites have mainly employed only one wideband analogue channel and transmission was achieved by modulating the transmitter carrier by this wideband signal. In the case of Geos, a total of six wideband channels were to be transmitted simultaneously and, as it was important to preserve the relative phase of all six signals, direct analogue transmission was very soon found to be impractical.

One solution that appeared feasible was digitisation of the analogue wave signals and transmission at a very high bit rate of about 8 Mbit/s. Such a bit rate, although feasible in principle, turned out to be too demanding in terms of transmitter power. It was then decided to employ sophisticated processors in the wave experiment. In this way it was possible to compress the above rate by a factor of nearly 100 and following extensive trade-off studies a final transmission speed of 94 kbit/s was arrived at.

The lack of balance in the telemetry allocation led to the adoption of two separate data streams for Geos, the low-speed (LS) and the high-speed (HS) streams. The former contains data from the six less-demanding experiments, while the HS stream contains the wideband wave-experiment data. As the two data streams are very different in both volume and content, they are separated upon reception and treated in two different branches in the ground data-handling system.

PROCESSING OF THE DATA IN THE LOW-SPEED STREAM

The processing of this data stream is divided on the basis of time constraints into three stages: 'on-line', with a response time of a few seconds, 'near-real-time', with a response time of a few hours, and 'off-line'.

The main role of the on-line and near-real-time processing is to support the generation of telecommands, including those that control the data-selection process on-board the satellite. The particle experiments, for example, employ a large number of detectors and their telemetry allocation can be assigned to all or only to selected detectors at any given moment. In the first case emphasis is placed on directional coverage at the expense of time resolution; in the second, directional coverage is sacrificed to obtain improved time resolution. The choice between the two must depend on the prevailing geophysical conditions and only a real-time computer analysis of the incoming data can decide sufficiently rapidly which of the two modes should be adopted.

The display of LS data in real time at experimenter consoles at ESOC, combined with a manual command facility at the disposal of experimenters, will enable them to assess the performance of their experiments in conversational mode and to adapt command schedules and procedures to what they see. This facility will be of particular importance at the beginning of the mission when establishing experiment behaviour in the space environment.

All LS data, and the compressed HS data to be discussed later, are routed to a magnetic disk which can hold 24 hours' worth of data. Any data in this 'store' can be accessed and displayed to study data quality and experiment behaviour. It will also be possible to compare data up to 24 hours old with the latest data being received. The LS data stored on disk form the basis for three important data outputs: the LS-data Archive Tapes, the 'Daily Summaries' and the 'Experimenter Summaries'.

All LS data are copied once per day onto magnetic tape so that the disk can be overwritten with the subsequent 24 hours of data. The magnetic tape is then further processed by an off-line computer. The latter also calculates auxiliary data that may be useful to the experimenter, such as spacecraft orbit, attitude and time parameters, and adds these to the individual experimenter tapes.

As opposed to the display facilities which permit a detailed inspection of small amounts of data, the Daily and Experimenter Summaries are intended to present, in a compact form, the most significant information derived from all the available data, and they are prepared on a special plotting facility.

The Daily Summaries consist of two data sheets per day – about 60 microfilm frames – and contain key results from the experiments. They are distributed world-wide in connection with Geos's key role in the IMS, described in the article on the scientific mission.

The Experimenter Summaries are plotted with better time resolution and are meant to assist the experimenters, and in particular the wave experimenters, in obtaining an initial survey of their data and in selecting periods of major scientific interest for detailed processing at their home institutes.

PROCESSING OF DATA IN THE HIGH-SPEED STREAM

The real-time and near-real-time facilities used for the LS data stream cannot be applied to the HS data because of the sheer volume of data to be received. The HS data are therefore handled by a dedicated computer system, consisting of two process-control computers, with peripheral electrostatic raster-plotters, magnetic-tape units and Fast Fourier Transform (FFT) processors.

The following tasks are performed:

- selected recording of 3 min of raw HS data every hour on the hour
- real-time display of wave-experiment data on the electrostatic raster-plotters
- on-line compression of wave data, by applying averaging techniques. The compressed data are transferred to the LS data branch, as mentioned in the last section, but they are also recorded separately on magnetic tape
- recording of all raw HS data, which results in the production of one HS tape every 40 min. The recorded tapes are deposited temporarily in a buffer store from which the experimenter can select a portion of the data for detailed analysis. Tapes not selected will be recycled. The buffer is sized to accommodate about three months' data, to allow sufficient time for selection and to ensure that 10% of the wave-experiment data can be archived and made available to the experimenter.

The archived raw high-speed data would fill about 20 000 reels of magnetic tape during Geos's lifetime if no pre-archiving selection were employed. The combination of compressed data, survey data and experiment summaries is intended to provide the experimenters with sufficient information to support the selection process.

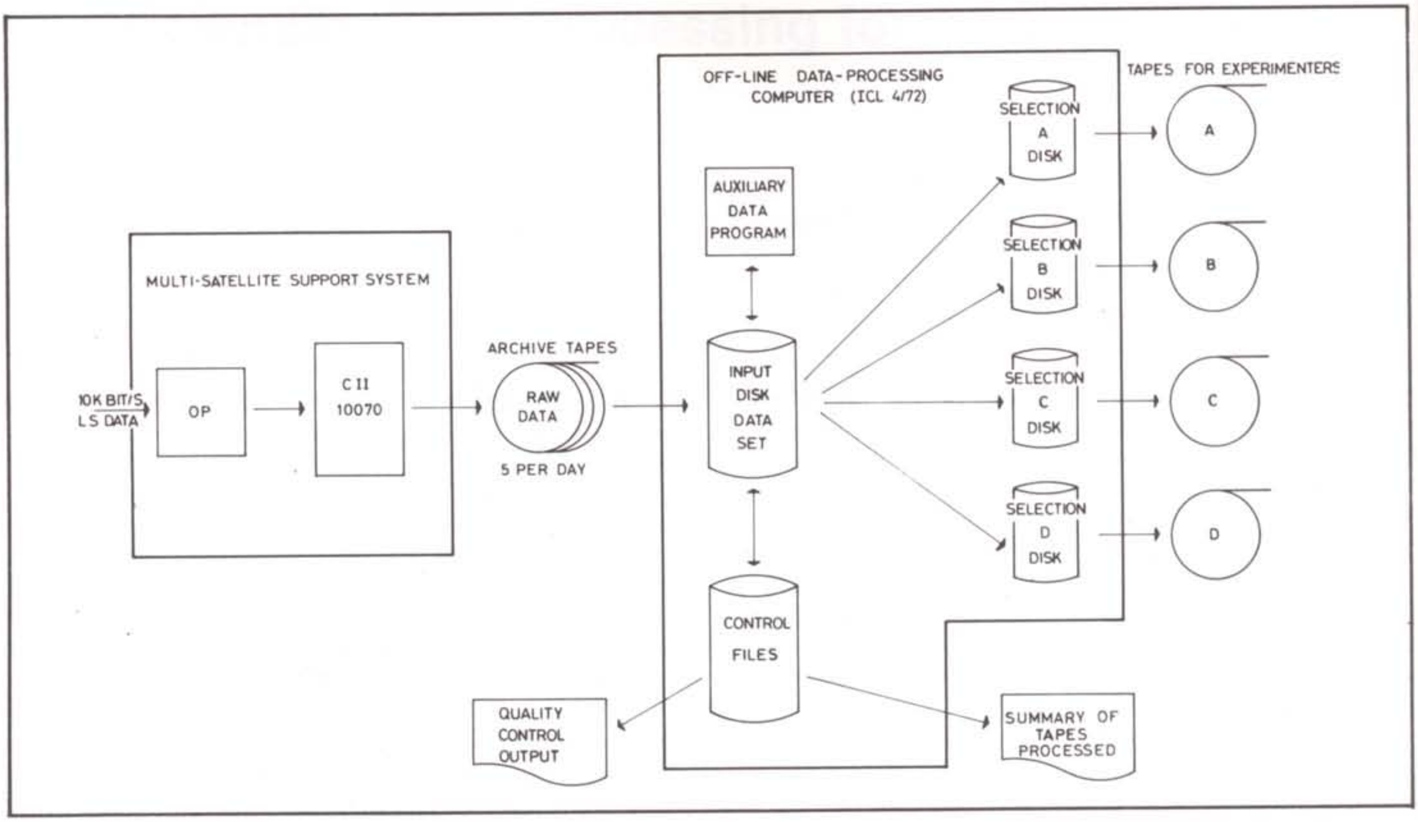


Figure 1 – Schematic of data flow for low-speed telemetry data.

THE PROCESSING HARDWARE AND SOFTWARE

To satisfy the mission's data requirements outlined above, a complex network of computers of several different types is used. The real-time and near-real-time functions are performed by the Multi-Satellite Support System (MSSS) computer network, while the off-line activities are assigned to an independent ICL 4/72 machine. The HS and LS data streams are, for most purposes, independent of each other, and the data flow can be conveniently represented in two separate diagrams (Figs. 1 & 2); only those functions directly linked with data-processing on behalf of the Geos experimenters have been shown for the sake of simplicity.

All data received at the Odenwald ground station from Geos are fed into a series of small computers (Siemens 330s), each of which has a specific task (HS1 = High-Speed Data Input, etc.).

Referring to Figure 1, the low-speed telemetry data are passed in real-time to the main MSSS computer, the CII 10070, by which all data are collected and written onto the set of archive tapes. At the same time, this computer performs all the real-time and near-real-time activities that have already been described. Having created a permanent archive of all data, these data must then be passed to the various experimenters for analysis and selection and this is done via the ICL 4/72. The processing of the LS data requires several hours of computer time each day, and it is thus essential that there is continuous and strict control over the output to allow any errors to be detected immediately.

As has already been mentioned, the HS data stream is so voluminous that only a selection of the data can be analysed. Figure 2 shows the flow of the high-speed data, all of which is initially written onto magnetic tape, and the small selection despatched to the experimenter. After the experimenter has decided which of the data he wants to keep for further analysis, the remainder of the data in the buffer are discarded and these tapes re-used for new data.

Some of the HS data passed to the CII 10070 computer have already undergone the sophisticated reduction and selection process. Because of the large volume of data to be processed in real time, the Fourier transformations that form part of this process must be performed extremely quickly. By using dedicated computers to perform this one task, a processing speed has been attained which would have been impossible with a general-purpose machine.

Generally speaking, the processing of data in a perfect environment would be a relatively simple task. The problems stem from having to deal with errors in the

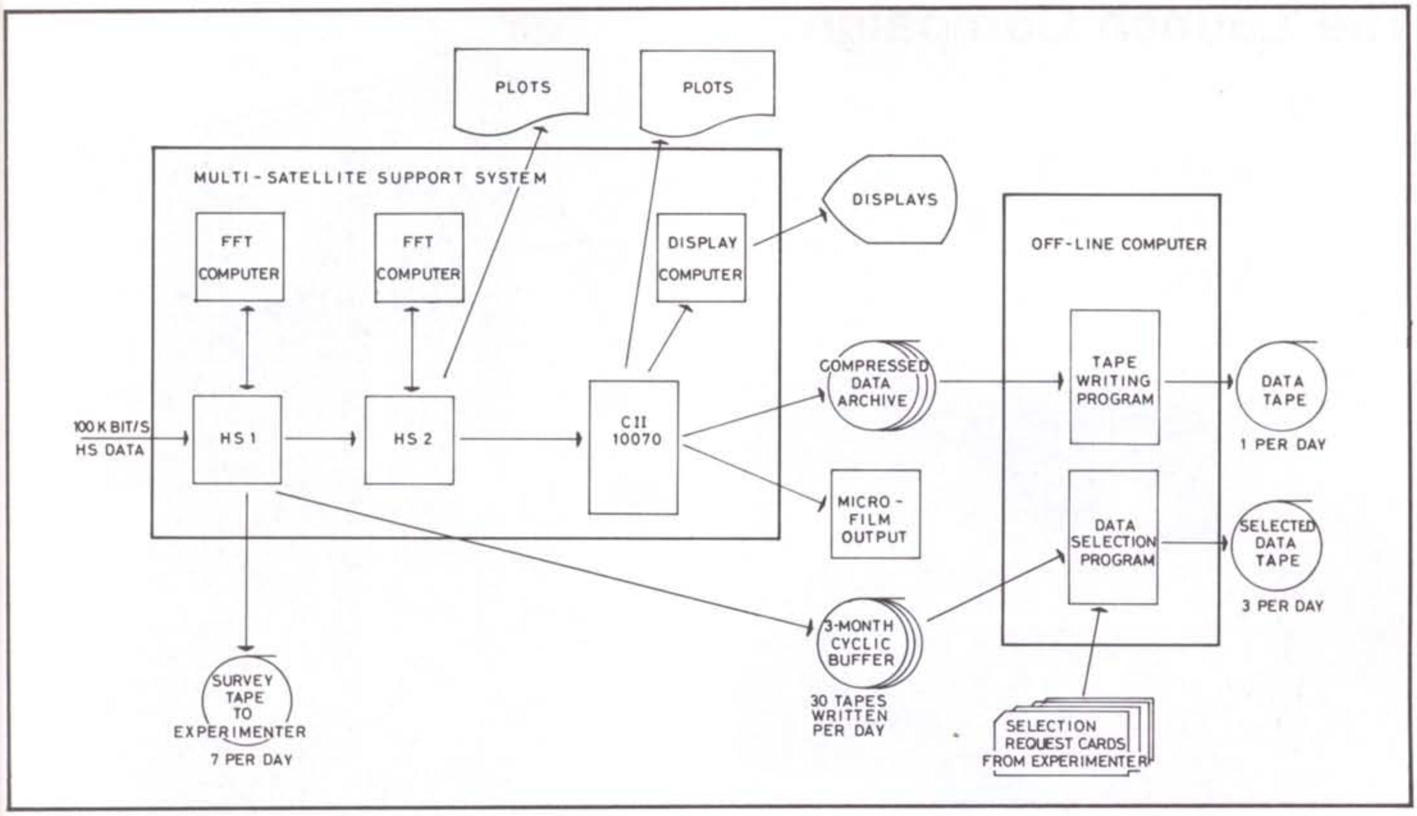


Figure 2 – Schematic of data flow for high-speed telemetry data.

incoming data and from handling large amounts of data. It is therefore important that the Geos software possesses sufficient resilience to detect errors and try to recover from as many different errors as possible, otherwise the incoming data could be lost or, in the case of the off-line processing, the backlog of tapes waiting to be processed could very quickly become unacceptably long.

Most of the programs used for the data processing are written in machine language, because a higher level language does not provide the necessary versatility and speed. To give an idea of the complexity of the task, the off-line data-processing program for the HS data consists of about 5000 instructions, the off-line data processing of the LS data has some 25 000 instructions, and the MSSS real-time and near-real-time programs have of the order of 200 000 instructions.

CONCLUSIONS

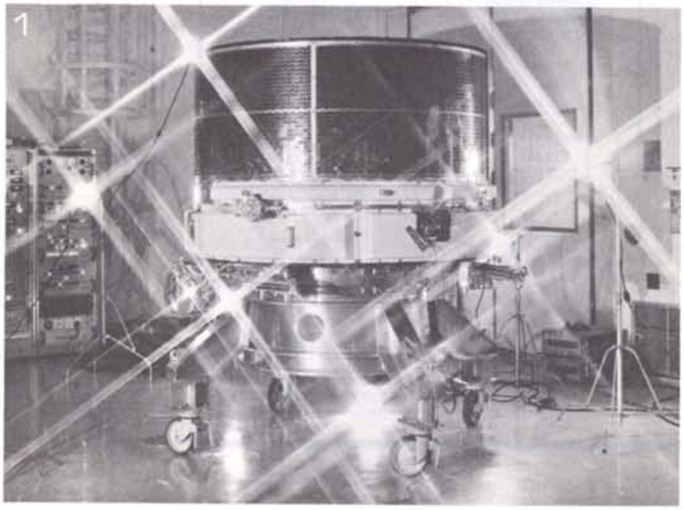
The scientific data processing that has been outlined is intended to provide a service to the experimenter such that he receives his Geos data in as optimal a form as possible for him to perform his final data reduction and analysis. The following table summarises the data production foreseen for a one-year period:

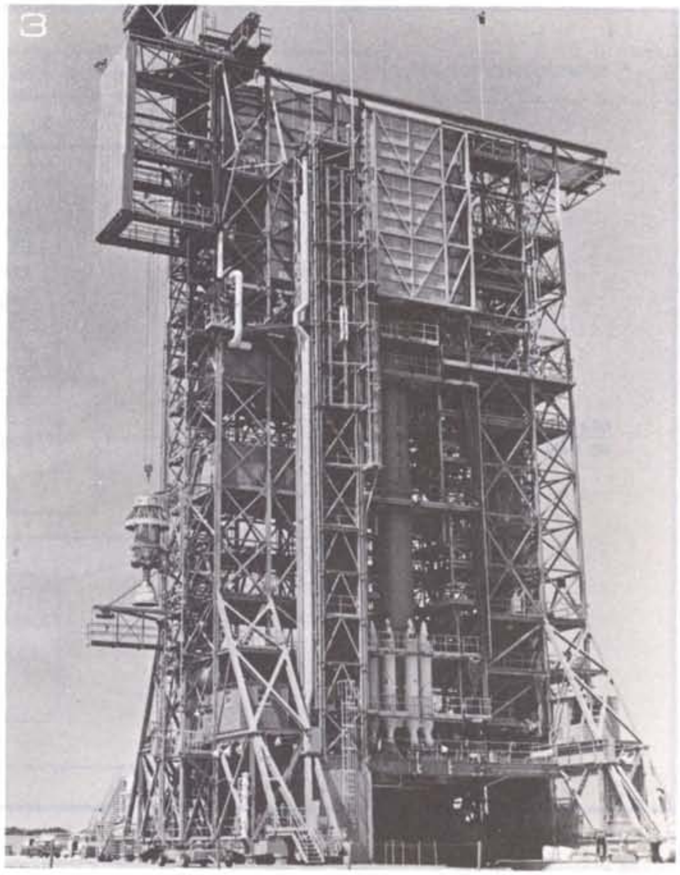
Number of HS data tapes to be recorded	11 000
Number of LS data tapes to be recorded	1 900
Number of survey tapes to be written	700
Number of tapes of compressed HS data to be written	700
Number of tapes of selected HS data to be sent to experimenters	700
Total number of LS data tapes to be sent to experimenters	800
Number of frames of microfilm for Daily Summaries	700
Total number of frames of microfilm for Experimenter Summaries	25 500
Hard copies of displays	3 000

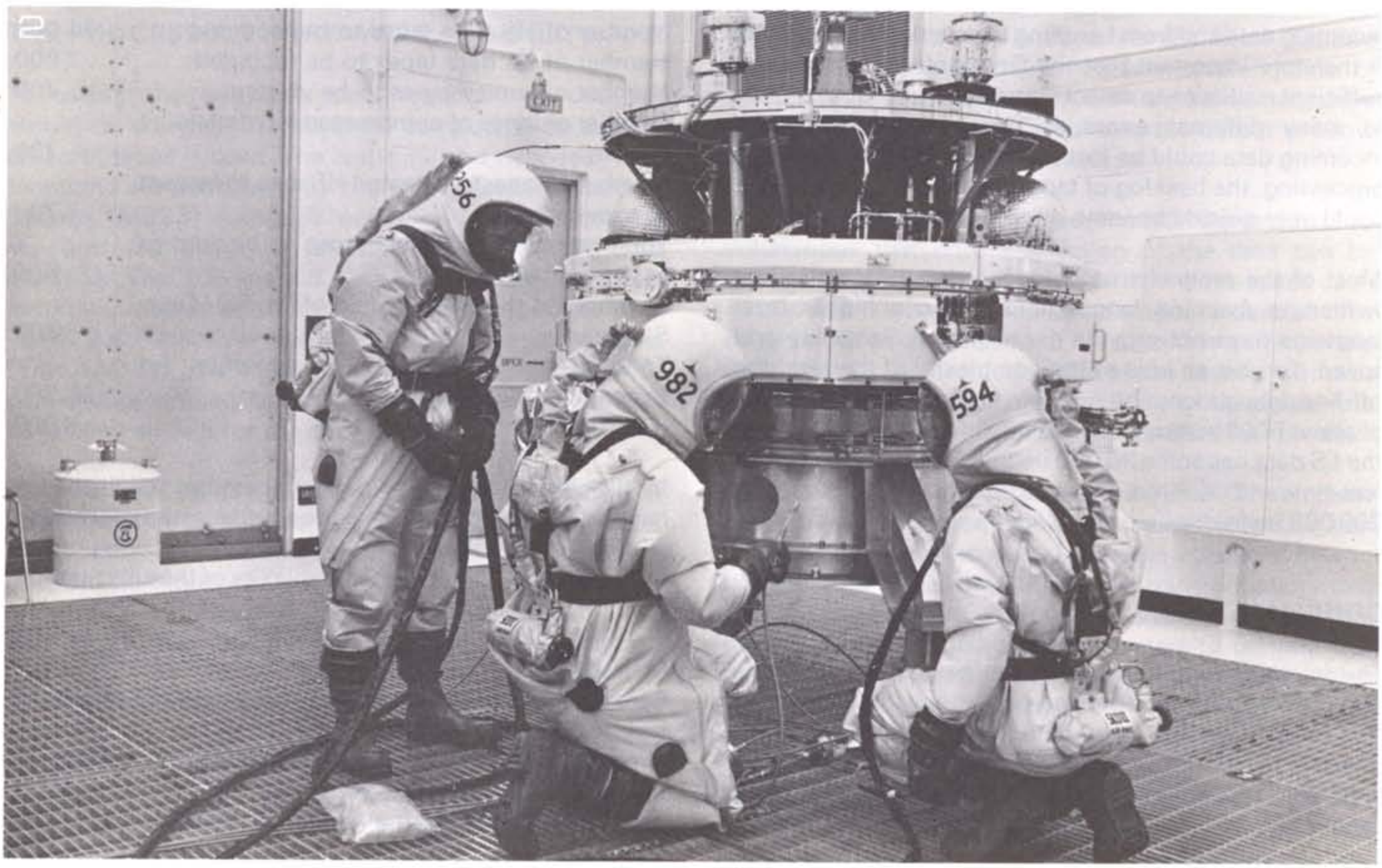
In describing the Geos data-processing activities, we have attempted to show that the sophisticated processing system needed on the ground is a direct consequence of the scope and the inherent complexity of the spacecraft's scientific payload.

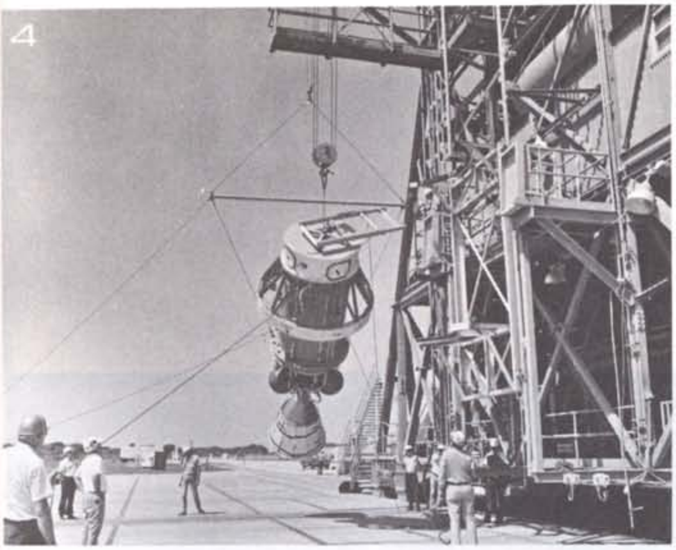
In designing the system, two of the most important points borne in mind were that, despite the complex nature of the task, the software had to be stable, to make the probability of errors as low as possible, and secondly the system had to be sufficiently flexible to permit modification to meet new requirements with a minimum of effort. □

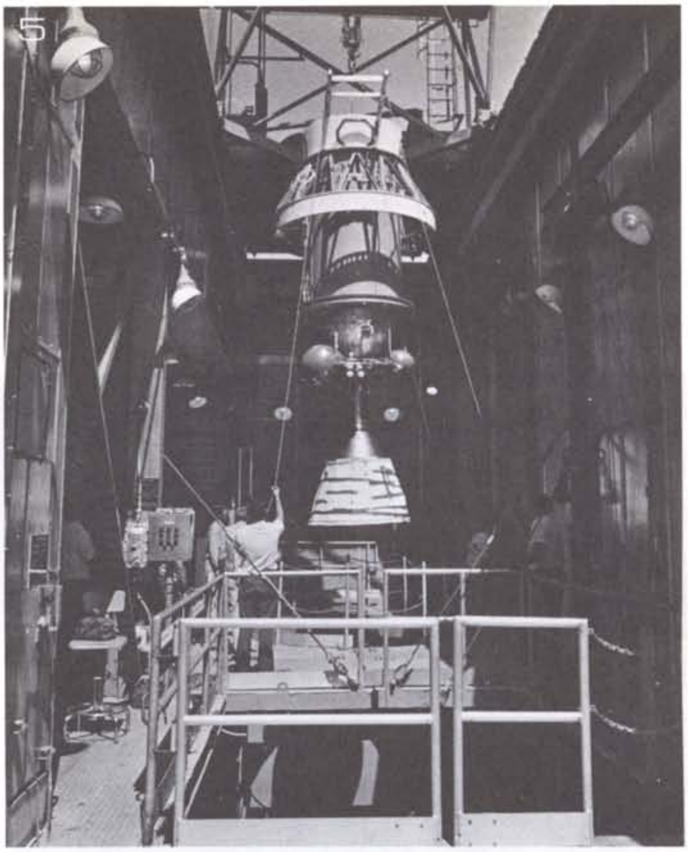
The Launch Campaign











(1) Satellite after final electrical checkout, ready for hydrazine filling and mating to launch vehicle.

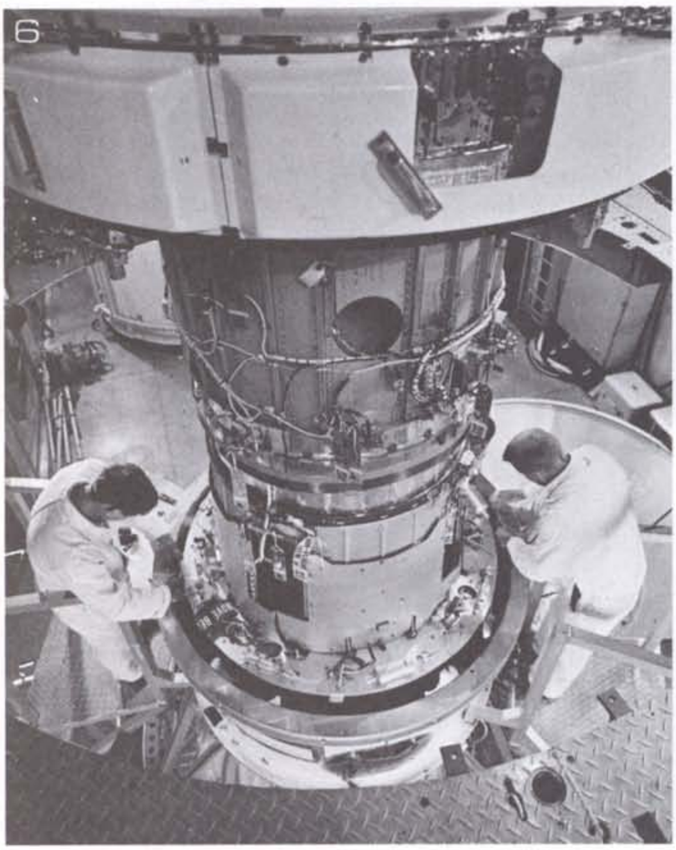
(2) Filling of reaction control equipment with hydrazine.

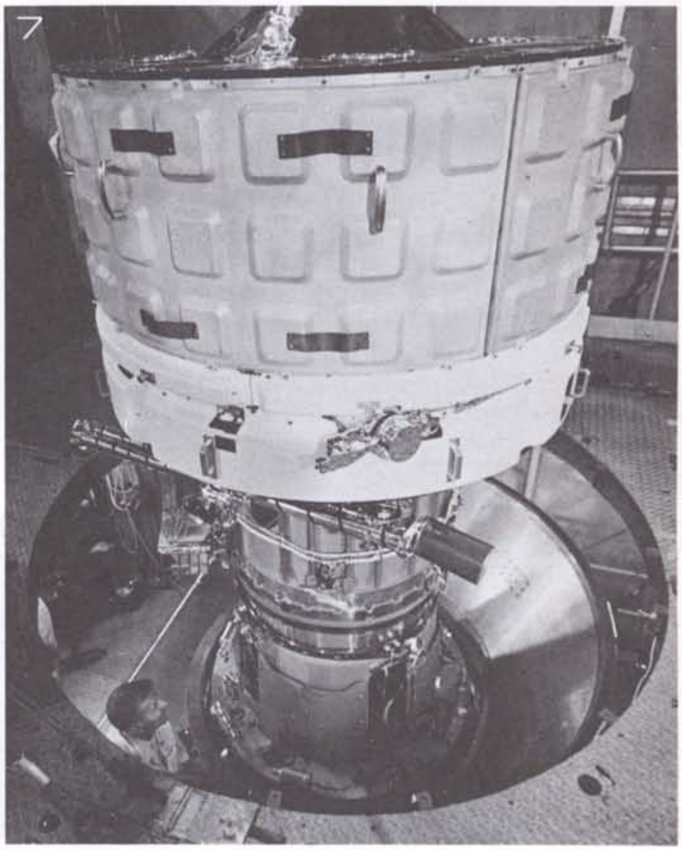
(3) First and second stages of Delta launch vehicle assembled in gantry.

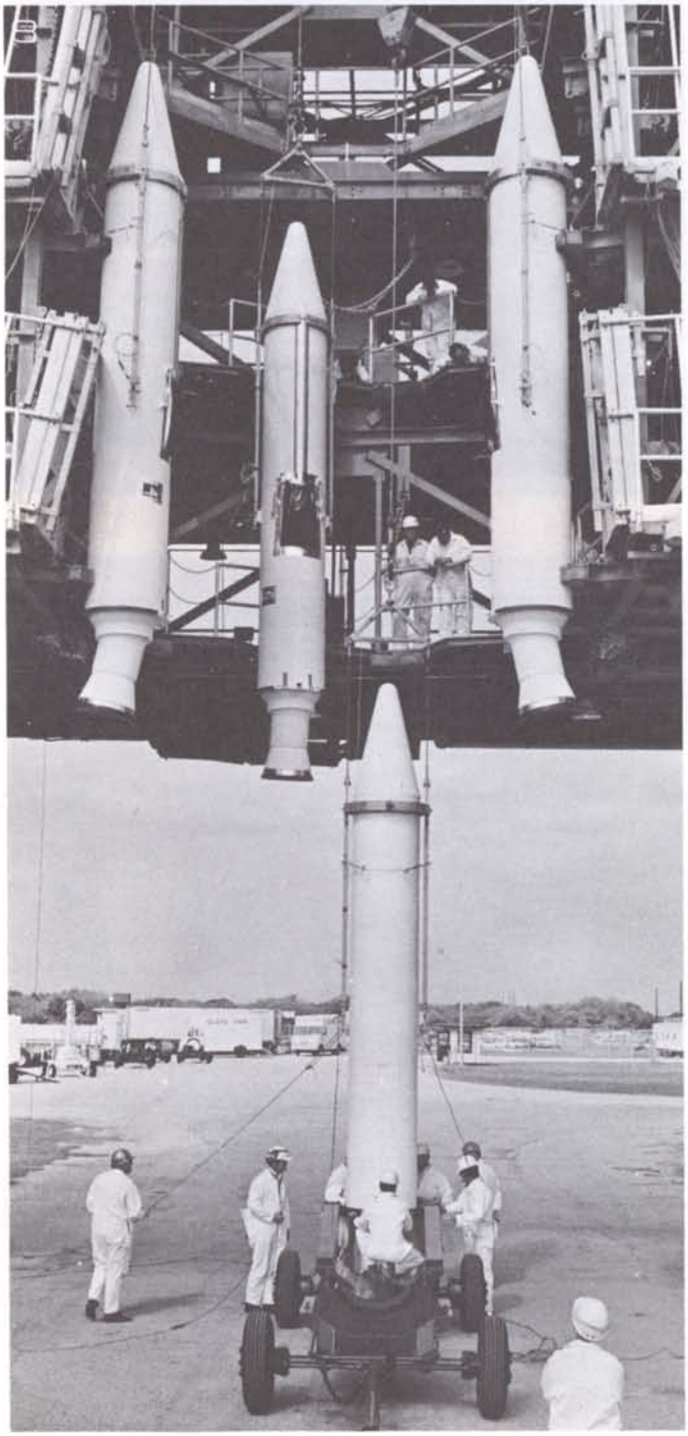
(4) Hoisting of third-stage/satellite combination into gantry.

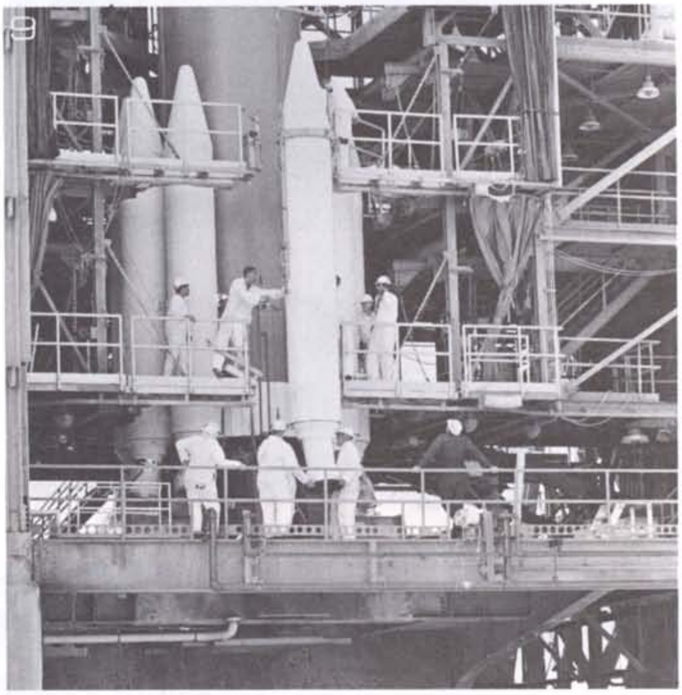
(5) Lowering of third-stage/satellite combination onto second stage of Delta launch vehicle.

(6)(7) Mating of satellite to Delta launch vehicle.









(8)(9) Fitting of strap-on boosters of first stage of Delta launcher.

(10) Ready for lift-off.

10

Geosari

K. Knott, Space Science Department of ESA, ESTEC, Noordwijk, The Netherlands

Following the announcement early in 1976 of satellite-launch opportunities on the first development flights of ESA's Ariane launch vehicle, three candidate satellites for flight as part of the Agency's scientific programme were studied. ESA's Solar System Working Group and Science Advisory Committee subsequently recommended that the Geos qualification model be selected, a recommendation endorsed by the Science Programme Committee in October 1976. All Geos experimenters had already expressed strong interest in this mission at a meeting in August and had stated their readiness to support it financially. Consequently, the Geos qualification model is now scheduled for launch, under the name Geosari, as the principal passenger on Ariane flight LO2 in December 1979.

The Geosari project has been approved with the proviso that no major technical changes are to be made to the existing Geos qualification-model spacecraft. Project activities will therefore be limited to refurbishment – where necessary – of the existing hardware and adaptation to Ariane specifications in terms of interfaces and final testing. Minor modifications to experiment sensors are possible, however, as long as the spacecraft interfaces and system requirements remain unchanged. The Geos payload already has a high degree of operational flexibility and adaptability to varying geophysical conditions, so that payload modifications for the Geosari mission need not be anticipated a priori. It must, nevertheless, be realised that Geos carries a number of very novel experiments and it is therefore quite conceivable that experience gained during its mission will result in a number of proposals for optimising and streamlining experiment performances for Geosari. Basically, however, the measuring capabilities of the current Geos payload will remain unchanged.

The new science to be derived from Geosari has, then, to come from a new orbit. Although technically feasible, it was not considered desirable for scientific reasons to merely 'repeat' the Geos mission by choosing a geostationary orbit for Geosari. The consensus among the participating scientists was that it would be more rewarding to refly the sophisticated and highly flexible Geos payload in an orbit that would provide wider spatial coverage of the magnetosphere. This philosophy was endorsed by ESA's scientific committees.

The Geos concept of keeping the satellite continuously in sight of one very sophisticated ground station more or less dictated that a geosynchronous orbit be retained for Geosari and the greater spatial coverage had to be achieved by choosing a suitable eccentricity for this orbit.

Combination of the transfer orbit offered by Ariane and the velocity increment available from the Geos apogee boost motor makes it feasible to achieve synchronous orbits with eccentricities between 0.35 (apogee 8.9 and perigee $4.3\,R_E$) and 0.64 (apogee 10.8 and perigee $2.4\,R_E$). Orbits with eccentricities greater than 0.5 would give rise to thermal problems with the existing Geos spacecraft design and would compromise visibility of the spacecraft from the ESOC ground station. Also, at such eccentricities it would not be possible for all experiments to achieve full orbital coverage as their dynamic ranges do not cater for the expected variations. It may therefore be necessary to limit the eccentricity to values around 0.5, but the final decision will depend on the outcome of a number of ongoing studies.

Eccentricities around 0.5 will give Geosari an orbit with better coverage of magnetopause and plasmapause boundaries than is possible with either Geos or any other presently planned highly eccentric orbiting satellite. Figure 1, a simplified section through the magnetosphere, shows both the orbit of Geos and that envisaged for Geosari. It should be evident that Geosari will be in a position to carry out very detailed studies of the magnetopause, as it will encounter this boundary near apogee where the low, nearly tangential velocity is in marked contrast to the radial, higher velocity encounters of most eccentrically orbiting spacecraft. The low orbital inclination ensures complete coverage of the entire trapped-particle population over a wide range of radial distances. Geosari will provide better coverage of the

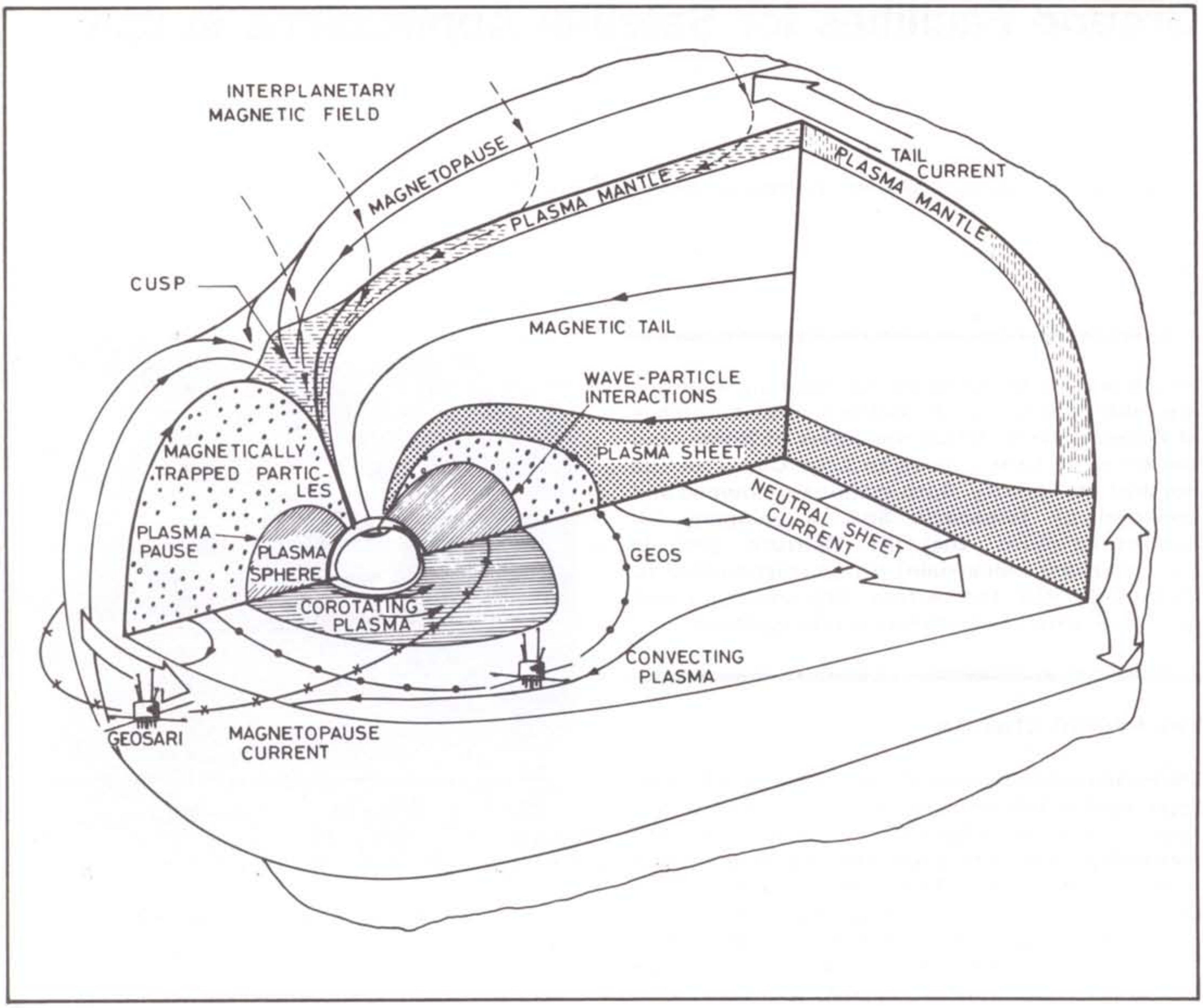


Figure 1 – Three-dimensional presentation of the magnetosphere showing the orbits of Geos and Geosari in the equatorial plane. The line of apsides of the eccentric Geosari orbit rotates by 360° per year. In the situation depicted here, Geosari's apogee is near the subsolar point of the magnetopause; six months later, it will be within the plasma sheet in the geomagnetic tail.

plasmasphere and the plasma sheet than Geos, which will 'see' these regions only under extreme – disturbed or very quiet – conditions. Geosari will explore both regions during 'average' and therefore perhaps more characteristic periods.

The data-handling task for Geosari will be as demanding as that undertaken for Geos. It should, however, be pointed out that Geosari will benefit from the investments made to develop the existing Geos hardware and that only the costs for operating the satellite and the ground station will have to be borne by the Agency.

The decision to fly Geosari with no basic change in payload precluded a call for new experiment proposals, which would have enabled groups other than those already involved with Geos to participate in the project. This constraint does not extend to experiment operation and data evaluation, where Geos experimenters are actively seeking co-operation with other interested groups within the ESA Member States.

In spite of the high scientific potential of this mission, it must not be forgotten that it is being undertaken on a test flight of a newly developed launcher. All investment by the Agency relating to Geosari is therefore being controlled on the basis of the implications that this entails for the success of the mission. □

Ground Facilities for Satellite Applications in Italy

G. Bressanin, S. Carretta & S. Tirrò, Telespazio SpA, Rome, Italy

Italy's ground facilities for satellite applications are centred at two earth stations, one of which is at Fucino, about 100 km northeast of Rome, and the other at Lario*, close to Lake Como, in the north of the country. Both stations are owned and operated by Telespazio SpA, a company incorporated into the IRI (Istituto per la Ricostruzione Industriale) group, responsible to the Italian PTT for testing, implementing and operating satellite communication systems.

THE FUCINO STATION

The Fucino station began activities in 1962 by embarking upon satellite telecommunication experiments with a single 10 m antenna. Since then it has increased progressively in size until today there are nine antenna systems on the site. One 13.4 m antenna (A in Fig. 2) is dedicated to telemetry, tracking and command, in addition to the monitoring of all Intelsat satellites located over the Atlantic and Indian Oceans. Two standard Intelsat antennas (B and C) handle commercial traffic associated with the Intelsats located over the Atlantic region (primary satellite) and the Indian Ocean region. Two other antennas (17 m and 3 m in diameter) will soon be used for propagation and telecommunication experiments with ESA's Orbital Test Satellite (OTS), to be launched in June, and also for maintaining this satellite in geostationary orbit. A further 10 m antenna receives data at 2 GHz from the American Landsat 1 and 2 earth-survey satellites, while another 10 m antenna is used for telemetry and command of Marisat. The last two of the nine antennas are to be used for in-orbit stationkeeping of Italy's Sirio experimental communications satellite, and for performing associated propagation and telecommunication experiments. The Sirio Operations Control Centre is also located at Fucino.

* The Lario station presently includes only a Sirio SHF antenna and a standard 30 m Intelsat antenna, for communications with the Atlantic Ocean satellite. It will therefore not be described in detail in this article.

Figure 1 – Magnola-Fucino line-of-sight radio path profile.

Two line-of-sight test ranges (boresights) are available in the neighbourhood of Fucino, the oldest at Monte Cimarani, to the west, and the other at Monte Magnola, some 20 km to the north (Fig. 1).

As outlined in a previous Bulletin (No. 5, May 1976), the reason for installing facilities at Monte Magnola was to conduct pre-operational compatibility tests between the Satellite Control and Test Station (SCTS) at Fucino and a communications 'payload' comparable to that to be flown on OTS. These tests will allow all telecommand and telemetry functions, as well as the operation of the telecommunications payload, to be checked under close to orbital conditions, thus minimising the risk of incompatibility between the OTS spacecraft and its ground system after launch. The Magnola facilities include an air-conditioned spacecraft room, incorporating a radio-frequency-transparent panel in front of the 'payload' and provided with anti-pollution filtering, and a storage room to house the spacecraft when experiments are not in progress.

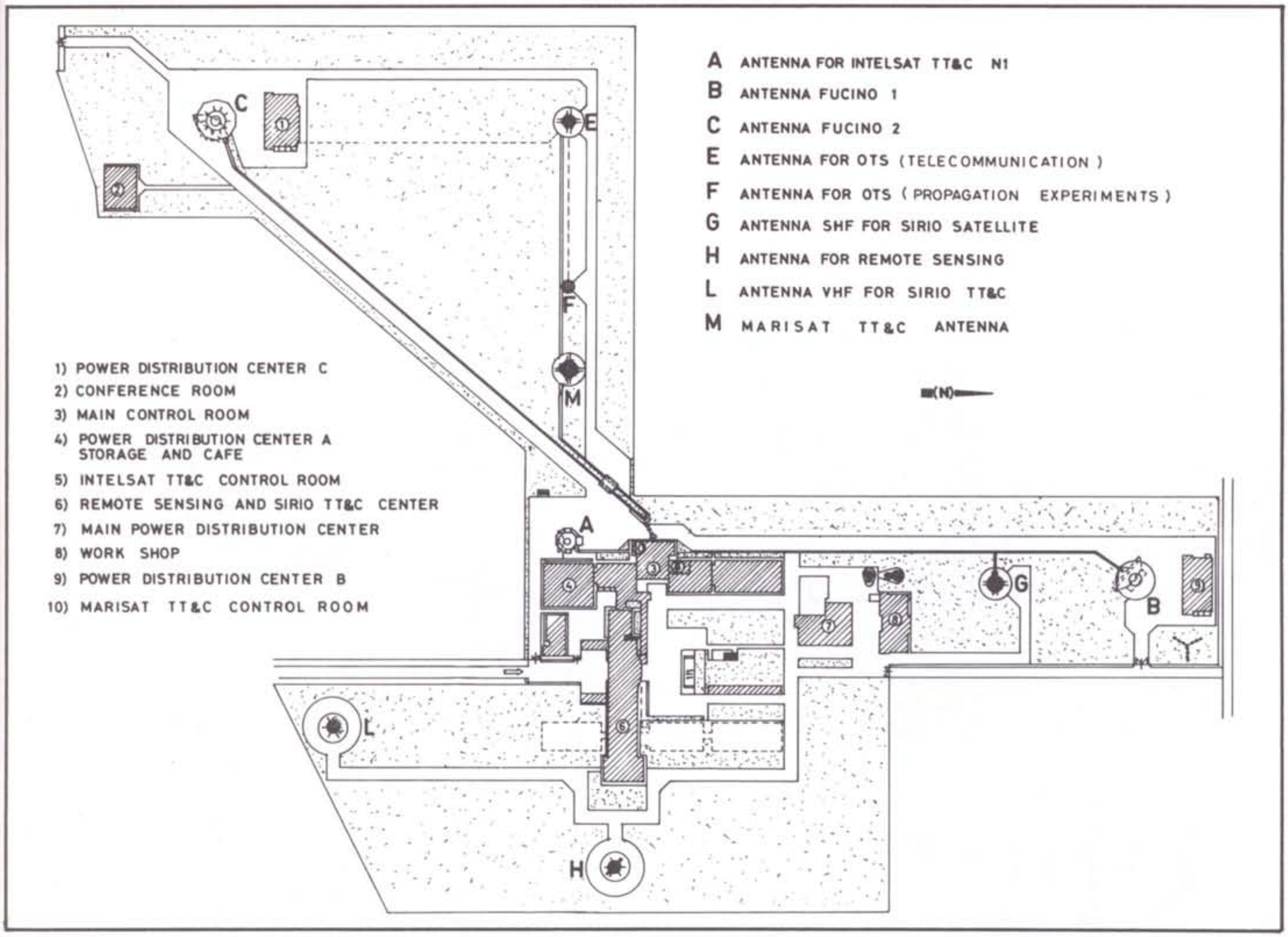


Figure 2 – Disposition of the facilities on the Fucino site.

The quality of the radio-frequency link is excellent, tests already performed with the SCTS having shown that the amount of ground reflection is very low for both co-polar and cross-polar signals (cross-polar purities better than 40 dB can be measured to a good accuracy). This makes the Magnola-Fucino traject particularly attractive for conducting antenna measurements and propagation experiments.

THE OTS FACILITY

As already mentioned, the Fucino SCTS station (Fig. 3) has two antenna systems:

- a large antenna (17 m diameter) for telecommunication experiments, including TV and digital transmission tests, TDMA tests at 60 and 120 Mbit/s, etc.,
- a small antenna (3 m diameter) for propagation tests at 11 and 14 GHz.

The station is also provided with ESA-owned telemetry, tracking and command equipment which Telespazio will operate under Agency contract to maintain OTS in geostationary orbit. It is for this purpose that the OTS station is linked to the ESOC Control Centre in Darmstadt, Germany.

THE EARTH-RESOURCES FACILITY

A Memorandum of Understanding was signed in May 1974 between NASA and Telespazio giving the latter the right to receive data from Landsat-type satellites in real time. The Italian ground station, which includes extensive facilities for processing remotely sensed data, began operating in July 1975 and is owned and operated by Telespazio. Initial activities are being carried out in the framework of an experimental programme, known as the TERRA (Tecniche di Elaborazione e di Rilevamento delle Risorse Ambientali, i.e. Techniques for Collecting and Processing Earth Resources Data) experiment.

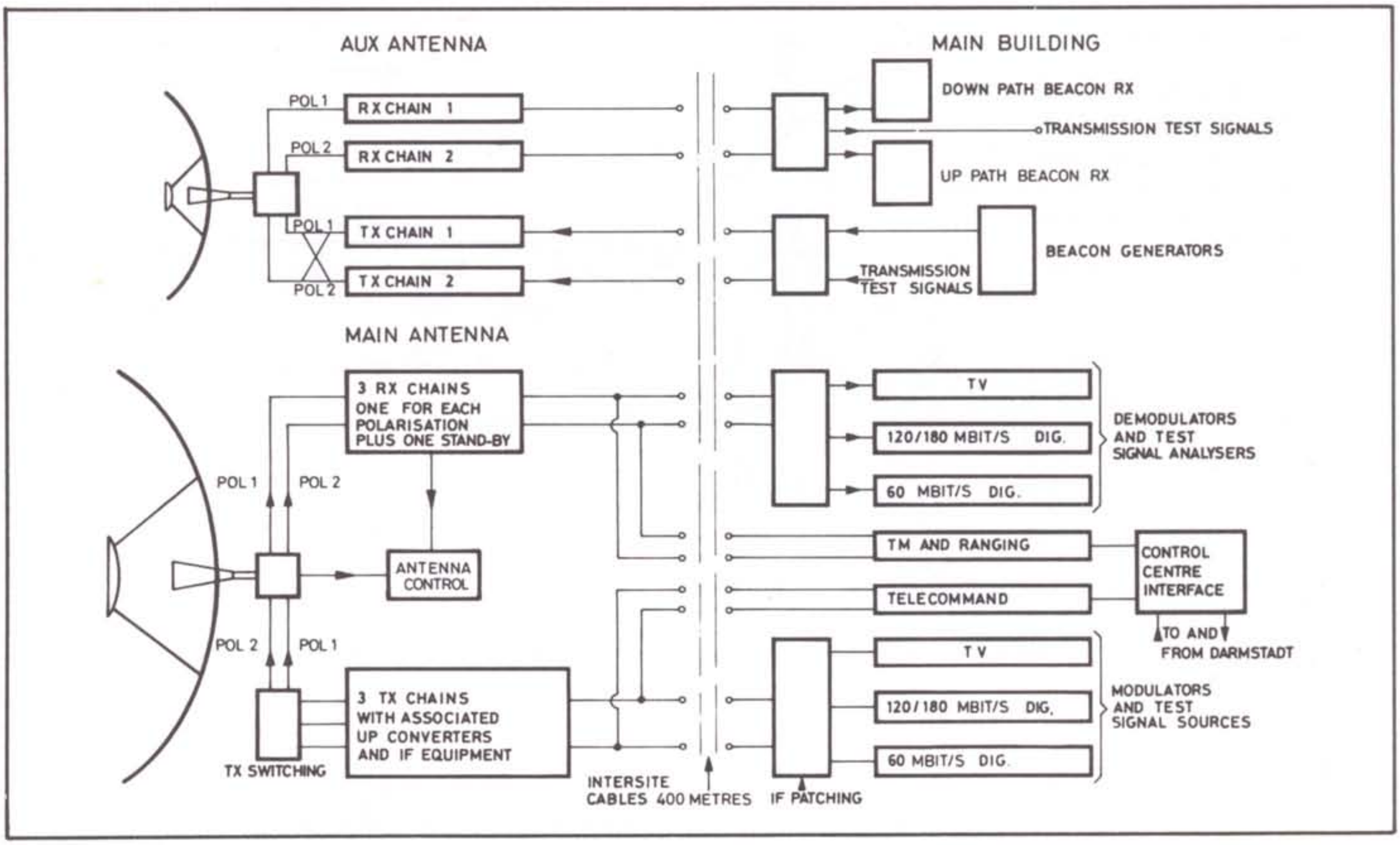


Figure 3 – Simplified block diagram of the SCTS facility at Fucino.

By experimenting in the field of remote-sensing data acquisition and processing, Telespazio's aim is to demonstrate the validity of remote-sensing techniques when applied in an operational context to the management of earth resources. Considerable care had therefore to be exercised in selecting the hardware to be adopted for the programme. The necessary studies, which were initiated in 1972, led to the concept of the regional facility that is currently operational at Fucino.

The 10 m antenna used for the experiments can be driven in both autotrack and preprogrammed modes. The feed is suitable for receiving data from weather satellites transmitting in the 1.7 GHz and 140 MHz bands, as well as for Landsat reception in the 2.2 GHz range.

Figure 4 shows the TERRA Information Processing System (TIPS).

Data received from Landsat's multispectral scanners are conditioned by bit-synchroniser and demultiplexer and transferred in serial form to High-Density Digital Tape (HDDT). On subsequent playback, the data are transferred to a Data Interface and Preprocessing Unit (DIPU), which performs radiometric and geometric corrections. A film recorder produces black and white or colour images of high quality.

In summary, the TIPS facilities at Fucino have the following features and capabilities:

Figure 4 – The TERRA Information Processing System (TIPS).

- Data from both space and airborne sensors can be converted into corrected and annotated images and Computer Compatible Tapes (CCT's). A number of standard products are generated on a routine basis, but special user requirements can also be accommodated.
- Processing operations can be performed on the image data. An interactive-operation mode allows the user to work with the data in real time.
- Processed results are displayed in enhanced form on a colour screen. Split-screen format permits the simultaneous display of several related images.
- Users can solve any processing problem by utilising a wide range of proven processing procedures inherent in the system.
- Users can run their own specialised software on the computer at Fucino, if necessary with the assistance of Telespazio staff.
- The entire library of images in store is available to the user for image and data selection purposes.

THE SIRIO FACILITY

The Sirio earth station has been designed to provide telemetry, tracking and command support for the Italian satellite during launch and throughout the duration of the telecommunication experiments. It consists essentially of:
(a) an antenna and servo subsystem
(b) a command encoder and decoder subsystem

(c) a high-power transmitter subsystem
(d) a receiving subsystem
(e) a telemetry decoder subsystem.

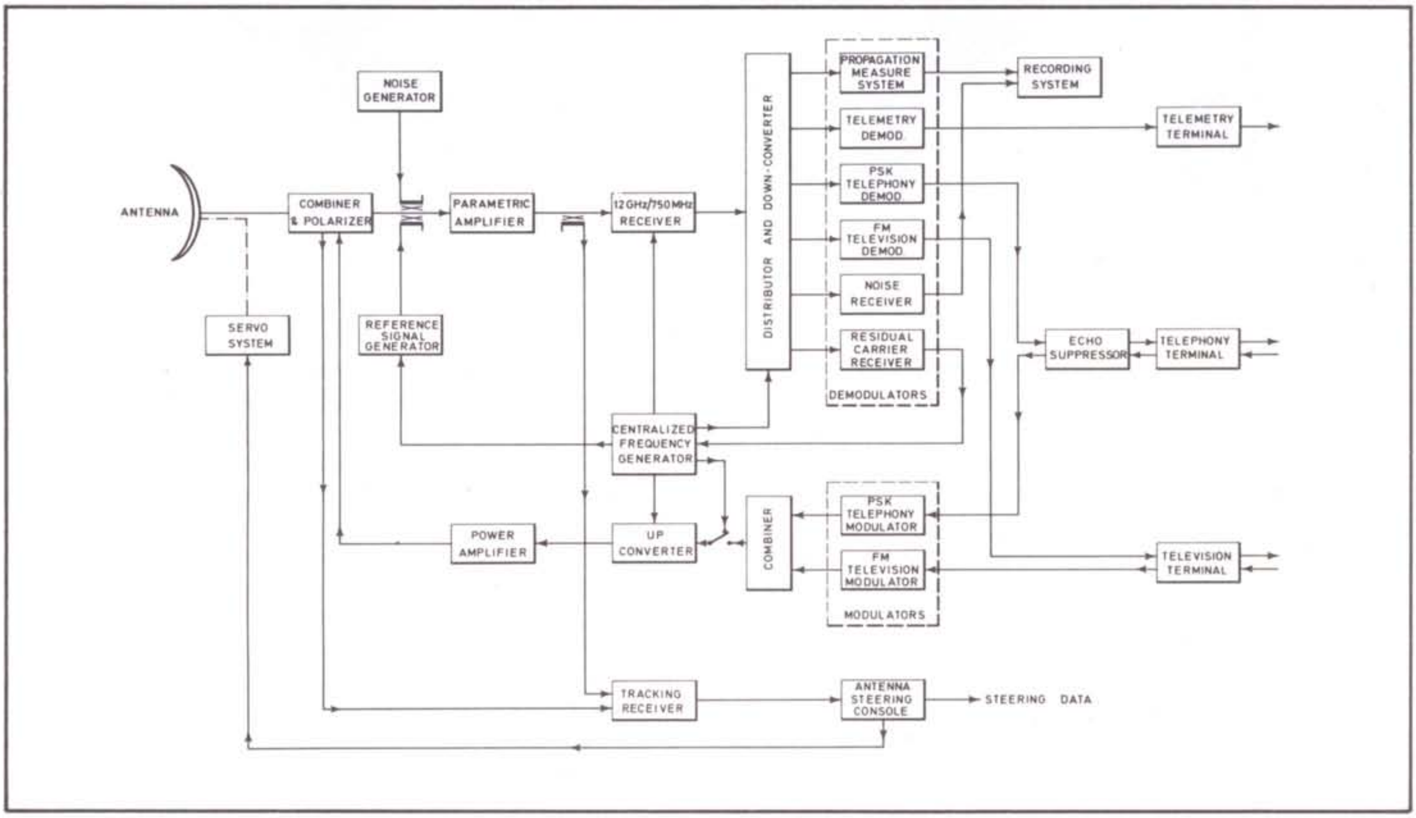
The VHF antenna is of the azimuth-elevation type, with a 32-element crossed log periodic array. It covers the 134-151 MHz frequency band, with a gain of 21 dB. The array and the RF combining circuitry allow simultaneous transmission and reception. The antenna can be equipped with a monopulse tracking receiver and has a maximum velocity of 5 deg/s along both the azimuthal and elevational axes.

The high-power transmitter subsystem has a complete-redundancy configuration and consists of an AM modulator, pre-amplifier tube and final amplifier with a maximum output power of 5 kW rms with 90% AM modulation and distortion of less than 5% at 8 kHz. The telemetry receiving subsystem is composed of four receivers, two of which can be connected in a predetection-combining configuration to improve signal-to-noise ratio by 3 dB for circular-polarisation reception.

THE OPERATIONS CONTROL CENTRE

The Sirio Operations Control Centre (SIOCC), designed to meet all the monitoring and control requirements of the spacecraft during the geostationary-orbit phase of the mission, will become operational with the Sirio spacecraft at 15° W, about one month after the planned August launch from Cape Canaveral. It will operate on a 24-hour per day basis, throughout the two-year lifetime of the satellite and will provide for:

- telemetry data acquisition and handling
- command encoding and transmission



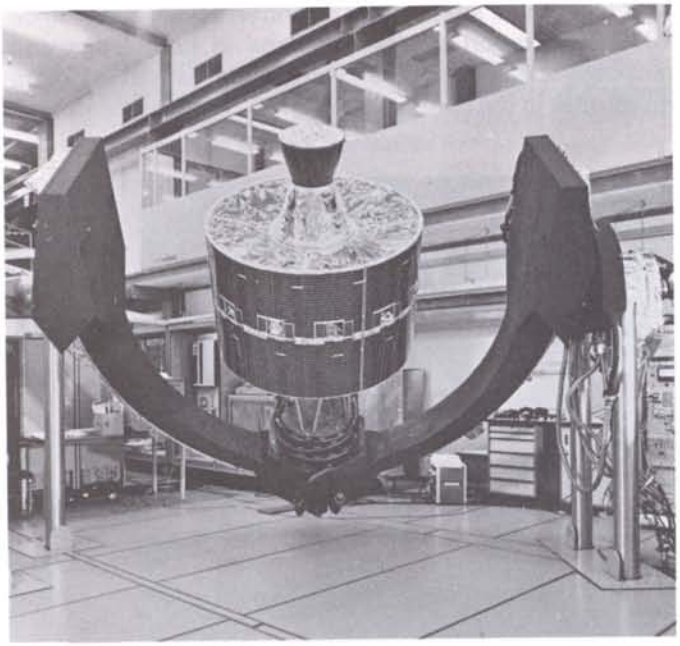
– SHF experiment control and data acquisition.

The Centre's hardware system is based on a PDP 11/70 computer (64 K memory) and two digital magnetic tape units will be used to store telemetry and SHF data. The raw telemetry data will be calibrated, translated into engineering units, and displayed in real time on three CRT displays. It is planned to store telemetry data on both analogue and digital magnetic tapes.

Changes in spacecraft configuration, attitude corrections and orbital manoeuvres will be performed via the computer and the command chain, the operator requests being handled by the computer and the commands sent through the command encoder and VHF transmitter. The SIOCC computer will also acquire data from an SHF ground station at Fucino, and these are to be processed and stored in real time on computer-compatible tapes.

Figure 5 – Block diagram of Sirio SHF stations.

Figure 6 – The Sirio spacecraft under test at ESTEC.



These CCT's will subsequently be distributed to the experimenters for further processing and analysis.

THE SHF STATIONS

The two SHF stations to be commissioned at Fucino and Lario this spring are to be used for propagation and telecommunication experiments at 11.6 and 17.4 GHz with the Sirio satellite (Figs. 5&6). Experiments with the orbiting satellite will probably continue until the end of 1979, and a number of features of the SHF stations make them attractive for re-use in future experimental activities:

- The surface geometry of the 17 m antennas is such that it is hoped to achieve an accuracy of 0.5 mm rms, at least for the inner 10 m, so that good performance can also be expected at 20 and 30 GHz from this portion of the dish.
- The propagation-experiment concept can be considered valid for future measurements at 20 and 30 GHz. Both the uplink (about 775 MHz) and downlink (about 530 MHz) bandwidths are in excess of 500 MHz, the highest band that can reasonably be foreseen today for use with a single carrier. Consequently, re-use for future 20–30 GHz missions of a large part of the hardware to be used for the Sirio propagation measurements can be anticipated.
- The software package developed for data acquisition, recording and real-time processing can be considered a good basis for the production of similar packages that might be needed in the future.

CONCLUSIONS

The facilities that have been described are representative of the potential that exists in Italy for in-orbit control of satellites, reception and processing of data from earth-observation satellites, and propagation and telecommunication experiments for frequencies higher than 10 GHz. Their existence could hopefully provide important opportunities when striving to optimise the operational configurations and economics of future national and European programmes in these domains. □

In Brief

First Council Meeting at Ministerial Level

The first ESA Council Meeting at Ministerial Level took place at the Agency's Paris Headquarters on 14/15 February 1977. The three accompanying photographs show the arrival of the outgoing President of Council, Mr. Gaston Geens, Belgium's Minister of Science Policy and Budget; the incoming President of Council Mr. Mario Pedini, Italian Minister of Scientific and Technological Research, in conversation with Mr. Roy Gibson, Director General of ESA; and a general view of the Council Chamber.

Signing of Arrangement between ESA and Canadian Center for Remote Sensing

An Arrangement defining the terms of co-operation between the Agency and Canada in the remote sensing of earth resources was signed in Paris on 21 March 1977. Under this Arrangement, ESA and the Canadian Center for Remote Sensing (CCRS) have agreed to intensify their relations and to increase their exchanges in a number of areas of common interest, including study of remote-sensing applications, development of microwave remote-sensing systems, optimisation of ground networks for reception and processing of satellite data, and utilisation of Spacelab for remote sensing.

At the recent meeting of the ESA Council at Ministerial Level, the Canadian Government affirmed its intention of increasing its collaboration in European space activities and of establishing permanent institutional relations with ESA. Signature of the Arrangement with the CCRS suggests that Canada may become an active partner in the remote-sensing programme which the Agency is currently seeking to establish.

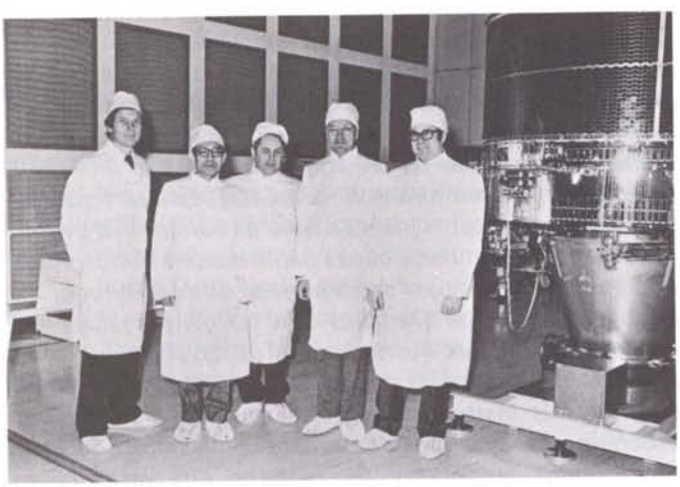
Signature of the remote-sensing Arrangement by Mr. Larry Morley, Director General of CCRS, and Mr. Roy Gibson, Director General of ESA.

IMS Steering Committee at ESTEC

On 24-27 January 1977, the International Magnetospheric Study Steering Committee held its 8th meeting at ESTEC, hosted by Dr. E.A. Trendelenburg and Dr. D.E. Page. The agenda included situation reports on Geos, ISEE and other IMS satellites. The main accomplishment of the meeting was the drafting of IMS Report No. 3, which contains a résumé of scientific achievement since 1972. The report points out gaps in knowledge and proposes strategies for their elimination, as well as noting milestones in the conduct of the IMS. The members of the

Committee had the opportunity to view the Geos spacecraft, which was undergoing final electrical testing at that time.

Members of the IMS Steering Committee viewing the Geos satellite at ESTEC. From left to right: Dr. G. Rostocker (Canada), Prof. J. Roederer (USA, Committee Chairman), Prof. I. Zhulin (USSR), Dr. M. Sugiura (USA) and Dr. K. Knott (Project Scientist for Geos).



Esrange Agreement Prolonged

At a Meeting of the Plenipotentiaries to consider renewal of the Esrange Agreement, called on 17 March 1977 at ESA Headquarters, the Final Act and annexed texts allowing the Agreement to be prolonged from 1 July 1977 until 31 December 1980 were approved.

The accompanying photograph taken during signature of the Agreement shows, from right to left: Mr. Xavier du Cauzé de Nazelle, French Plenipotentiary Minister, Mr. Roy Gibson, Director General of ESA, and Dr. H. Kaltenecker, Head of ESA's Department of International and Legal Affairs.

ESA Publications

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

ESA Journal

The following papers were published in Vol. 1, No. 1. (The ESA Journal supercedes the ESA Scientific & Technical Review.)

The International Sun-Earth Explorer (formerly IME), *by A.C. Durney*

The scientific development of this mission is described, including the basic ideas that generated it and the steps that led to the present concept. The capabilities of the three spacecraft are presented briefly, followed by an overview of some of the scientific areas where these spacecraft should make a significant contribution. A description of the orbits is given, together with the scientific reasoning which decided their parameters and the philosophy behind the separation strategy that has been adopted. The payload contents, the matching of the experiments, the number of investigators and the institutes involved are discussed with the use of tables and the concept of this mission within the framework of the International Magnetospheric Study is outlined. The data processing is described, together with the methods for data exchange and distribution.

On décrit la genèse de la mission scientifique d'ISEE ainsi que les principes de base du projet actuel qui s'inscrit dans le cadre de l'Etude Internationale de la Magnétosphère. Les possibilités des trois véhicules spatiaux A, B et C sont brièvement présentées, suivies par une revue des différents domaines scientifiques où leur contribution devrait être importante. On explique le choix des paramètres d'orbite ainsi que les principes du plan adopté pour la séparation des véhicules. La composition de la charge utile, l'agencement des expériences ainsi que le nombre des responsables sont illustrés par des tableaux. On termine par la description des méthodes de traitement, d'échange et de distribution des données.

A Large Infrared Telescope on Spacelab (LIRTS), *by V. Manno*

A wide variety of celestial objects emit predominantly in the infrared region. These include intrinsically cool objects, but there are also hot objects, such as early type stars, whose energy is re-emitted by the circumstellar clouds at infrared wavelengths. Progress has been made in the past by ground observatories looking at celestial objects in the few near-infrared windows of the atmosphere. The region above 20 μm is inaccessible to ground observatories and can be explored only by reaching above the atmosphere. Balloon-and aircraft-borne instruments are still severely hampered by the residual atmosphere and by the thick forest of molecular lines, from which only instruments in space will be freed. However, the cryogenic requirements linked with any infrared observation have until recently made it impracticable to fly such instruments on a satellite. The forthcoming availability of the Shuttle/Spacelab system at last opens the door of space to IR instruments. A large IR uncooled telescope for high-sensitivity and high-spatial-resolution measurements has been studied by ESA for a series of flights on Spacelab. The principal emphasis is on operations in the 30 μm to 1 mm ground-inaccessible wavelength region.

Un grand nombre d'objets célestes émettent leur rayonnement principalement dans l'infrarouge. Il s'agit essentiellement d'objets froids, mais aussi d'objets chauds, tels que des étoiles jeunes dont l'énergie est réémise dans l'infrarouge par des nuages qui les entourent. Jusqu'ici, les observations se faisaient à partir du sol en mettant à profit les quelques fenêtres que présente l'atmosphère dans l'infrarouge. Mais au-delà de 20 μm, les moyens d'observation basés au sol sont inopérants et il devient indispensable de s'affranchir de l'atmosphère terrestre. Même les instruments placés à bord de ballons et d'avions sont sérieusement handicapés par la couche atmosphérique qui subsiste et par l'épais barrage que constituent les raies moléculaires. De plus, les exigences dues au refroidissement des instruments d'observation font que jusqu'à une époque récente, il était impossible d'embarquer de tels instruments sur un satellite. L'avènement prochain du système de transport Navette/Spacelab ouvre enfin les portes de l'espace aux instruments *d'astronomie infrarouge. Un grand télescope infrarouge non refroidi, possédant à la fois une grande sensibilité et un pouvoir de résolution spatiale élevé, a été étudié par l'ESA en vue d'une série de vols à bord du laboratoire spatial. Il sera principalement utilisé pour des observations dans les longueurs d'ondes allant de 30 μm à 1 mm, totalement inaccessibles à partir du sol.*

Etat actuel de la recherche sur la dynamique des fluides en rotation – 1ère partie –, *par Y. Ousset*

On présente une revue bibliographique des études qui ont été menées dans le domaine de la dynamique des fluides en rotation, en l'orientant vers l'application particulière aux amortisseurs montés en bout de bras et vers l'évaluation de la dissipation créée par le mouvement relatif du (ou des) fluide(s) par rapport aux parois du réservoir. Sont successivement abordés: l'étude analytique des équations du problème; les études expérimentales qui ont été menées pour évaluer la dissipation du liquide; la résolution numérique des équations de Navier-Stokes et les applications qui en ont été faites aux fluides en rotation; et enfin les problèmes liés aux tensions superficielles aux interfaces lorsque le fluide est sous faible pesanteur. Une conclusion fait le point de ce que l'on peut attendre des différentes approches possibles du problème.

A bibliographical review of studies conducted in the field of rotating fluid dynamics is presented, with special emphasis on applications to tip-dampers and on evaluation of the dissipation due to fluid movement against the tank walls. The following topics are covered: an analytical study of the problem equations; experimental studies for evaluating the fluid dissipation; numerical resolution of Navier-Stokes equations and subsequent applications to rotating fluids; and lastly problems related to surface tensions at interfaces when the fluid is under low gravity. The conclusions point out various possible approaches which might be used to tackle the different problems.

Performance Criteria for Satellite Digital Transmission Systems, *by R.A. Harris*

The origins of the Energy Contrast Ratio E_b/N_0 and its use as a measure of QPSK system performance are discussed. Although E_b/N_0 provides a measure of the performance of a given system with respect to that theoretically obtainable, it is not a good indication of the relative performance of different nonlinear systems. A modified term $E/N_0|_{SAT}$ is developed which takes account of the effects of TWTA back-off, noise power variation, and signal power loss. Procedures for measuring E_b/N_0 and $E/N_0|_{SAT}$ are given. The Intelsat procedure for modem performance characterisation is reviewed. It is shown that the criterion used is not E_b/N_0, and while it is suitable for comparing the performance of modems having the same type of filters, it should not be used when comparing different modem types.

On examine les origines du rapport de contraste énergétique E_b/N_0 et son utilisation pour la mesure de performance du système de modulation quadriphase (QPSK). Bien que ce taux E_b/N_0 fournisse la mesure de performance d'un système donné par rapport à celle qu'on peut théoriquement obtenir, il ne donne pas une idée exacte des performances relatives des différents systèmes non-linéaires. On fait intervenir un terme modifié $E/N_0|_{sat}$ qui tient compte des effets du recul donné au point de fonctionnement des ATOP, de la variation de la puissance de bruit et de la perte de puissance du signal. Les méthodes de mesure des rapports E_b/N_0 et $E_b/N_0|_{sat}$ sont présentées ainsi que la procédure Intelsat de caractérisation des performances des modems. On montre enfin que le critère utilisé n'est pas E_b/N_0, et que, si son emploi se justifie pour la comparaison des performances de modems ayant le même type de filtres, il n'en est pas de même lorsqu'on a affaire à des modems de types différents.

Analyse assistée par ordinateur des réseaux micro-ondes dans le domaine fréquentiel (ESA-MEC), *par J.G. Ferrante, J.K. Nielsen & A. Montenegro*

Cet article présente deux méthodes générales d'analyse

de réseaux micro-ondes destinées à être intégrées ultérieurement dans un logiciel de conception aidée par ordinateur (CAO) appelé 'ESAMEC' (ESA Microwave Electronic Circuits). Ces méthodes sont d'une part la méthode des opérateurs de connexion qui est basée sur les représentations équivalentes des matrices de transfert et d'autre part la méthode d'analyse nodale utilisant la matrice d'admittance infinie.
Avant tout, le logiciel ESAMEC est un programme d'analyse universel, capable d'évaluer les performances de gain, stabilité et bruit d'un réseau micro-ondes dont les éléments et la topologie sont définis par l'utilisateur lui-même. L'utilisation d'un langage de description très clair et la simplicité de l'organisation des données d'entrées permettent à l'ingénieur de se concentrer tout de suite sur l'aspect analyse du problème en réduisant au maximum les contraintes de programmation.
L'originalité et aussi la supériorité d'ESAMEC vis-à-vis des autres logiciels actuellement en exploitation réside dans la mise en oeuvre simultanée dans un même programme des deux méthodes d'analyses. Cela permet l'association harmonieuse des avantages propres à chacune d'elles (rapidité d'exécution, faible encombrement en mémoire, universalité d'application) tout en réduisant considérablement leurs inconvénients particuliers. La démonstration en sera donnée dans une application réelle du programme: l'analyse de pannes d'un réseau déphaseur variable à diodes pin destiné à être embarqué sur Météosat.

This article presents two general methods for microwave network analysis to be integrated into computer-aided design (CAD) software known as 'ESAMEC' (ESA Microwave Electronic Circuits). They are the wiring-operator method, based on equivalent representation of transfer matrices, and the nodal-analysis method, using an infinite admittance matrix (IAM).
ESAMEC is, firstly, a general-purpose software suite capable of evaluating the gain, stability and noise performances of microwave networks, the elements and topology of which are defined by the user himself. The very clear descriptor language and the simplicity of input-data organisation enable the microwave engineer to concentrate his attention immediately on the analysis, thus minimising the programming constraints.
ESAMEC's originality and superiority resides in the simultaneous operation of two analysis methods in the same simulation. This allows a harmonious association of their specific advantages (speed of execution, low storage requirement, general-purpose application), together with a considerable reduction in their particular inconveniences.
A practical application of the program is demonstrated in the failure-mode analysis of a variable phase-shift network (using PIN diodes) to be flown on Meteosat.

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ESA SP-122 Feb 1977, *Satellite broadcasting, Proc Symp Stockholm, Sweden 22-24 Nov 1976,* Guyenne T D & Rosetti C (Ed). [Price Code: C_1]

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SCIENTIFIC NOTES

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ESA TM-158 Fév 1977, *Etude du dégazage de manchons soudables fabriqués par Raychem,* par Prémat G A F. [Price Code: E_1].

ESA TM-168 Jan 1977, *Performance analysis of on-board particle- or photon-counting experiments* *and the effects of processing and telemetry-rate constraints*, by Okkes R W. [Price Code: C_1]

ESA TM-174 Feb 1977, *'CNESRO' 'CNSIM-CNSTAT' – Programs for the study of the maintenance and availability of a space system*, by Debruyn J Cl.
Vol I –*Problem analysis and program realisation* [Price Code: C_1]
Vol II –*User's guide* [Price Code: C_1]

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PROCEDURES, STANDARDS AND SPECIFICATIONS

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Vol 2 – *Facility Definition*
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Vol 1 (Oct 1975) – *Etudes théoriques*
Vol 2 (Sep 1976) – *Méthodes numériques*
Vol 3 (Dec 1976) – *Programmes et résultats numériques*

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ESA CR(X)-903 Jul 1976, *On/off shutter for satellite thermal control; design of the prototype*, by CASA, Spain.

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ESA CR(X)-905 Oct 1976, *Storage evaluation tests of Ni-Cd cells in geostationary cycling – SAFT VR 6FS cells. Final report, third part*, by INTA, Spain.

ESA CR(P)-906 Juin 1976, *Une étude de recherche appliquée sur un système de contrôle de réseau de calculateurs* Vol 1–2, par ECS-Automation, France.
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Vol 2 – *Systèmes de contrôle proposés*

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Tome 2 – *Essais de qualification et complémentaires*

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Vol 1 – *Introduction general preliminaries; quasi-rigid dynamics*
Vol 2 – *Deployment of booms; dynamics of fully deployed spacecraft; general conclusions; references*

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PUBLICATION	Availability Note	DISTRIBUTION OFFICE
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ESA Special Publications (ESA SP)	(1) and (2)	
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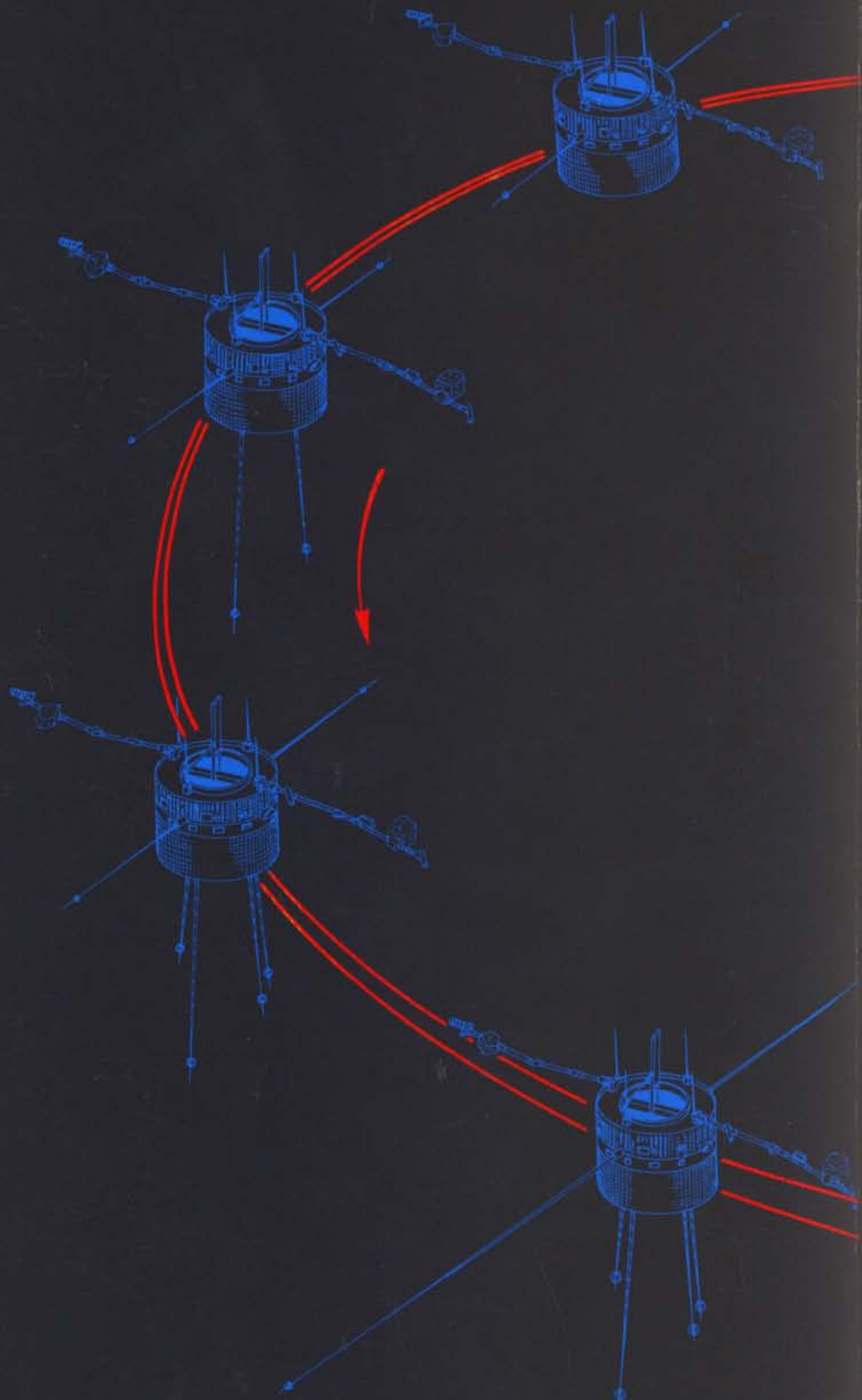

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