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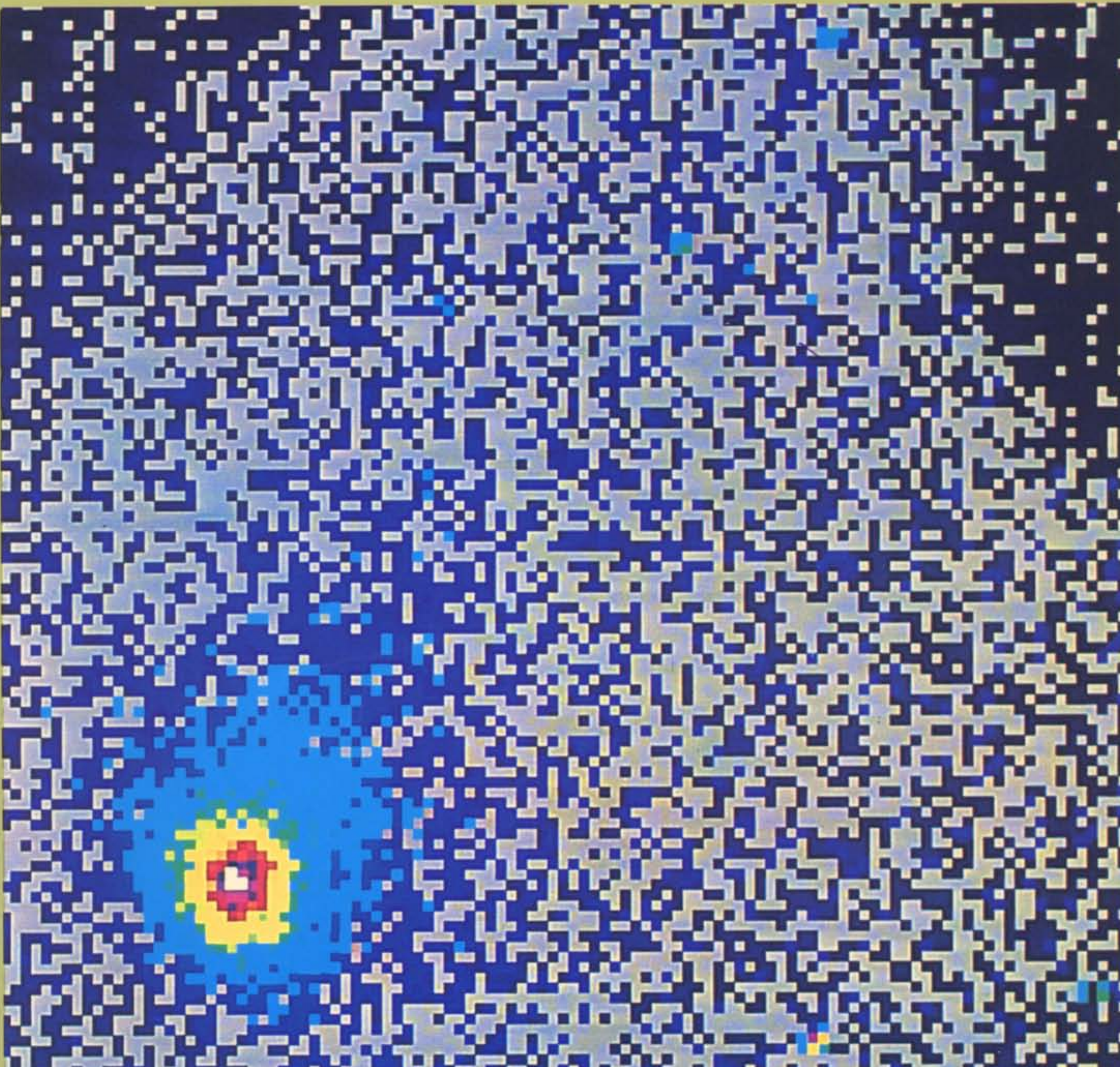
february 1986



european space agency

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

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

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

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

The Directorate of the Agency consists of the Director General; the Inspector General; the Director of Scientific Programmes; the Director of the Earth Observation and Microgravity Programme; the Director of the Telecommunications Programme; the Director of Space Transportation Systems; the Director of the Columbus Programme; the Director of ESTEC; the Director of Operations and the Director of Administration.

The ESA HEADQUARTERS are in Paris.

The major establishments of ESA are:

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

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

ESRIN, Frascati, Italy.

Chairman of the Council: Dr. H.H. Atkinson.

Director General: Prof. R. Lüst.

agence spatiale européenne

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

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

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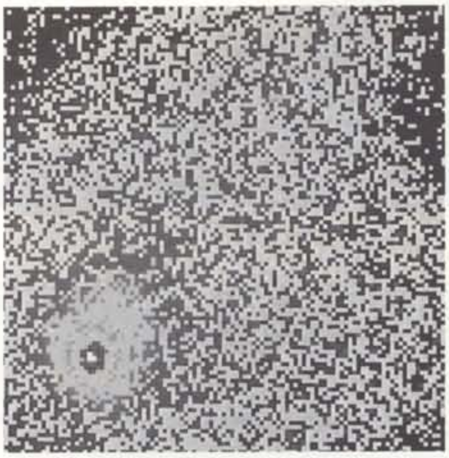

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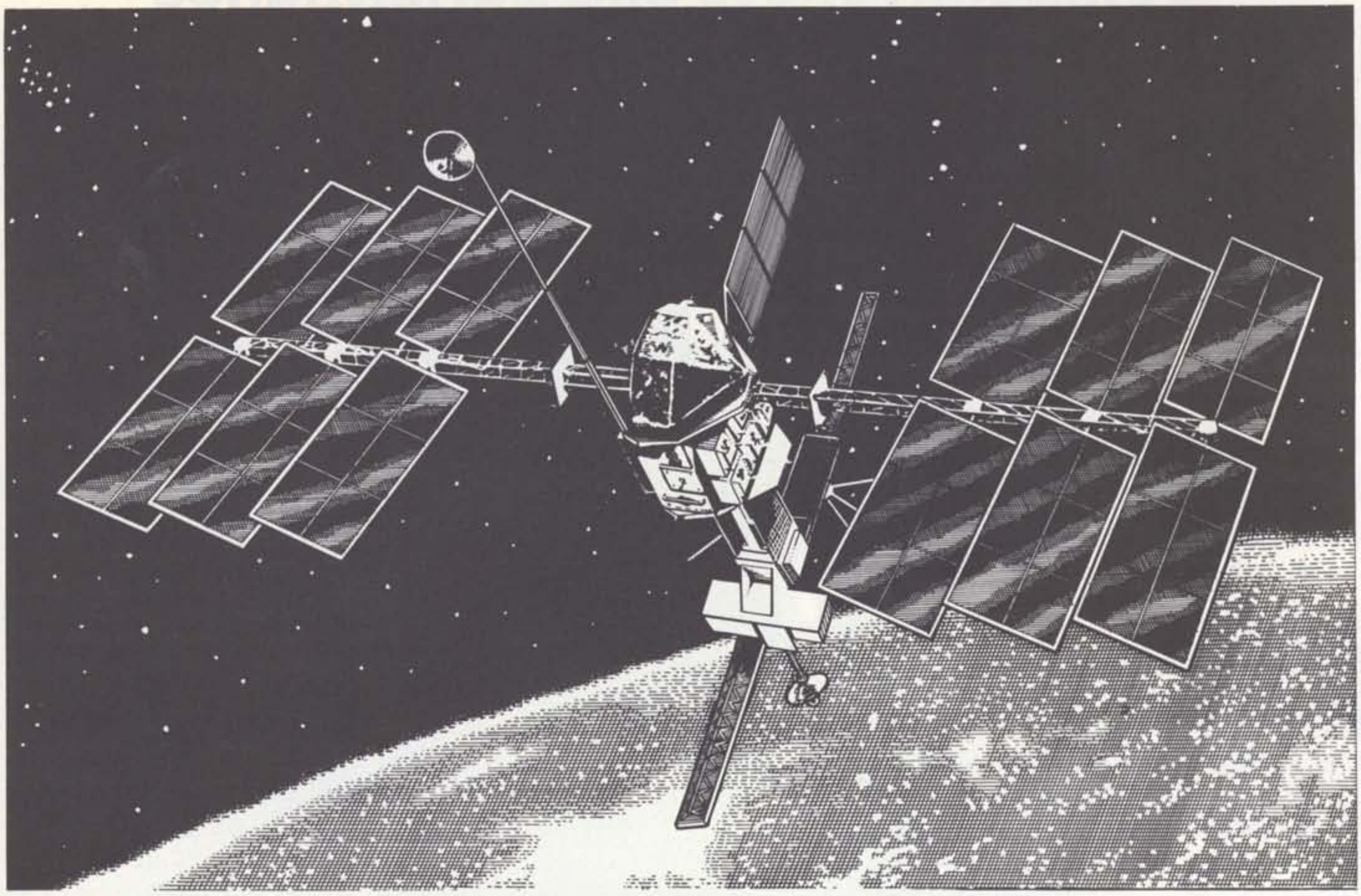

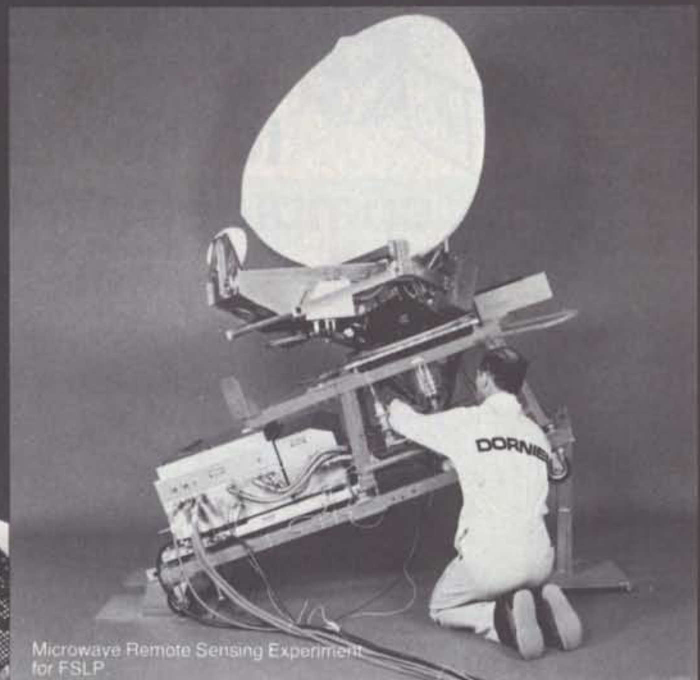

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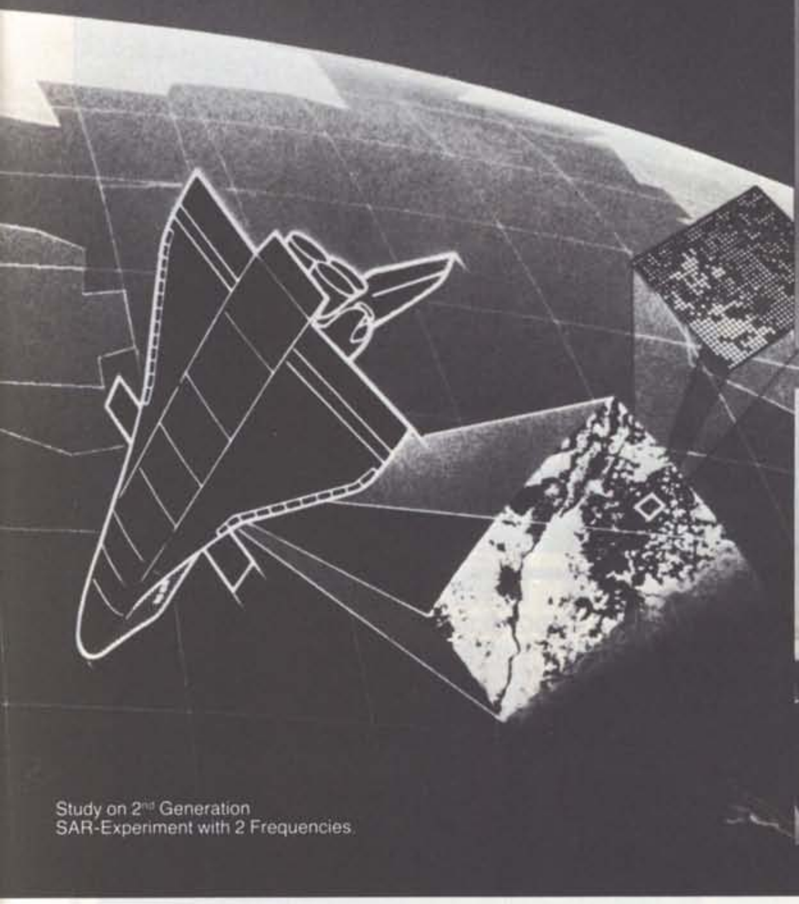

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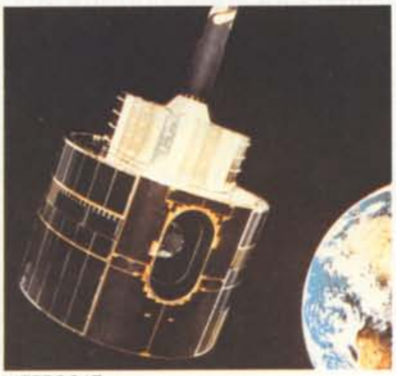

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Message from the Director General

To: Dr. W. Graham, Acting Administrator, NASA

At this time of intense grief, all of us here at ESA share your great loss and express our deepest sympathy with you and everyone at NASA.

Challenger's accident serves as a bitter reminder that along the difficult way we follow in the exploration of space, even with every possible precaution, the risk of accident cannot be entirely excluded.

We pay our deepest respects to Challenger's Astronauts and Crew Members, men and women of the United States, who have given their lives for their country and for the exploration of space.

R. Lüst
Director General, ESA

The Cosmos — As Scientists Understand it Today*

R. Lüst, Director General, European Space Agency, Paris

Introduction
To many members of this audience, the night sky is a familiar sight either from the cockpit or from the windows of today's high-flying commercial aircraft. Some stars, some constellations are like old friends in their apparent steadfast domination of the heavens. Yet I would be prepared to bet that all of us, looking at the individual stars, the constellations, and the bright band of the Milky Way, remain impressed and still feel deep down inside that indescribable emotion as we try to imagine the size of our Universe and ponder its origins.

Throughout history, mankind has found numerous ways of describing and accounting for the Universe as he sees it. The views have varied as certain religions and philosophies have flourished, until in the last few hundred years there have been radical changes in our knowledge, as we have devised instruments for more precise measurement and developed theories to explain what we have measured.

You have kindly invited me to address your Annual General Meeting and to give you a summary, as it were, of how far today's science has probed into the Universe. The title of my address includes the word 'Cosmos', and in a certain way this is both restrictive and yet descriptive of what the scientist hopes to find. Coming, as it does, from the Greek word for order, the Cosmos implies the Universe conceived as an orderly and harmonious system; in fact the opposite of chaos.

What makes the viewpoint of the scientist so distinct? No doubt you know the difference between a politician and a scientist. A scientist, it is said, knows everything about nothing, and a politician knows nothing about everything.

As far as the Universe is concerned, scientists certainly do not know everything yet, and I am not certain whether they ever will. But what is the Cosmos? Can we think of it as ordered and harmonious, or is it just chaos?

The knowledge that scientists have about the Cosmos is based on observations. The results are put together to form a consistent picture which is, wherever possible, compared with theory and hypothesis. There is, moreover, today a strong and vigilant scrutiny of all concepts and theories, which must be in line with the results obtained by the observations to have any chance of achieving recognition.

In earlier times, the only way to observe the Universe, or rather some objects in the Universe, was with the naked eye. With the development of the telescope it was possible not only to observe astronomical objects more closely, but also to penetrate the Universe much more deeply. Galilei was among the first, in the year 1609, to use a telescope of his own making for astronomical observations and to tell us more of the solar system and the Universe beyond.

In the thirties, the scientists learned to detect the radio waves coming from astronomical objects, telling us even more about the Universe. Nowadays, we are no longer hindered by the Earth's atmosphere, which absorbs electromagnetic waves in all other parts of the spectrum. With rockets, satellites and space probes we can observe the Universe from above the Earth's atmosphere in practically all wavelength

* This article is based on an Invited Address to the Annual General Meeting of the International Air Transport Association (IATA).

Figure 1 — The planet Saturn and its moons (photomontage from Voyager images)

regions, and our picture of the Universe has therefore dramatically changed once more. In addition to studying the electromagnetic waves, we have been able, for more than 70 years, to observe and analyse the particles emitted from the objects in the Cosmos, thus filling in more of the gaps in our jigsaw of knowledge.

Let me present to you this picture of the Cosmos, as a scientist sees it, in two steps. Firstly, I would like to invite you on a journey through the Cosmos. After you have seen some of the objects in the Universe, we will consider how the Universe originated and how it has developed. In using these words, I am already hinting that the scientist's viewpoint is that the Cosmos is finite in time and space. It had a beginning, and it has a certain size.

The objects in the Cosmos

So, please 'fasten your seat-belts', and we will start our space voyage. The purser will explain that due to the vast distances we have to cover, we will be travelling at the highest speed possible for any matter or signal, which is the speed of light, 300 000 km/s. Before you have fully settled back in your seat, we have already passed the first landmark on our journey, namely the Moon, which we reach within 1.3 seconds. This is so far the only natural object beyond the Earth that has been visited by man, who set foot on it for the first time in 1969. We pass the two inner planets of Venus and Mercury, after some 8 minutes, very close to the Sun. Then we move on outwards towards Mars, Jupiter, Saturn, Uranus, Neptune and Pluto. On our way we see a comet coming from the outermost part of the solar system, a journey which may have taken it millions of years. After some days we reach the outer region of the solar system, and now we can really relax for a while because even onboard this high-speed spaceship we have to travel for four more years and three months to reach the nearest star. This star and the Sun belong, together with 100 billion other stars, to our Galaxy, a stellar system that has a spiral structure. The stars within the Milky Way circle around a very dense centre, and our Sun is about 33 000 light years from that centre. The space between the stars is not empty, but is filled with gas and, in certain regions, also with dust.

The stars are not uniform in size; some are smaller than the Sun, some are much larger and heavier. There are quite a number of double star systems, in which two stars circle around each other; several of these 'binary systems' can be directly observed from the Earth. Some stars explode from time to time and expel their mass into interstellar space; these are the so-called 'novae' or 'supernovae'. In the year 1054 Chinese astronomers observed such a supernova explosion through a tremendous increase in the brilliance of the star. The remains of this star have been detected recently, while the mass that exploded into space has already been visible for quite a while as a nebula in the sky.

However, our own Milky Way is not alone in the Universe: there are about 100 billion other stellar systems. The two nearest are the Magellanic Clouds and the Andromeda nebula, the latter at a distance of 2 million light years. These

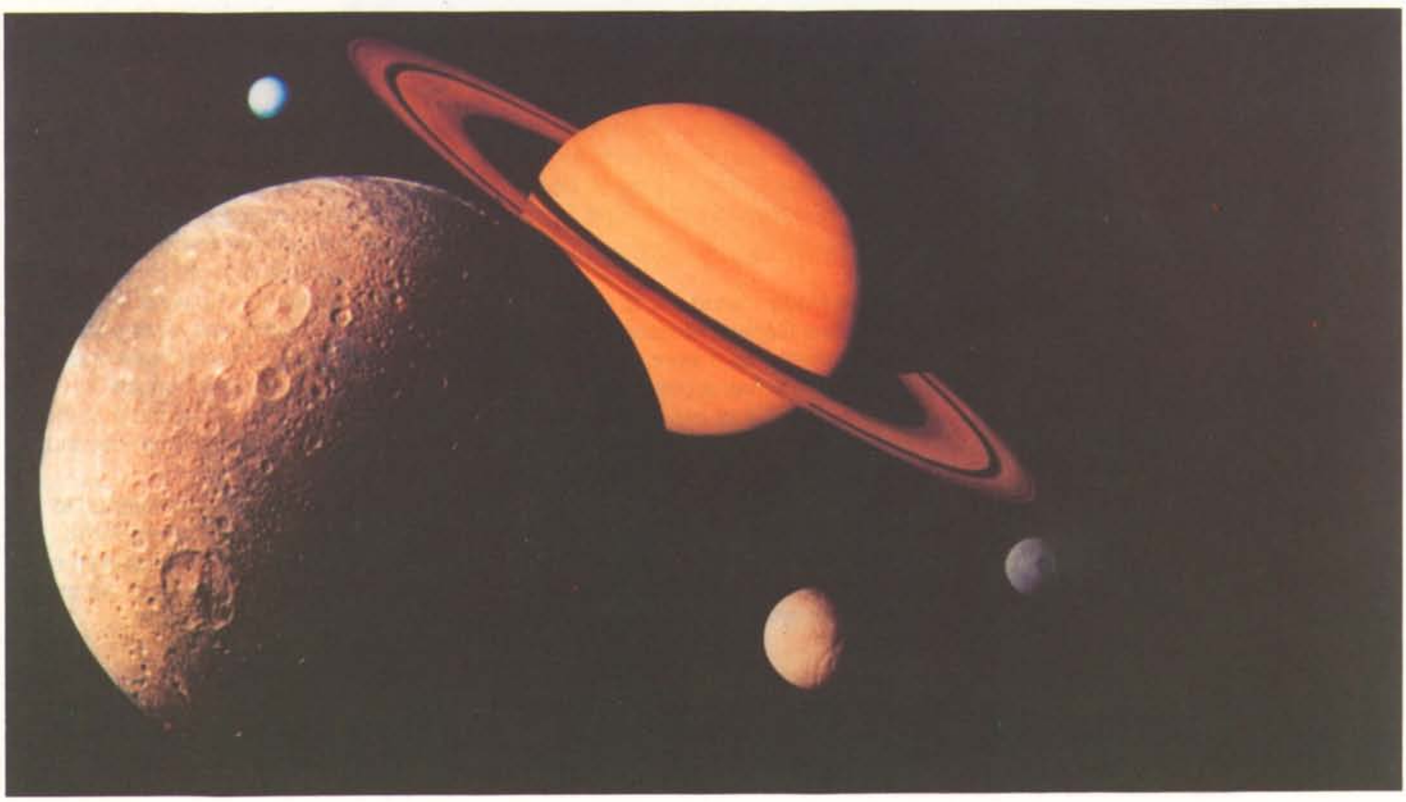
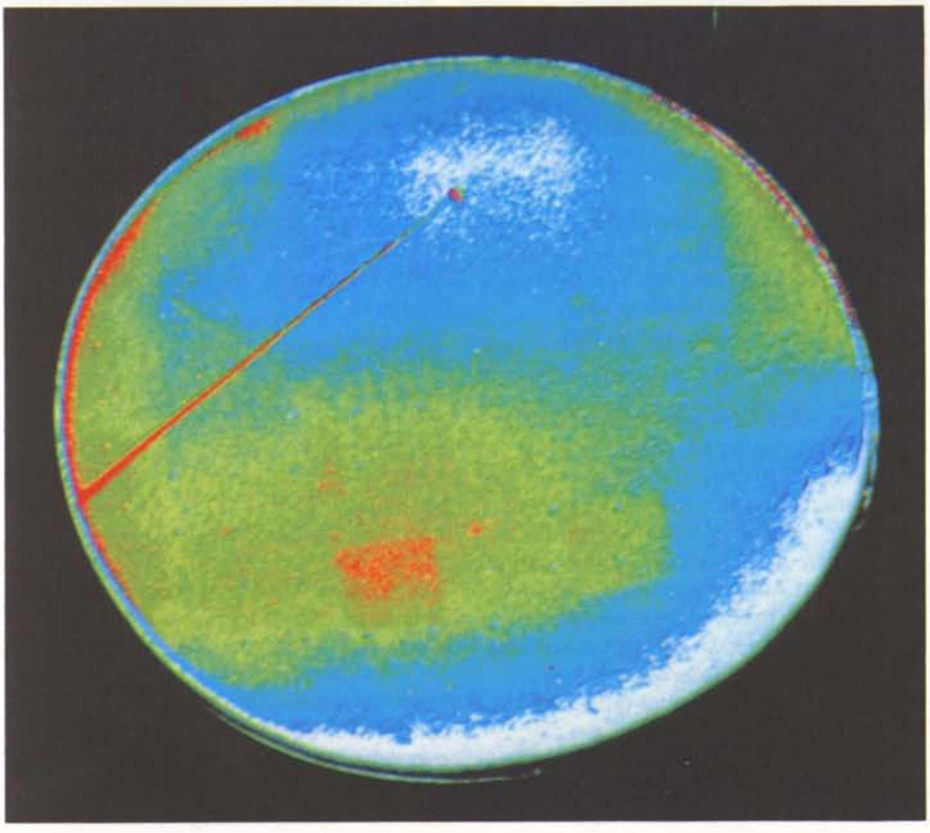


Figure 2 — Spectrum of the Supernova 1980 in the Galaxy NGC 6946



galaxies differ considerably in form. In the 1920s, the American astronomer Hubble detected a remarkable characteristic of these galaxies, namely that they are moving away from us, and the greater the distance they are from us, the faster they appear to move. The velocity of these galaxies can be measured with the help of the so-called 'Doppler effect'. Most of you recognise how the sound of a train changes, i.e. first as it approaches and then as it goes away. You are then experiencing the Doppler effect acoustically. But what does this Doppler effect tell us?

To explain it, we must take another journey, not through space, but through time. Let us assume that you are not the International Air Transport Association, but the International Ocean Transport Association and that you held your meeting about 100 years ago here in Hamburg. If that were the case, everybody from outside Europe would have had to come to Hamburg by boat, taking days or weeks for the journey rather than hours. Your spouse back home would of course have wished to hear from you, and you would have promised to send a letter every day by carrier pigeon. Being a meticulous person, you would have sent off the pigeons at exactly 24-hour intervals.

However, their times of arrival at home would not follow the same pattern. Only those despatched while you were staying in Hamburg would arrive at 24-hour intervals. Those pigeons sent off from the boat on your way to Hamburg would arrive with a time difference of more than 24 hours, while those that flew off on your way home would have returned in intervals shorter than 24 hours. The reason for this is that each of the pigeons would have to fly a longer distance than the one the day before, as your ship travelled towards Hamburg; during your stay in Hamburg each pigeon would have to fly the same distance, while on your way home each would have a shorter distance to travel than the one sent off the day before.

What is valid for the pigeon is also valid for electromagnetic waves, which means that from the changes in the frequency of the waves we can determine the velocity. Thus when an object is moving away from us, the wavelength will be longer, and shifted towards the red part of the spectrum. One therefore speaks about the 'red-shift' of the spectral lines absorbed in the galaxies. The measured red-shift in the wavelength is a direct measure of their velocity. Since there is — according to the observations made by Hubble — a unique relation between the velocity and the distance of the galaxies, the observed velocity gives us also the distances of the galaxies. The most distant galaxy that has been observed so far is about 13 billion light years away, but we can already observe light from objects at distances of about 16 billion light years.

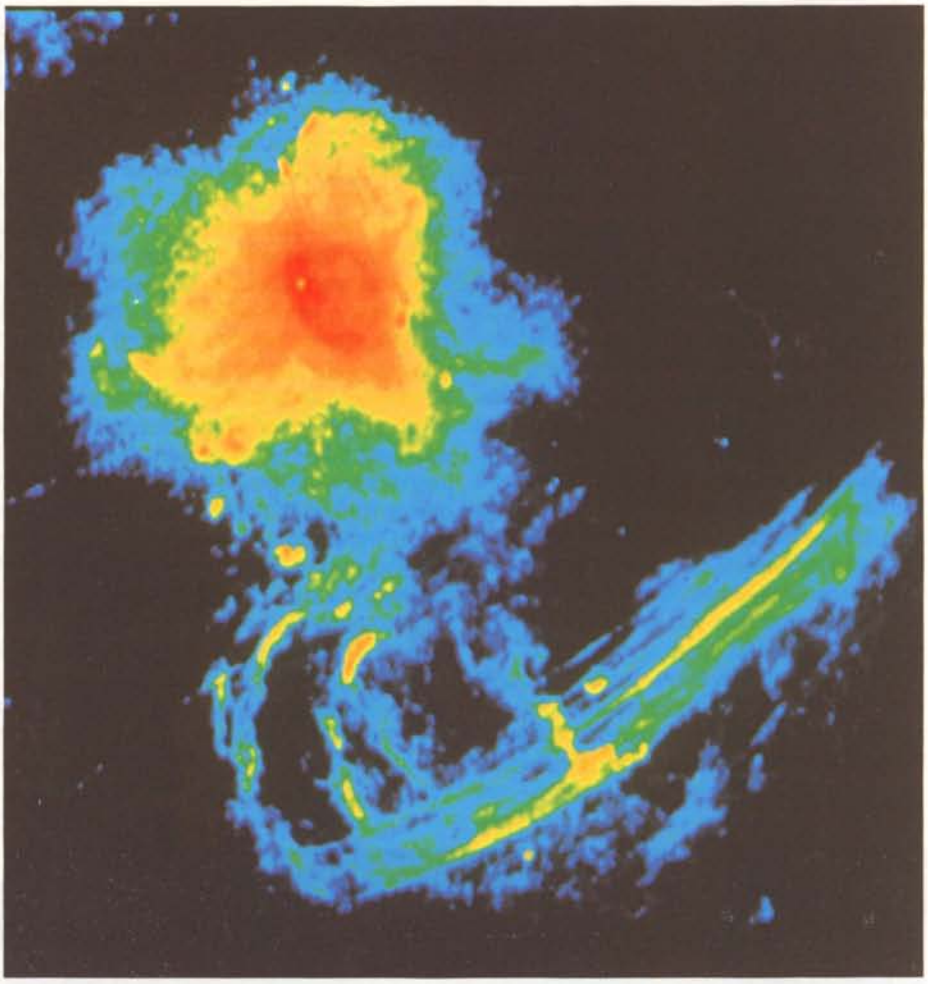
Although we observe that all galaxies are moving away from us, it would be wrong to believe that we are at the centre of the Cosmos. Let me try to explain this by a further comparison. We discard our executive role, don an apron, and enter the kitchen, a latter-day Escoffier, to bake a cake with raisins in it. If the temperature is just right, the cake expands and each raisin becomes more distant from all of the others. Moreover, those that are more distant are moving away with an even greater velocity. Each raisin observes this for itself, but still no one raisin can conclude from this that it is located in the middle of the cake. The same holds true for the galaxies in the Cosmos. But what can we learn from this observed expansion that will improve our understanding of the Cosmos?

The history of the Cosmos

Let's now wake up from our imaginary trip through the Universe and consider what we know about its history. What we know is based not on fiction or belief, but is due to comparatively recent observations. We have indeed discovered quite a lot about the history of our Cosmos in the last few decades.

The observed expansion of the Universe, as seen in the velocities of the distant galaxies, gives us an important clue to its history. Since we know their velocities and their distances, we can calculate by

Figure 3 — Radio-continuum observation of the source Sagittarius A



means of simple mathematics the time that the galaxies have taken to travel from their common starting point. Our calculations suggest that the starting time was 20 billion years ago.

If the Universe has existed for an infinite time, then we could go backwards, jumping over billions and billions of years without ever coming nearer to the beginning of the Universe. One could say quite rightly that our Universe never had a beginning, that it has always existed. But with the observation of the expansion of galaxies, one has an indication that there was an occurrence 20 billion years ago which might have marked the beginning of the Universe. Even though it happened a very long time ago, it delineated a finite period.

Of course this new knowledge did not suit everybody, and there have been attempts to avoid interpreting this observation as the beginning of the Universe. Some fascinating theories have been developed to demonstrate that our Universe had no beginning and has no limits, the best of which is the so-called 'steady-state theory'. There was, however, one physicist of Russian origin who eventually went to live in the United States, whose name was George Gamow. He took Hubble's observation of the expanding Universe at face value. In 1940, Gamow had already developed the theory of the Big Bang. At the time of the latter, matter must have been in an extremely dense state, being composed of hydrogen atoms from which all other elements have been built during and after the gigantic explosion.

However, if at the Big Bang the temperature in the Universe had been very high — millions of degrees — which was the conclusion drawn by Gamow and his collaborators in 1949, the material thrown out in the explosion must have been extremely hot, and the accompanying radiation must have been very intense, and this radiation should therefore still exist in the Universe. As the Universe has expanded, this radiation must have cooled down. Gamow believed at that time that this radiation would not have an important role to play in the Universe during our time, since by now it would be of very low intensity and at rather long wavelengths. Not too many physicists and astronomers took Gamow's theory seriously, and nobody really devoted very much thought to this radiation's existence.

Thirty-five years later two physicists, Arno Penzias and Robert W. Wilson, were interested in the development of very sensitive antennas for radio and television reception. They were trying to test their antennas by directing them to that part of the sky from which they would not expect any signals in the very-short-wavelength radio spectrum. However, to their surprise they detected a radiation which they received not only from that particular direction, but from all parts of the sky, and which had an intensity corresponding to a temperature of about 3.5 Kelvin, i.e. a temperature near the absolute zero point of —273°C. Very soon it became clear that this radiation must be the remnant of the radiation from the Big Bang.

In the meantime many more measurements have confirmed the observations of Penzias and Wilson, whose work on this background radiation earned them the Nobel Prize in 1978. The observations in support of, as well as the theory of, the Big Bang have been refined, and now we know in much greater detail what happened in the very early phases of the Universe, even the events of the first seconds and minutes.

From the expanding material, galaxies condensed, and within the galaxies stars condensed and even planetary systems. The stars evolved and some burned up their atomic fuel, existing now, after

Figure 4 — X-ray image of the Sun taken from Skylab

gigantic supernova explosions, as white dwarfs, neutron stars or black holes. Others, like our Sun, which has an age of about 4.5 billion years, still have enough fuel to live for several billion years. Provided we do not destroy the Earth ourselves first, our Sun will give us light and energy here on Earth for many thousands of generations to come.

I have tried to give you a brief glimpse of our Cosmos and how we now believe it developed, but it is almost impossible to get a true feeling for the time that has elapsed since the Big Bang, 20 billion years ago. Perhaps we can reduce it to proportions that we can understand if we imagine for a moment that the whole history of the Universe took place within one year. It is now New Year's eve, and we are waiting for the clock to strike midnight.

We look back over the year. Twelve months ago everything was very dense. The Big Bang occurs. In the fraction of a second on 1 January, matter with the most simple atomic nuclei has its origins. At the end of January, the galaxies are condensing, and the first stars within them. About the middle of August, a spiral cloud has condensed with gas and dust, and this is the origin of our solar system, and with it the Earth. At the beginning of October the first algae develop, and in the next two months flora and fauna develop in the oceans in a large multitude. On 16 December the first vertebrates are seen and on 19 December the plants conquer the continents. On 20 December the continents are covered by forests, and this generates an oxygen-rich atmosphere. The ultraviolet light from the Sun is now unable to reach the Earth's surface and more complex forms of life become possible. On 24 December the first reptiles appear, on 27 December the birds, and on 28 and 29 December the birds, together with the mammals, hold sway on Earth.

During the night of 31 December we witness the origin of the human race. With 20 generations passing every second, mankind takes only one day to develop. Two minutes before midnight we discover fire, five seconds before midnight Christ is born. Within these five seconds modern civilisation, with all of its highlights and tragedies, manifests itself.

We do not know what will happen as the bell strikes the hour. Will it toll for man's demise, or will it herald new horizons?

Certainly no scientist can give you an answer.

Heading for The Giotto Encounter with Comet Halley

R.E. Münch, Orbit Attitude Division, European Space Operations Centre (ESOC), Darmstadt, Germany

On 14 March 1986 at 00:00 h UT, the Giotto spacecraft will fly by Comet Halley at a distance of less than 500 km. Numerous preparations for this event have been undertaken, many of which have been recounted in earlier Bulletin issues. This article concentrates on the flight-dynamics efforts supporting this historic rendezvous in deep space.

Introduction
In the context of ESA spacecraft missions, 'flight dynamics' embraces the determination and control of a spacecraft's dynamical state throughout a mission, taking into account the environmental conditions prevailing in space and the characteristics of the spacecraft itself. In the case of Giotto, this translates into several discrete tasks that are necessary to ensure that the spacecraft passes the comet at the desired distance and with the correct orientation for a successful scientific data take.

For this goal to be achieved, the orbital movements of both the spacecraft and the comet must first be determined, and then predicted until the moment of the encounter, with the required accuracy. Only then can one plan the necessary orbital correction manoeuvres to be executed using the spacecraft's propulsion system. The spacecraft's attitude must be determined and controlled so that its antenna always points towards the Earth for communications purposes and so that all spacecraft power and thermal constraints are honoured (Fig. 1).

Determination/prediction of Giotto's orbit
As Giotto began its eight-month voyage to encounter Halley's Comet, ESA's

Figure 1 — The Giotto spacecraft

Figure 2 — The Giotto ground station antenna at Weilheim, part of ESA's Deep-Space Tracking System (DSTS)

newly-developed Deep-Space Tracking System (DSTS) began operating. During July, tracking support was also provided by the NASA Deep-Space Network (DSN), with the primary objective of validating the DSTS. Giotto's orbit, as computed by NASA/Jet Propulsion Laboratory (JPL), under a consultancy agreement, was compared with the results from ESA-developed orbit-determination software. These checks soon established the correct functioning of the ESA hardware and software. Since then, except for a two-week DSN tracking campaign in September 1985, Giotto's tracking and orbit control has been conducted totally independently using the ESA navigation system.

The main purpose of the September campaign was to improve our knowledge of the exact locations of the ESA DSTS ground stations, Carnarvon in Western Australia and Weilheim in Germany (Fig. 2). Radiometric signals are sent and received via a 15 m antenna at Carnarvon and a 30 m antenna at Weilheim. An accurate measure of the signal round-trip time provides the range to the spacecraft and the range rate, i.e. the velocity of Giotto relative to the ground station, is computed from the Doppler frequency shift in the downlink signal relative to the uplink signal.

Carnarvon is the prime station and tracking data are obtained every day during the period of about 10 h when the spacecraft is visible to the station. Weilheim is used two days per week and has somewhat shorter passes. At both stations, range measurements are initially taken every 10 s when Giotto is visible, and 10 range-rate measurements are taken every second. Preprocessing of this data consists of compression and smoothing, after which a typical output is a range-rate measurement every 10 min. During the mission, the range will eventually be 143 million km and the range rate is typically 10—20 km/s. The DSTS provides measurements of these quantities with accuracies, after compression and smoothing, of better than 10 m in range and 1 mm/s in range rate.

The tracking data are transmitted to ESOC, where they are processed by navigation experts using purpose-designed computer programs. The result is a highly accurate determination of the spacecraft's orbit. Comparison of successive orbit determinations has shown that, for most of the cruise phase, Giotto's position on its heliocentric trajectory has been pinpointed with an uncertainty of less than 50 km, and its velocity to an accuracy of better than 0.1 m/s.

Since the orbital determination is extremely sensitive to the assumed locations of the ground stations, these accuracy figures apply only after the initial improvement in DSTS station co-ordinates. The position of Carnarvon had in fact to be changed by 5 m, and that of Weilheim by 8 m, compared with the pre-launch values assumed.

Special techniques had also to be employed in the orbit-determination process to improve the modelling of dynamical influences and thereby improve the prediction capability. Solar radiation pressure and manoeuvre calibration both fall into this category. Radiation pressure, for example, acting over the duration of the Giotto mission, causes the spacecraft's position at encounter to be about 6000 km away from where it would be if the radiation were not present. The calibration of the models, which could only be carried out during the period before the daily attitude manoeuvres started in November 1985, will now be exploited to help meet the stringent navigation requirements that must be satisfied to ensure a successful encounter with the comet.

Determination/prediction of the comet's orbit

An even more challenging problem is precise determination of the orbit of the comet. Here, reliance has to be placed on observations of a completely different kind.

Since 1982, professional and amateur astronomers all over the World have been pointing their telescopes at the famous visitor. Observations are usually made in the visible region of the spectrum, but some are also made in the infrared and

Figure 3 — Photographic plate of Comet Halley in 1910 taken at the Cordoba Observatory in Argentina

ultraviolet, the latter needing an observatory in space such as the International Ultraviolet Explorer (IUE) satellite.

Of special interest to the Giotto flight-dynamics team are astrometric observations, which are accurate measurements of the comet's position on the celestial sphere. They constitute the fundamental data needed to improve the accuracy of the determination of the comet's trajectory around the Sun. Data from previous apparitions (Fig. 3) have to be used as well as data from the current one. For almost all new observations, ESA has to depend upon the skill and dedication of the individual observers and the efficiency of the Astrometry Network of the International Halley Watch (IHW), which has the task of co-ordinating all of the observations.

More than 100 different observatories, located in all parts of the World, have provided such observations. At the peak of these efforts, in late 1985, more than 200 new measurements of the comet's position were being reported every week.

Two days before Christmas 1985, Comet Halley crossed the equator travelling south. Even so, during January 1986, it was still better placed for observation from the northern hemisphere. However, with the new year came a dramatic decrease in the abundance of observations just at the time when they are most needed for the final navigation of Giotto. The reason is that, on 6 February, three days before perihelion passage, when the comet reaches its closest point to the Sun, Halley will move behind the Sun and will not be visible from Earth. Even within two or three weeks of this date, the visibility conditions are very unfavourable. Observations must be made in twilight — at dusk in January and dawn in late February/early March — and in a direction close to the horizon. Few telescopes are designed to operate with such low elevation angles.

During this difficult observing period, some observations are being provided via the IHW. However, arrangements have also been made directly with some key observatories for supplying accurate observations with the minimum of delay between the time of exposure and reception at ESOC of the reduced positions.

In January, we relied heavily on observations from the Calar Alto Observatory in Spain (Fig. 4), run by the Max-Planck-Institut für Astronomie in Heidelberg. During late February and early March, when the comet will be visible only from the southern hemisphere, we are looking forward to receiving observations particularly from the European Southern Observatory in La Silla, Chile (Fig. 5); the UK Schmidt telescope at Siding Spring in Australia; the Mt. John University Observatory in New Zealand and from Perth Observatory in Australia.

The 'unknown' comet and the need to model the unknown

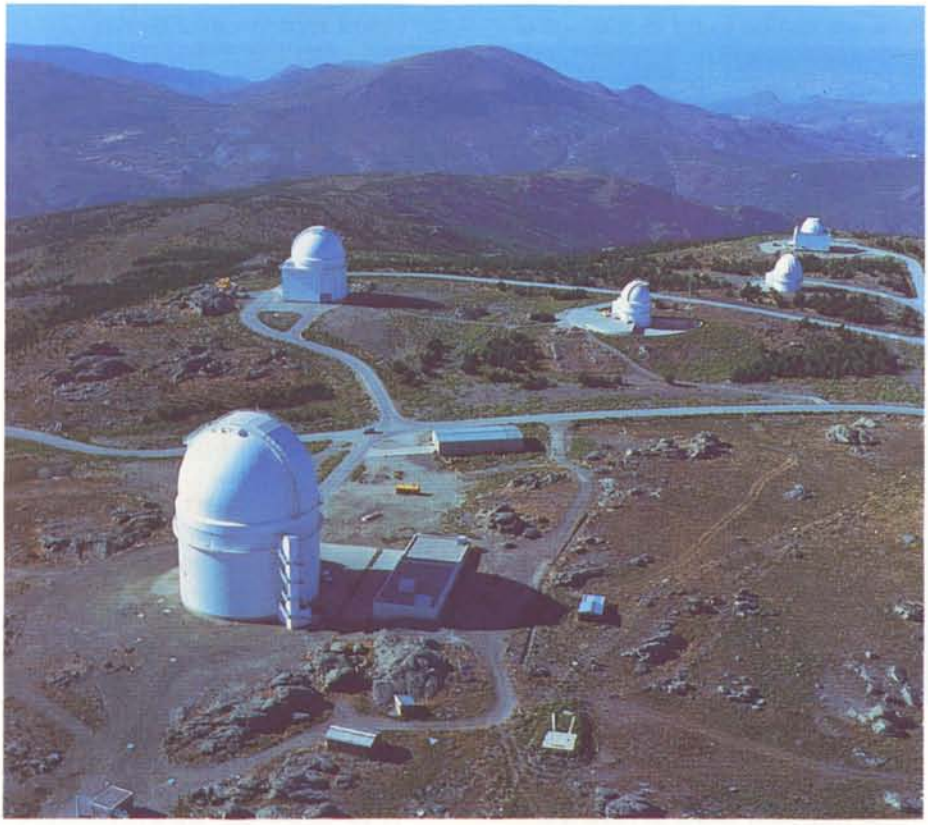
As early as the 1830s, the German mathematician and astronomer F.W. Bessel pointed out that the motion of Halley's Comet is very different from the motion of other bodies in the solar system such as planets and asteroids. Additional forces, not originating from the gravity forces in the solar system, act on the comet in such a way that its period of revolution around the Sun is modified by an average of four days after each 76-year revolution, in addition to the planetary-induced disturbances. These extra forces act over an interval of approximately four years when the comet is closest to the Sun. They are assumed to originate from a rocket-like effect due to the water evaporation and dust emission that takes place under the Sun's influence.

This material, in the visible parts of the comet, in its coma and its tail, originates from the almost always invisible nucleus, which is assumed to be a conglomerate

Figure 4 — The Observatory of the Max-Planck-Institut für Astronomie (Heidelberg) at Calar Alto in Spain's Sierra Nevada

Figure 5 — The ESO Observatory in the mountains of La Silla in Chile, at a height of 2600 m

Figure 6 — Temperature distribution on the surface of a comet's nucleus, as calculated with a thermal model for a slowly rotating body



of dust and ice. The ice sublimates under the influence of solar radiation and carries away the dust. It is this outgassing that influences the motion of the nucleus and makes the orbit determination all the more difficult.

A quantitative description of the dust-production and outgassing forces must be based on modelling of the thermal behaviour of such an icy mass as it progresses along its orbit, subject to a number of assumptions regarding its physical, chemical and dynamical properties. The prime output of such a 'thermal model' is the temperature distribution on the comet's surface as a function of its orbital position. Figure 6 shows the results of a typical ESOC computation in which isotherms (°K) are assigned to the surface of a rotating spherical comet. A dramatic decrease in temperature occurs in a strip on the comet's surface which moves as the comet rotates with a period of a few hours. High temperature gradients produce high stresses and these may in turn be responsible for the 'erosion' and jets.

What happens to the material that leaves the nucleus is also very important for the flight-dynamics assessment. Here the accuracy of astrometric measurements and the distribution of especially heavy

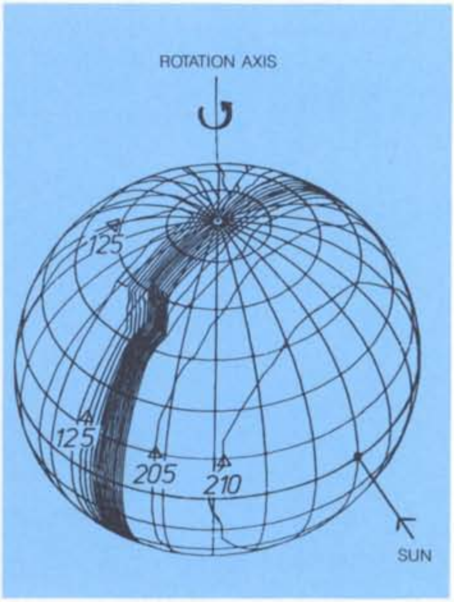


Figure 7 — Two of the famous drawings of the German/Russian astronomer Struve, showing Comet Halley as it appeared in 1835

Figure 8 — Two illustrations of dust-jet structures on photographic plates taken at Cordoba Observatory in 1910:
(a) black and white photographic plate
(b) colour-enhanced picture digitised from the photographic plate

dust particles play an important role. The ejection of dust from the cometary nucleus is anisotropic and the resulting spatial density variations are visible as prominent, fan-shaped coma features or cometary jets. Early information about these jets can be found in drawings of the apparition in 1835; excellent examples can be found in the book of observations by the German/Russian astronomer Struve (Fig. 7). Photographic images are available from the 1910 apparition that show the rapid evolution of these jets from night to night. Typically, they begin as a spiral that unwinds from the nucleus and develops into an expanding envelope in the outer coma. The dust content in a jet (Fig. 8) must be one or two orders of magnitude higher than in the background. The motion of the particles is governed by their initial velocity of ejection and solar radiation pressure. Jets frequently appear as spirals because of the rotation of the nucleus.

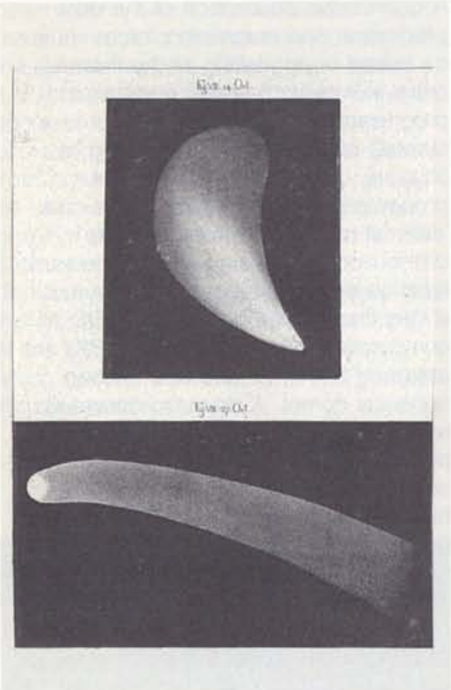


Figure 9 shows, in a series of simulated images, the typical temporal evolution of two hypothetical jets. Aside from the location of the jets on the nucleus, all other parameters in this model simulation are thought to be realistic and reflect our best current knowledge of the cometary nucleus and its environment.

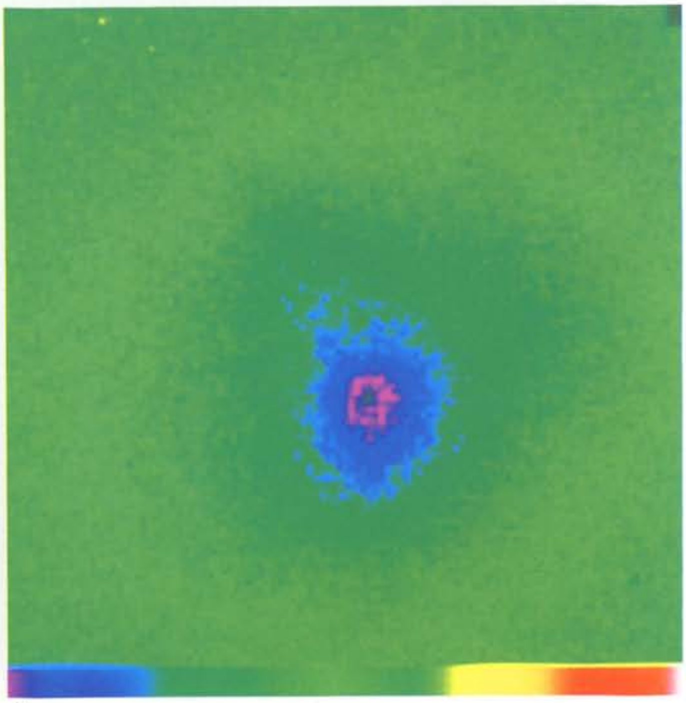
These modelling efforts all have one common goal, namely to improve the accuracy with which the comet's trajectory can be determined. This is of the utmost importance for Giotto's planned close flyby, in that the comet's position must be predicted with the utmost precision at the time of the encounter, when astronomers will have difficulty in locating the exact position of the nucleus and where the nongravitational forces have their greatest influence.

The influences of spacecraft design

Throughout its interplanetary cruise to Halley's Comet, the spinning spacecraft's attitude must satisfy several constraints. Firstly, the despun high-gain antenna, mounted at 44.2° to the spin axis, must be kept Earth-pointing to maintain the telecommunications link with the spacecraft. Secondly, the spacecraft's solar aspect angle has to be kept within certain limits for the body-mounted solar arrays to generate enough power and to ensure that the spacecraft does not heat up or cool down beyond the allowed temperature limits. The green lines in Figure 10 define the communications band, the red curves the power/thermal constraints.

The operations to be performed as a result of these constraints consist of attitude-correction manoeuvres that turn

8a



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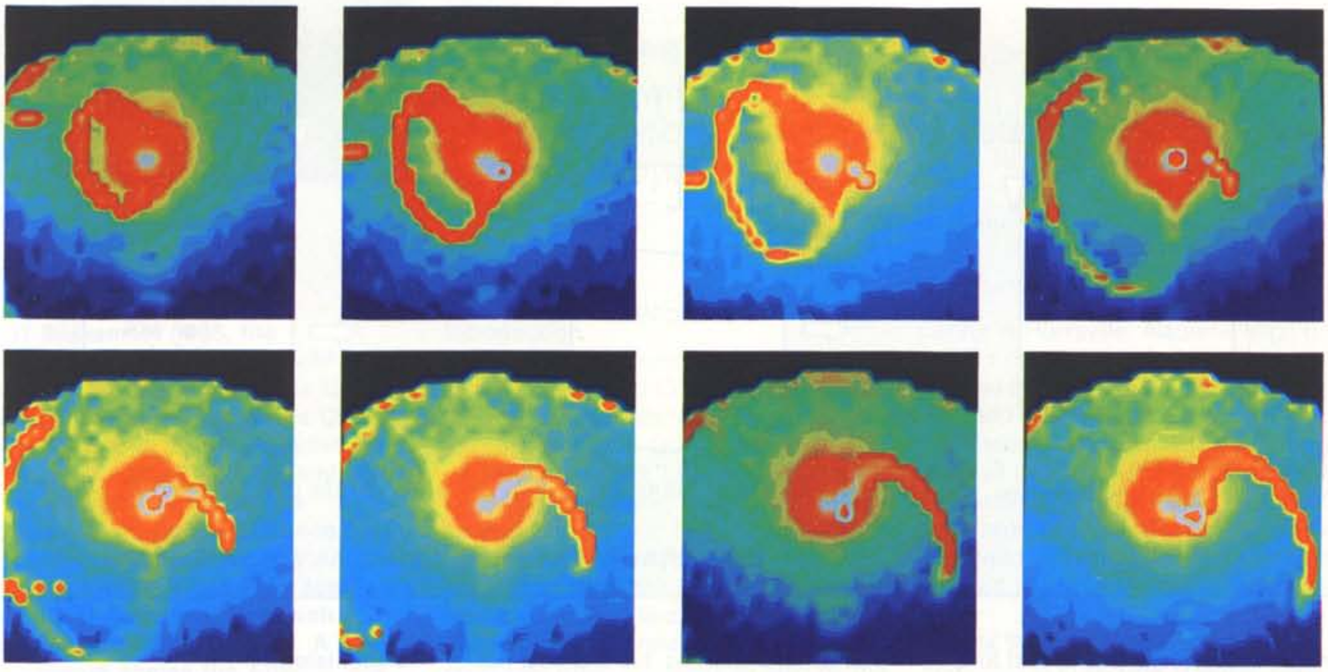


Figure 9 — Time history (9 h difference between frames) of a dust jet's evolution simulated with ESOC models and facilities. The colour-enhanced pictures show the dying-out of one jet, the creation of another, and its evolution with time

the spacecraft's spin axis frequently in such a way that all the constraints are satisfied, whilst at the same time fuel consumption throughout the cruise phase is minimised. A total of 120 manoeuvres, ranging from 0.8° to 14° in amplitude, are necessary, only infrequently in the early cruise phase, but daily as the encounter date is approached.

Aside from these attitude manoeuvres, key orbital manoeuvres critical to Giotto's navigation to the desired flyby position have to be performed. For these manoeuvres, the spacecraft's propulsion system is used, consisting of a solid-propellant perigee kick motor and hydrazine thrusters used for both attitude and orbit manoeuvres.

The firing of the kick motor, which took place on 3 July 1985 to transfer the spacecraft from an Earth orbit to an orbit around the Sun, was very accurate. The first orbit determinations after the firing indicated that only a very small adjustment was required to correct for the firing dispersion. In view of the uncertainty in the comet's prediction position at encounter, it was decided to forego this additional manoeuvring effort

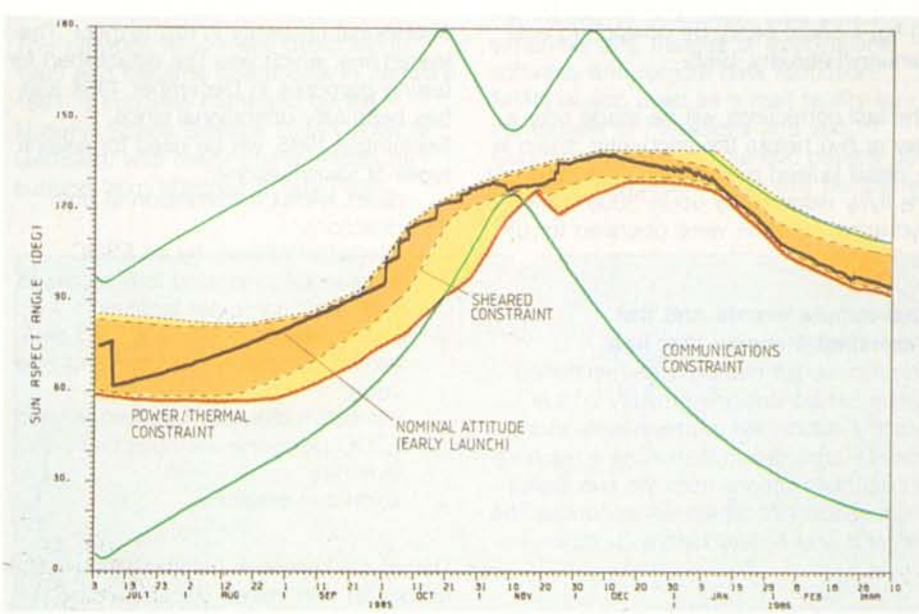


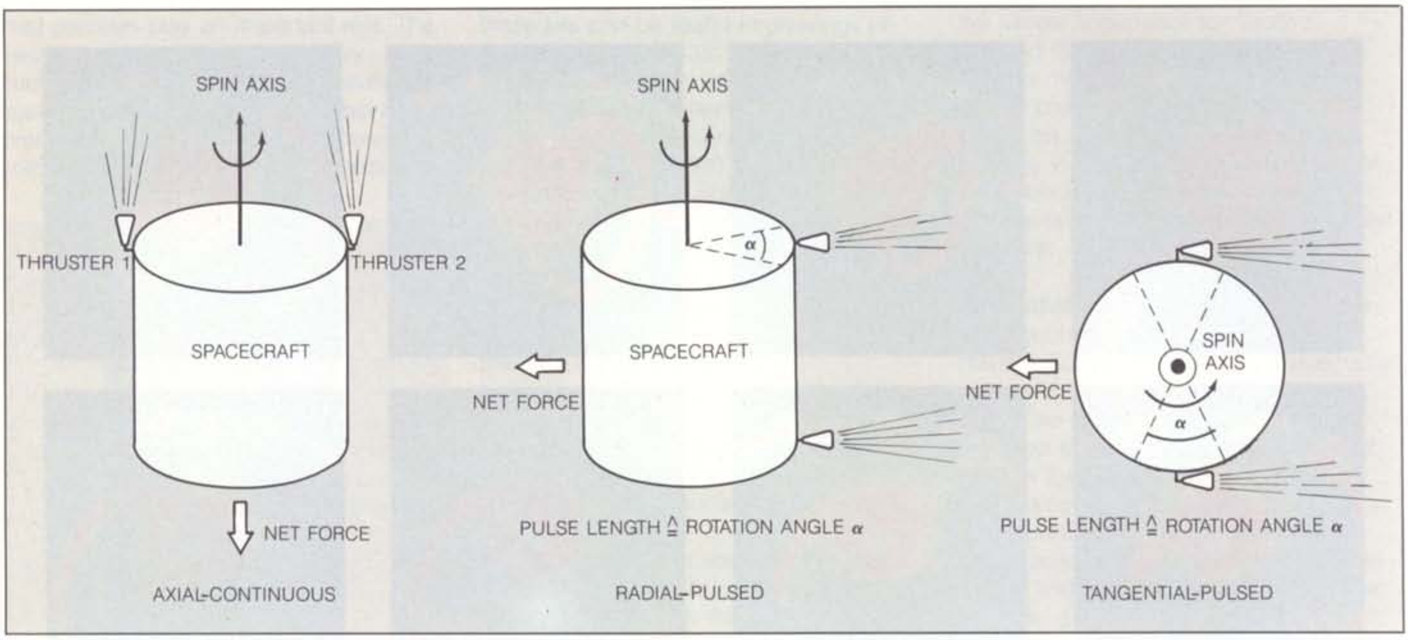
Figure 10 — The spacecraft attitude strategy, showing the corridor through which the attitude has to be manoeuvred in order to arrive safely at encounter

at that stage.

Only after further comet observations became available was a first trajectory correction manoeuvre performed, on 26 August 1985. By then the uncertainty in the predicted comet position at encounter on 14 March 1986 was estimated as 5—10 000 km, compared with the predicted flyby distance of about 120 000 km. The manoeuvre was made as a 'radial pulsed burn' of 7.4 m/s, and the predicted effect was to reduce the flyby distance to less than 4000 km (Fig. 11).

No more trajectory corrections were to be made until the comet's position on 14

Figure 11 — Realisation of different orbital-manoeuvre modes by using gas-jet activations for a spinning spacecraft



March 1986 could be established to a higher accuracy. The sooner a correction is made, the smaller it will be, of course, but with the fuel reserves available (ca. 61 kg) it could easily be postponed until January/February 1986.

The last corrections will be made only a day or two before the encounter, again in a 'radial pulsed mode'. This could change the flyby distance by up to 3000 km if the hydrazine thrusters were operated for up to 16 h.

Last-minute events and the Darmstadt/Moscow 'hot line'

The last-minute manoeuvres mentioned above will be designed mainly on the basis of substantial improvements in the comet's orbit determination as a result of optical observations from the two Soviet Vega spacecraft, which will encounter the comet 3 and 5 days before Giotto's arrival.

As such an improvement can only be achieved if the accuracy of the orbital determinations for the Vega spacecraft themselves is very high, NASA is performing very precise tracking of the Soviet spacecraft. These international 'Pathfinder' activities hinge on efficient data exchange between the three Agencies involved — NASA, ESA and Intercosmos.

The communications 'hot line' that has been established between ESOC in Darmstadt and the Institute for Space Research (IKI) in Moscow is an operational necessity in this respect. The leased line, which was first established for testing purposes in December 1984 and has been fully operational since September 1985, will be used for several types of transmissions:

- direct telefax transmission in both directions
- interactive access, by an ESOC representative located in Moscow, to the ESOC computer facilities
- transfer of computer-generated data from Darmstadt to Moscow and vice versa
- interactive dialogue between IKI and ESOC personnel via computer terminals
- voice conversation.

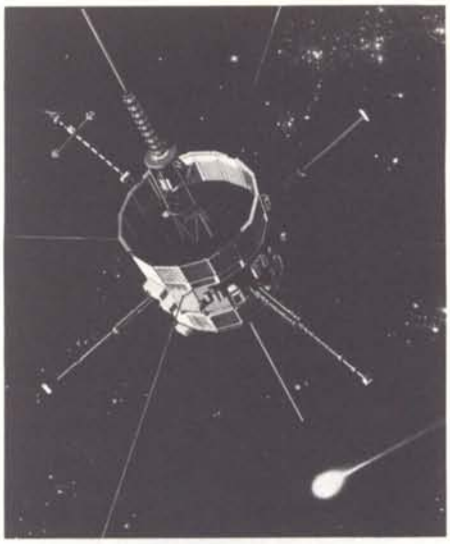
During the last week before Giotto's encounter with Halley, the link will be used extensively for the transmission of the Vega observations from Moscow to Darmstadt, and for dialogue between the Soviet and European flight-dynamics teams. As data transfer will also be taking place between NASA and ESOC, the latter
is performing a coordinating role for the 'Pathfinder'-related data transfer, from its Communications Control Centre.

Conclusion

The several challenging aspects of the Giotto flight-dynamics effort that have been outlined serve to illustrate the complexity of the spacecraft navigation problem for this and other complex missions and its interrelationship with the many other scientific and technical disciplines involved within ESA and industry in designing and undertaking a successful mission.

Acknowledgement

This article has been produced in ESOC's Orbit Attitude Division with the particular help of P. de Broeck, J. Fertig, F. Hechler, P. Mahr, L. Massonne, T.A. Morley and M. Rosengren, whose contributions are gratefully acknowledged.



Near-Real-Time Data Transmission during the ICE—Comet Giacobini-Zinner Encounter

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N. v.d. Heijden & E. Jabs, ESA Computer Department, ESOC, Darmstadt, Germany
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On 11 September 1985, the International Cometary Explorer (ICE) spacecraft, formerly known as ISEE-3, passed through the tail of the Comet Giacobini-Zinner (see ESA Bulletin No.44,pp.32—39). Rapid dissemination and analysis of data from the encounter were greatly enhanced by the use of the Space Physics Analysis Network (SPAN), which links together many US Universities, Research Institutes and NASA Centers. A link to this network across the Atlantic was established for the first time to support Investigators involved in a European experiment onboard the ICE spacecraft.

Introduction

During the recent encounter between the ICE spacecraft and Comet Giacobini-Zinner, scientific data were transferred in near-real-time from Goddard Space Flight Center in Maryland, USA, to ESOC in Darmstadt, Germany, using the SPAN network and then on to ESTEC in The Netherlands for analysis. Processed data in the form of graphs were subsequently sent back to Goddard, using facsimile transmission, for presentation in the post-encounter Press Conferences held on the day of cometary encounter and two days afterwards.

This network, which was designed in 1980 and became operational in January 1981, is currently managed by the National Space Science Data Center at Goddard, with major communications support from Marshall Space Flight Center in Huntsville, Alabama (Fig. 1). Current membership includes institutes such as the NSSDC, NASA/Marshall and Goddard Space Flight Centers, NASA/Jet Propulsion Laboratory, Los Alamos National Laboratory, The Applied Physics Laboratory, The NASA Spacelab Mission Integration and Planning System, TRW, Lockheed, and several major Universities involved in space physics.

A Data System Users Working Group has been set up to provide scientific user guidance in the future development of the network, which is used extensively for the transfer of processed data between experimenters, transfer of applications software, and remote data reduction. SPAN is also used as a mail facility for the transfer of messages and text. Documents such as scientific papers can be easily prepared at one site, transferred

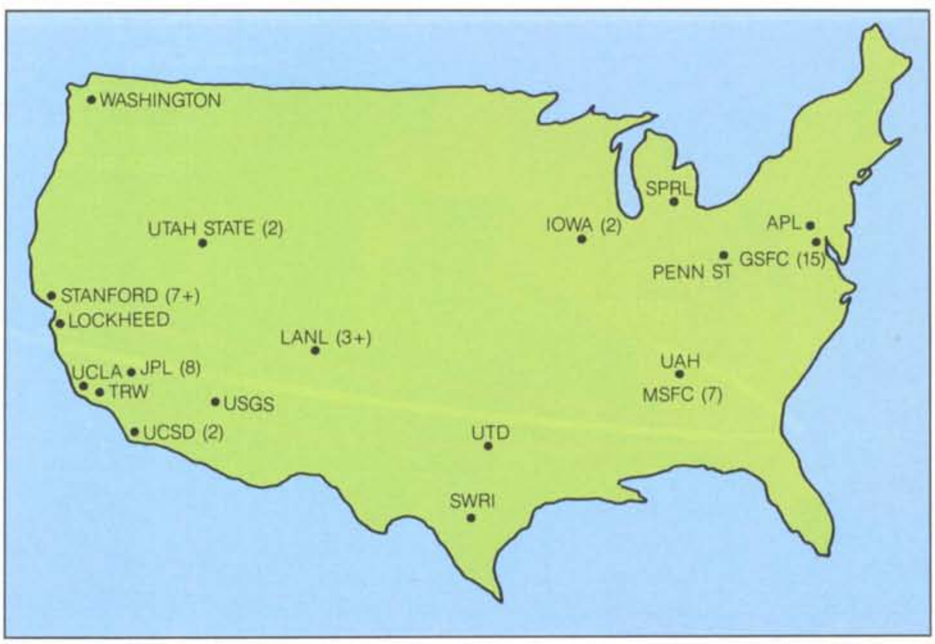


Figure 1 — Map of the USA showing the locations of the nodes of the Space Physics Analysis Network (SPAN) as of July 1985

Figure 2 — Data links established between the US and Europe during the ICE spacecraft encounter with Comet Giacobini-Zinner

to another for editing, and then forwarded to yet another site for printing or publication. In fact, this article was initially prepared on the ESOC node edited by J. Green on a US SPAN node and returned to ESTEC the next day.

In 1984, an ESA Working Group on a possible European Space Science Data Centre, including representatives from the Space Science Department of ESA, ESOC and ESRIN, decided to use the opportunity of the forthcoming ICE Giacobini-Zinner Comet encounter for the ESA Computer Department at ESOC to set up a pilot project to install a link to SPAN and so gain some experience in the use of a network with real-time data. By this time many of the US ICE investigators had already approved plans for using SPAN for the encounter data transmission and analysis.

The pilot project required the collection of data from the joint ESA Space Science Department/Imperial College London/SRL, Utrecht experiment on ICE by the Information Processing Division at Goddard, pre-processing in their Laboratory for Extraterrestrial Physics (LEP), transmission to ESTEC for data processing, then return transmission of results to Goddard for use during the post-encounter Press Conferences.

Because the SPAN uses almost exclusively VAX computers networked together, the obvious choice was to use the VAX at ESOC as the European node. An X.25 gateway was installed at ESOC to enable the ESOC VAX to be connected via the German PTT's packet-switched network to the trans-Atlantic carrier, GTE-Telenet. A similar gateway was installed on a SPAN node in the Space Science Laboratory at Marshall Space Flight Center to enable their computer to form a network bridge to GTE-Telenet.

To transfer data from ESOC to ESTEC, use was made of the existing 14.4 kbit/s leased line which forms the main ESANET highway between ESOC and ESTEC. (ESANET is the ESA computer, terminal, and facsimile network linking the ESA Establishments at ESOC, HQ, ESTEC, and ESRIN; see ESA Bulletin No.44, pp.87—91). At ESOC a suitable link to the leased line, via the Siemens computer, was already in existence. At ESTEC, a connection between the line and Space Science Department's HP1000 computer was installed using Hewlett-Packard Multijob Remote Entry Software. Finally, a remote-terminal mode link was made available from ESTEC directly to Marshall Space Flight Center for contingency purposes.

Operational experience

Two months prior to the encounter, a full dress-rehearsal was held at the US National Space Science Data Center (NSSDC), where data from the spacecraft were made available to the experimenters for transmission within the US and across the Atlantic. The NSSDC was to be used during the encounter as the science control centre for the TRW, NASA/Jet Propulsion Laboratory, Los Alamos National Laboratory and ESA/ESTEC ICE Science Teams.

Due to delays in the procurement of hardware for the ESTEC HP1000 computer, the data was transferred to the ESTEC IBM, once received at the ESOC VAX, then transferred by tape to the HP1000. The SPAN link across the Atlantic performed flawlessly, demonstrating that the data could be reliably transferred to Europe. The HP1000 hardware was installed one month prior to the actual encounter, which was predicted for Wednesday, 11 September at 11.00 UT. Two days prior to the encounter, data files were transferred across the SPAN link to ESTEC, from the NSSDC to ensure that all was operational.

On the day of the encounter, Goddard made available data tapes at 4 h intervals

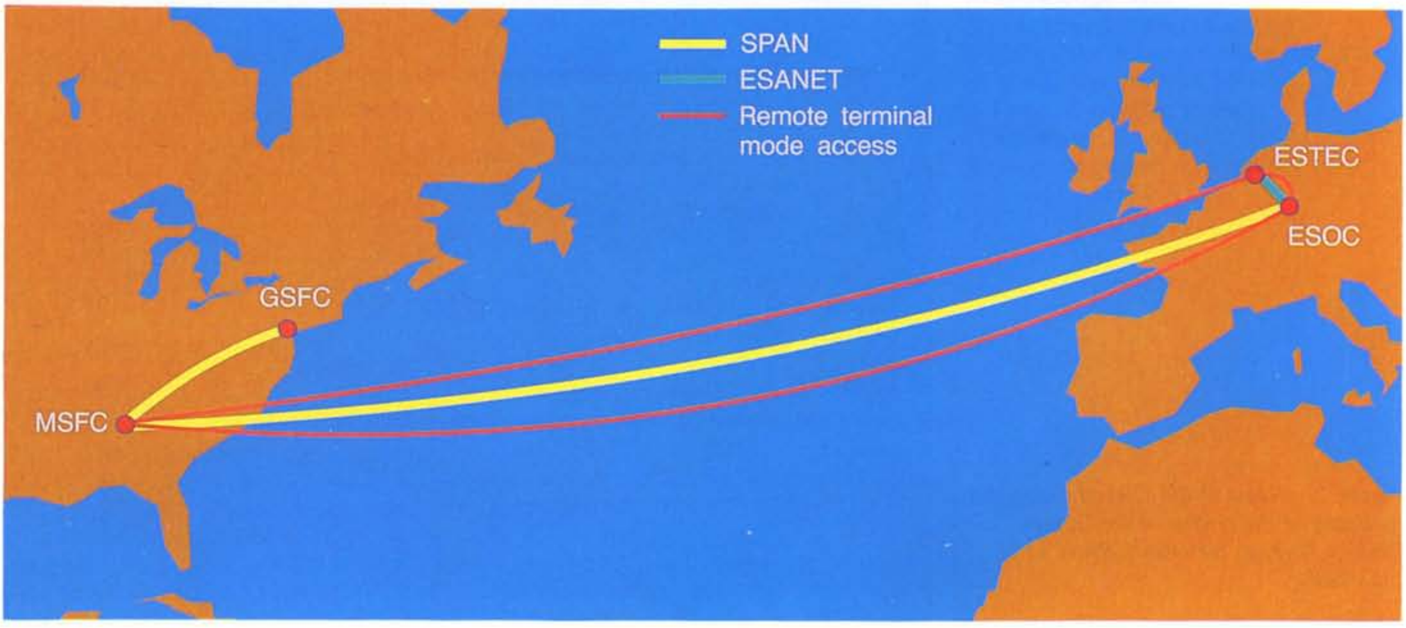
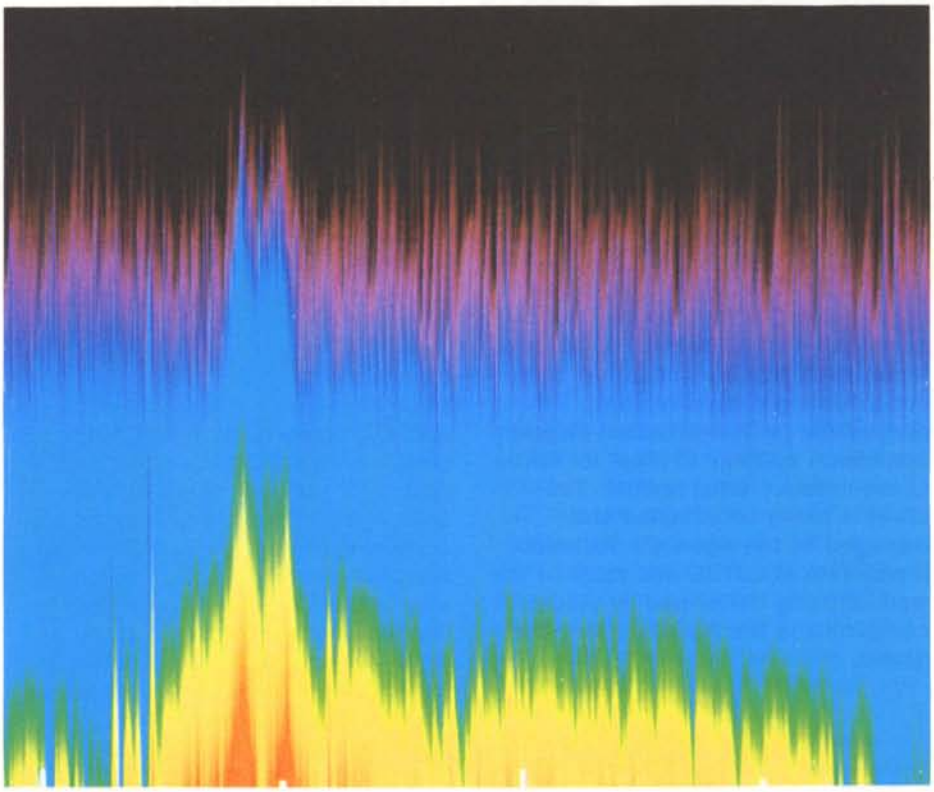


Figure 3 — False-colour spectrogram of energetic ions observed during the ICE spacecraft's encounter with comet Giacobini-Zinner. It shows 1.5 days of data as the spacecraft crossed the comet's tail. Two regions can be distinguished: (i) an inner region some 10^5 km across, with intense particle fluxes (left of figure) corresponding to the coma of the comet, and (ii) an outer region, some 10^6 km across, where cometary ions are observed for several days in the solar wind



within 2 h of the data having been captured by NASA's Deep-Space Network. The actual encounter data itself was received by the 1000 ft radio telescope at Arecibo, Puerto Rico, and transmitted to Goddard via the Nascom network, where it was decoded. The encounter data, lasting from 08.00 to 12.00 h UT on 11 September, was made available to experimenters at 14.00 h UT. For real-time monitoring, quick-look printouts were made available to all experimenters at the NSSDC science analysis centre. The encounter data tape was loaded into the LEP's VAX, producing a file of 56 blocks of 3556 bytes, which was transferred via the SPAN from the NSSDC computer at Goddard to ESOC. The transfer took approximately 10 min, representing an average data rate of around 1700 bit/s. At ESOC, the data were transferred from the VAX to the Siemens, taking 3 min, then from the Siemens to the HP1000 in ESTEC via the ESOC/ESTEC leased line, taking another 8 min.

Approximately 10 min later, the first processed data appeared at ESTEC in the form of plots, ready for scientific evaluation, and immediate facsimile transmission back to the NSSDC in good time for the first Press Conference held at 1600 h UT, 5 h after the encounter.

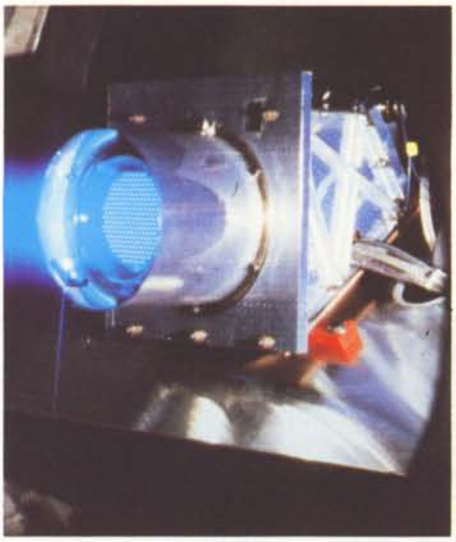
Both pre- and post-encounter data were transmitted across the Atlantic. A total of 18 files were transferred, comprising a total of approximately 1400 blocks of 3556 bytes of data, representing around 4 days of spacecraft coverage. Only one transfer failed, for as yet unexplained reasons, but the data was retransmitted successfully. No errors have been found in any of the transferred data. Some minor problems were, however, encountered. For example, some hours prior to the encounter a computer at Goddard was shut down due to the presence of very intense thunderstorms moving through the area. That computer was, however, brought on line again within hours.

Conclusion

The highly successful ICE Giacobini-Zinner encounter provided a unique and exciting opportunity for ESA personnel and scientists to experience near-real-time data acquisition, dissemination, and analysis using the Space Physics Analysis Network. A large volume of data was transferred from the US to Europe and processed within hours of being telemetred from a spacecraft tens of millions of kilometres away from Earth. Considering the experimental nature of the link, the data transfer was performed with remarkable ease and reliability. The experience gained has been invaluable in assessing ESA's needs for future participation in scientific international networking.

Acknowledgements

The authors gratefully acknowledge the assistance of the many individuals who contributed to the success of this operation. These include Bill Mish of Goddard Space Flight Center, the personnel of the NSSDC at Goddard, Dave Peters and Linda Porter of Marshall Space Flight Center, Jenny Franks and Martin Geliot of ESA/ESOC Computer Department, Peter Wenzel and Marek Szumlas of ESA Space Science Department, Chris Holt and John Simms of ESA/ESTEC Computer Department and Bob Hynds of Imperial College London.



The Status of ESA-Sponsored Developments in Electric Propulsion

W. Berry, Mechanical Systems Division, ESTEC, Noordwijk, The Netherlands

Since 1982, ESA has been consolidating a development programme for four different electric-propulsion systems to meet its future space-mission requirements. The effort is being coordinated and managed by the Agency's Technical Directorate at ESTEC and most of the work is being performed by industrial companies in the Agency's Member States.

Introduction

Since the advent of the space era, electric propulsion has been a subject of great interest in Europe, inspired by the promise of achieving specific-impulses an order of magnitude higher than the best-performing chemical propulsion systems. European efforts to realise this promise were initiated at Giessen University, Germany in 1960. These efforts resulted in the well-known Radio-frequency Ionisation Thruster (RIT) concept, which is one of the family of electrostatic gas discharge ion engines. Since then, progressive development of the RIT concept has taken place, resulting in a family of such thrusters, one of which, RIT 10, has been ground qualified and is now being prepared for a space test in 1988.

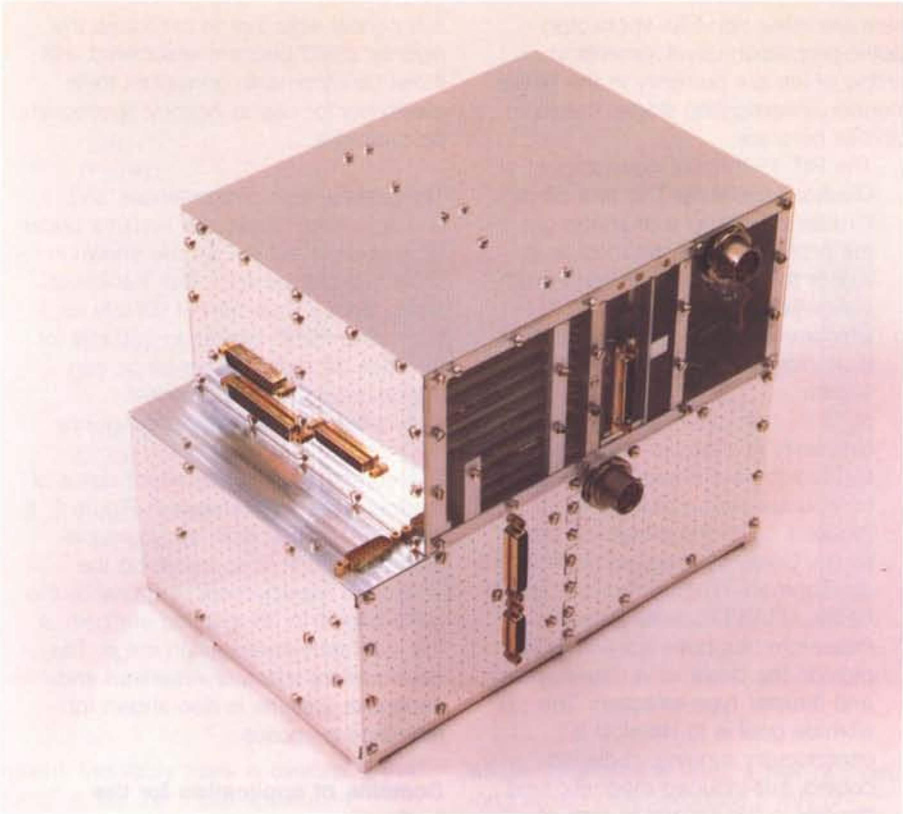
The European interest in electric propulsion then spread to France and the United Kingdom. France undertook the development of a cesium contact ionisation system, financed by CNES, and a cesium-bombardment system was undertaken as a private venture by the French company SEP. The UK undertook the development of a mercury-bombardment ionisation system, which culminated under a progressive development programme in the T5 ion engine in 1976.

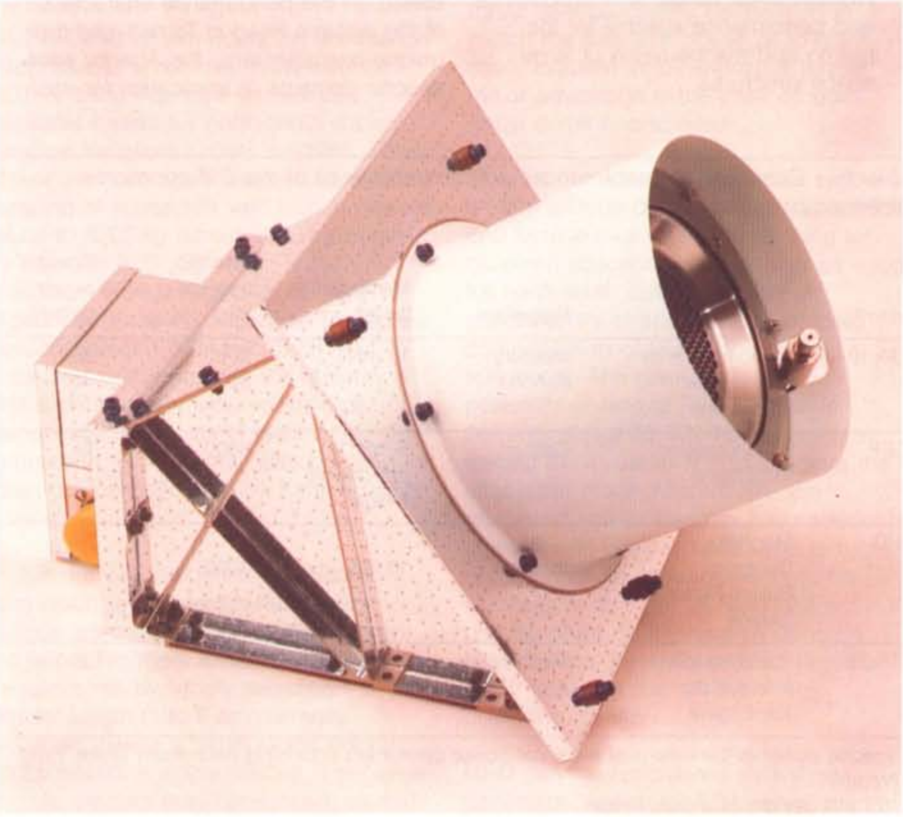
To complement these national efforts in Europe, ESRO initiated the development in 1968 of a colloid propulsion system. This effort was terminated in 1972, when it was discovered that the propellant was susceptible to dissociation by radiation energy in the space environment. The colloid work was superseded by the development of the Field Emission Electric Propulsion (FEEP) system, using cesium as the propellant. The development of the FEEP system, which was then a laboratory curiosity, has since made significant progress.

By 1976, we had five different electric-propulsion systems under development in Europe. This appeared to be an excessive and dispersed effort for the then rather small potential market, aimed primarily at the north-south station-keeping of telecommunications spacecraft in geostationary Earth orbit. Consequently, at the request of its Member States, the Agency evaluated the development status and potential of each technology and made recommendations for an ESA policy for electric propulsion. This evaluation took place in 1976, with recommendations that the RIT 10 and the T5 systems were sufficiently developed to warrant completion of their development programmes and to prove them in space tests. The FEEP system was also found to be very promising, with unique advantages, which warranted its continuing development as a second-generation system. Following these recommendations, the two French lines were terminated by their sponsors in 1977 and the UK T5 system was also terminated in 1977. This left Europe with only the RIT 10 system in Germany and the FEEP system development in ESA.

The period from 1976 to 1980 was a productive one for both the RIT 10 and FEEP systems. The life-endurance and reliability proving phase of RIT 10 was completed in Germany under national funding from the Germany Aerospace Research and Development Organisation (DFVLR), with the worthy achievements of 8150 h of continuous operation on a single RIT 10 thruster and 4140 h of cyclic operation, with 2010 starts on another thruster. The FEEP system

Figure 1 — The RITA 10 power-conditioning and propulsion units packaged for direct mounting to a spacecraft





completed its basic laboratory investigation phase at ESTEC, enabling a start to be made on the transfer of the technology to industry for the engineering development phase.

During this period, several efforts were made by ESA and MBB, the industrial contractor for RIT 10, to seek a space test opportunity for RIT 10, firstly on the APEX test satellite planned to be launched on the fourth qualification test flight of the Agency's Ariane launcher; secondly on the ESA H-Sat telecommunication satellite, or thirdly on the German-French TV-Sat telecommunication satellite. Unfortunately, none of these efforts materialised, but considerable progress was made by MBB in the development of the RIT 10 system as a modular, self-contained, externally mounted assembly for north-south stationkeeping applications. The designation of this RIT 10 assembly was then changed to RITA 10, the configuration of which has remained virtually unaltered since. The propulsion unit and the power-conditioning unit are shown in Figure 1.

The failures to obtain a space test for RITA 10 convinced the Agency that it was futile to seek space-test opportunities on operational satellites, even if the experiment was fail-safe for the satellite. What was needed was a nonintrusive test flight on a satellite conceived for multi-mission experiments. Such a flight opportunity arose in 1982 when a Call for Experiments was made by ESA for its then newly proposed Eureca Project, a Shuttle-launched and retrieved, free-flying platform to be launched in March 1988. RITA 10 has in fact been accepted for the Eureca-1 flight and experiment preparation is well advanced.

The acceptance of the space test of RITA 10 on Eureca-1 in 1982 also heralded a resurgence of interest in Europe in electric propulsion for a new range of potential applications and the Member States authorised the Agency to coordinate and sponsor the development of new electric-propulsion systems to meet these future needs. The new applications have arisen because of the expansion and evolution of the Agency's space programme in high-energy interplanetary space-science missions and in the Earth-observation programme using low Earth orbits. For the high-energy science missions, electric propulsion will be essential. For the Earth-observation and other low-Earth-orbit missions related to the ESA Columbus/Space-Station Programme, electric propulsion could ideally be used for atmospheric drag compensation with minimum attitude disturbance and low propellant consumption.

The potential uses of electric propulsion of interest to the Agency are:

- north-south station-keeping for geostationary satellites
- drag compensation for low-Earth-orbiting satellites
- orbital transfer propulsion for high-energy interplanetary missions
- fine attitude control for satellites
- relative station-keeping for clustered satellites.

Secondary interests are:
- transfer of spent or failed satellites from the geostationary orbit
- control of spacecraft charging.

To prepare for these needs, since 1982 the Agency has consolidated a programme for the development of four different electric-propulsion systems. These systems comprise three generations of electric propulsion and three different methods for ion and plasma generation. Each of these systems has unique advantages and domains of application, thereby warranting the development of electric propulsion on this wide front.

The four systems, in chronological order of their development are:

- Radio-frequency Ionisation Thruster Assembly with a 10 cm discharge chamber (RITA 10)
- Field Emission Electric Propulsion (FEEP)
- Magneto-Plasma-Dynamic Propulsion (MPD)
- Radio-frequency Ionisation Thruster Assembly with a 35 cm discharge chamber (RITA 35).

There are other non-ESA-sponsored electric-propulsion developments in Europe which are currently in the basic laboratory-investigation stage. The main activities here are:
- The RIT 15 thruster development at Giessen University. This is a 50 mN thruster operating with xenon gas as the propellant and destined as a higher thrust system for north-south station-keeping of large telecommunications spacecraft. The technology is based on the RIT 10 system.
- MPD thruster development at the University of Stuttgart. The unique facilities there are suitable for continuous testing of plasma thrusters up to the megawatt power range. Currently, the plasma-thruster development programme (supported by the USAF Office for Scientific Research) has been continued to provide the basis for a future system and thruster type-selection. The ultimate goal is to develop a continuously running, radiation-cooled, self-induced magnetic-field thruster in the several to tens of Newton thrust range, with propellants and performance suitable for the raising and manoeuvring of large space structures.

It is conceivable that in the future the Agency could become associated with these developments, to ensure their availability for use in Agency spacecraft programmes.

The comparative performances and characteristics of the four systems under development within ESA are shown in Table 1. It can be seen that the thrusts range from a minimum of 0.3 mN for a 1 cm long FEEP emitter, to 200 mN for the RITA 35 system. This range can adequately cover the potential applications of interest to the Agency.

The comparative development status of the four systems is shown in Figure 2. It can be seen that RITA 10 is ground-qualified, FEEP is approaching the advanced development stage, while the MPD and RITA 35 systems are both at the laboratory-investigation stage. The development status of American and Japanese systems is also shown for reference purposes.

Domains of application for the systems

Based on the performance characteristics of the systems listed in Table 1 and their unique characteristics, the Agency sees specific domains of application for each

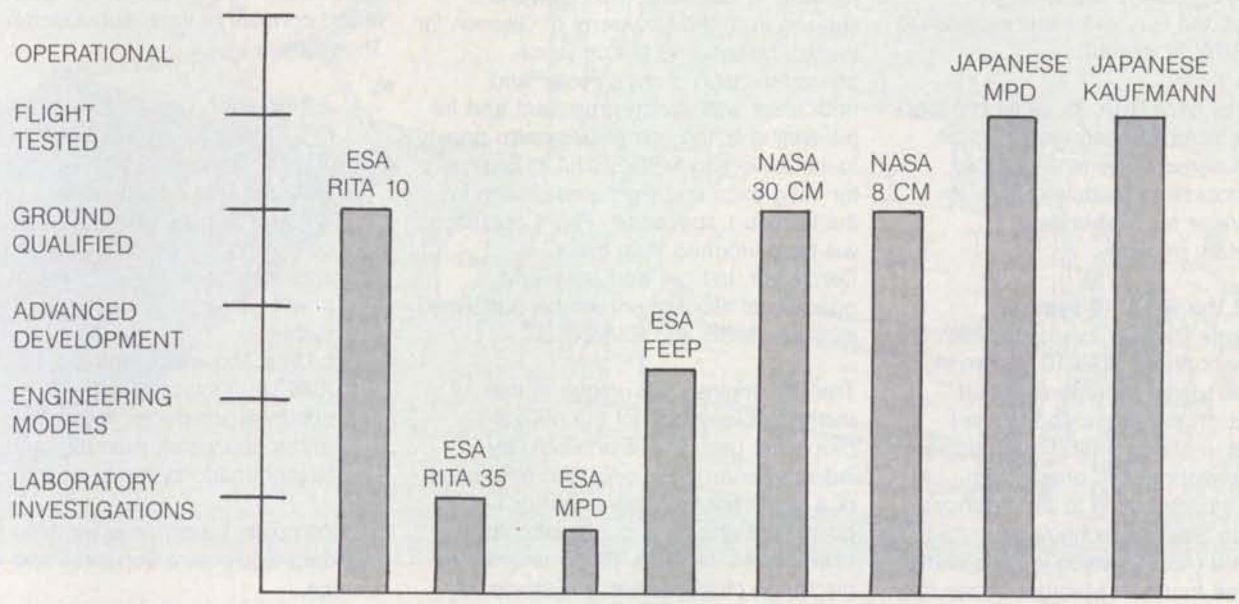
Table 1 — Comparative performances and characteristics of the ESA-sponsored electric-propulsion systems

System	Type classification	Propellant	Nominal thrust	Specific impulse (s)	Specific* power (W/mN)
RITA 10	Radio-frequency Electrostatic Ion Engine	Mercury Xenon	10 mN	3000 3500	35 45
FEEP	Field Emission Ion Engine	Cesium	5 mN** per double emitter	6000	55
MPD	Magneto Dynamic Pulsed-Plasma Engine	Teflon	10 mN	3000	35
RITA 35	Radio-frequency Electrostatic Ion Engine	Mercury	200 mN	3200	30

* Specific power is the ratio total electrical power consumed (including neutraliser) to the thrust (W/mN)

** 0.3 mN per cm of emitter length

Figure 2 — Development status of the major electric propulsion systems



system. Inevitably there is overlap of the domains, but the 'most applicable' domains can be readily identified.

The RITA 10 system operating with xenon propellant at a nominal thrust level of 10 mN is the Agency's immediately available system for north-south station-keeping for geostationary satellites. This thrust level can adequately cover station-keeping of spacecraft with launch masses of up to 4200 kg (about 2600 kg begin-of-life mass in GEO), which is the maximum launch capability of the Agency's Ariane-44L launcher. The space test on Eureca-1 in March 1988 is expected to demonstrate the maturity of this system and provide operational experience in the use of electric propulsion. RITA 10 may also be used for drag compensation for low-Earth-orbiting spacecraft.

FEEP is a second-generation electric-propulsion system which has several unique advantages: the thrust level can be tailored to meet a wide range of requirements by simply selecting the emitter length (1 to 8 cm currently achieved, giving a thrust range from 0.3 to 2.5 mN for a single emitter). For higher thrusts, emitters may be stacked, so that as demonstrated in tests, a pair of 8 cm long emitters can produce 5 mN of thrust. FEEP is also unique because the thrust level can easily be throttled to match the available power, or to meet control-system requirements. A further major advantage is the instantaneous thrust on/off characteristic.

FEEP is the Agency's candidate system for fine attitude control of large spacecraft and for fine relative station-keeping for clustered spacecraft. It may also be used for north-south station-keeping of geostationary spacecraft and for drag compensation of low-Earth-orbiting spacecraft. The relatively high power/thrust ratio of FEEP, which is currently about 55 W/mN, necessitates limiting the thrust level and therefore the spacecraft mass. Alternatively, the spacecraft must inherently have adequate power for its basic mission. The reduction of the power/thrust ratio seems to be reaching its limit, for reasons of the physics of the field-ionisation principle. Nevertheless, the unique advantages of FEEP outweigh this relatively high power/thrust ratio.

MPD may be considered as a third-generation system for ESA, which started in 1980 with a new look at this technology by the SNIA-BPD company in Italy under an ESTEC contract. Some previous work had been done on MPD propulsion at the Universities of Rome and Pisa in the 1970s. The new look was triggered by the renewed interest in MPD in the USA and in Japan. The SNIA-BPD study results showed that MPD was a system worthy of further development, because of its basic electrical and mechanical simplicity, especially the pulsed solid-propellant type. In MPD systems, the propellant is expelled as a neutral plasma, thus obviating the need for neutralisers, with the resulting further simplification of the system.

The Agency foresees the use of MPD for station-keeping applications at the low end of the thrust range (10 mN) and for high-energy orbital-transfer applications at the higher thrust levels (200 mN). The ESA work on MPD is in its infancy and further work is needed to see if the inherent advantages of these systems can be realised in practice.

The RITA 35 system is a high-thrust version of the RITA 10 system. Although new ESA-sponsored activities to develop this system were initiated only in 1984,

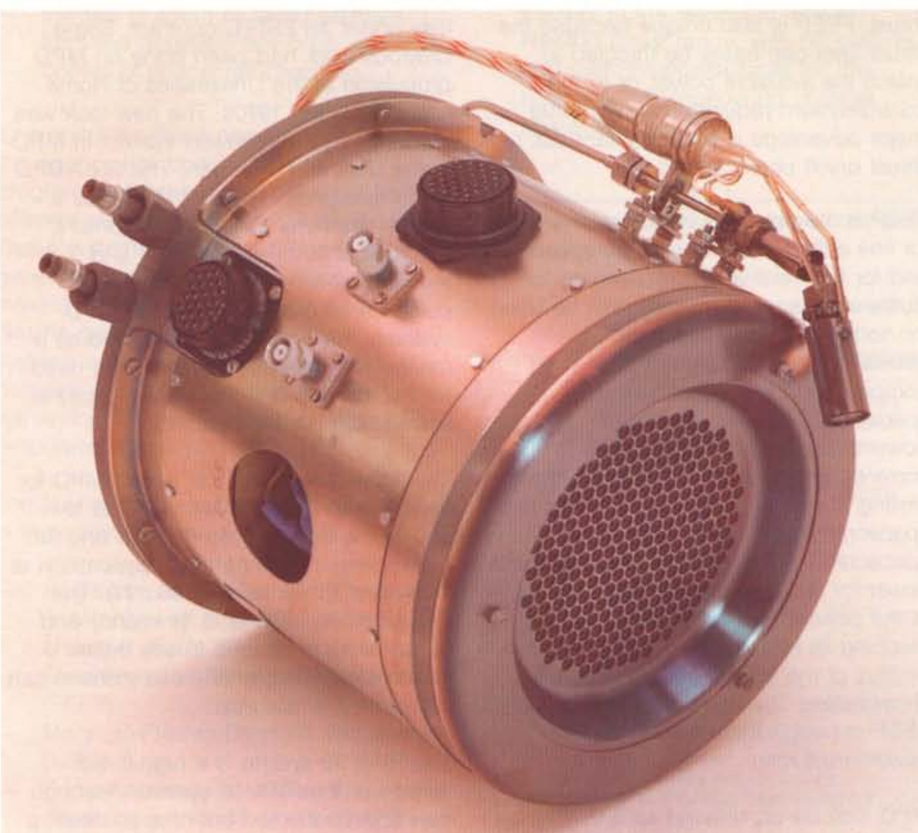


Figure 3 — Life-tested version of the RITA 10 ion engine

rapid development is expected by drawing on the very extensive experience with the RITA 10 system.

The Agency sees RITA 35 as its first high-thrust electric-propulsion system to be used, in a versatile, general-purpose Electric Propulsion Module (EPM), for orbital transfer for high-energy interplanetary missions.

Status of the RITA 10 system

ESA became formally associated with the development of the RITA 10 system in 1982, specifically to prepare it for a space test on the Agency's Eureca-1 spacecraft in March 1988. The funding for this development is drawn from Germany's contribution to the Agency's Application Satellite Technology Programme (ASTP), which is an optional programme to which Member States may contribute to fund developments in their own countries under ESA management.

The RITA 10 space test programme is managed by ESA/ESTEC and executed by MBB in Germany, with scientific support from the University of Giessen for the adaptation and performance characterisation of the thruster and neutraliser with xenon propellant and for the testing of the complete system prior to its delivery to MBB/ERNO in Bremen for integration and flight preparation in the Eureca-1 spacecraft. Flight operations will be performed from ESOC in Darmstadt. In-flight and post-flight operational assessment will be performed jointly by MBB and ESA/ESTEC.

The RIT engines are unique in their method of ionisation of the neutral propellant gas. This is achieved by inducing energy for ionisation by means of a high-frequency generator coil positioned around a quartz discharge chamber. In the RITA 10 ion engine, the discharge chamber has a diameter of 10 cm and produces a nominal thrust of 10 mN (Fig. 3).

Figure 4 shows the Eureca-1 spacecraft and the planned location of the RITA 10 experiment. The system to be space tested consists of three sub-assemblies. These are:

- a Propulsion Unit (PU), containing a RIT 10 thruster with its neutraliser and RF Generator coil; a propellant tank and flow control unit;
- a Power Supply Unit (PSU), containing the power interface to the spacecraft bus and the several power converters needed for the system;
- a Data Acquisition and Control Unit (DACU); containing a microprocessor controller, interfaces to the PSU and to the spacecraft telemetry and telecommand systems.

The complete system is assembled on a standard Equipment Support Panel for Eureca.

As far as possible, use has been made of existing hardware, available from the RITA 10 mercury ground test programme completed in 1980. The thruster and neutraliser have been converted for use with xenon and the PCU design has been updated with the use of modern electronic components. The DACU is completely new.

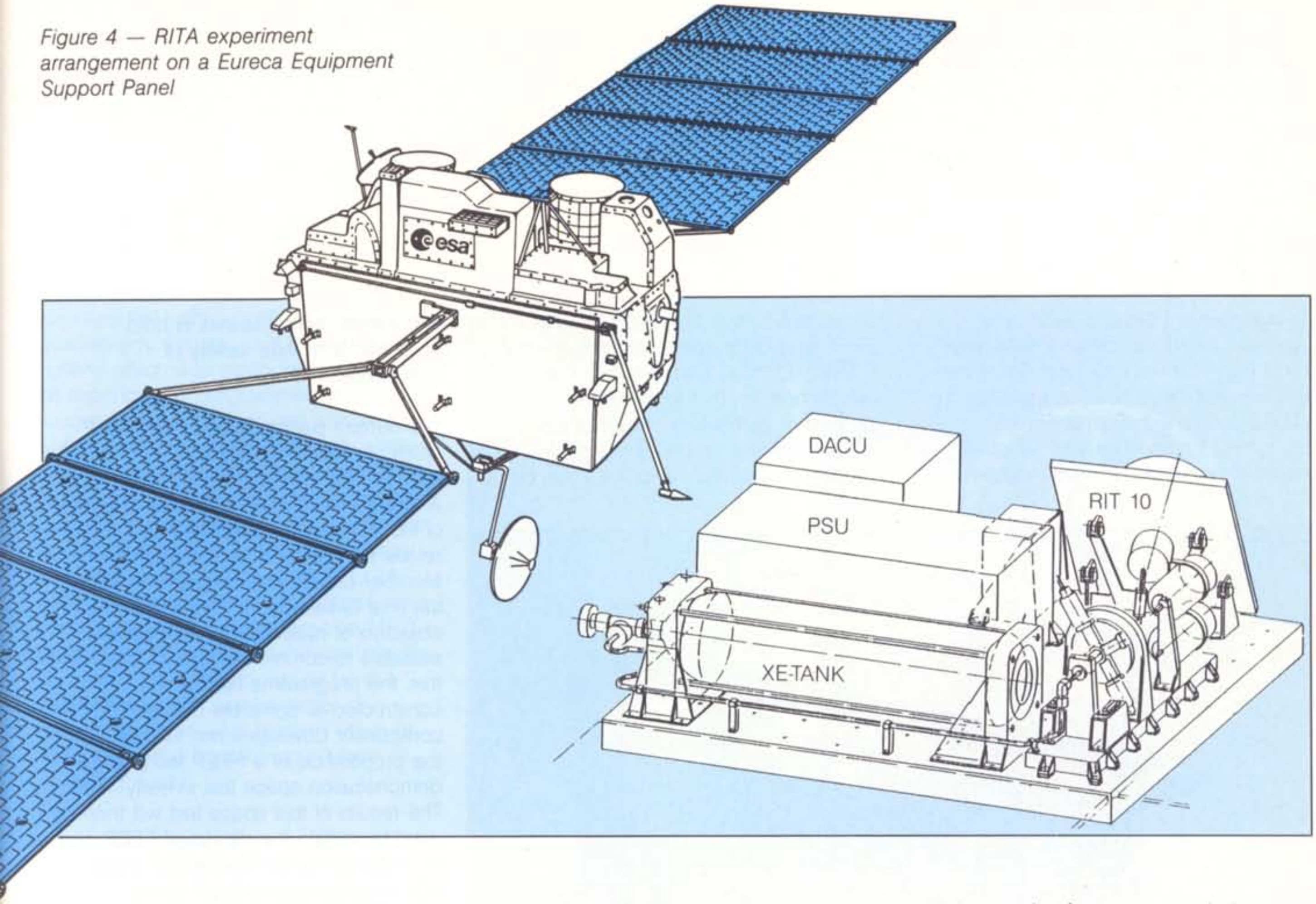
Operational programmes will be loaded into the microprocessor controller by telecommand. The RITA 10 system will then be operated completely autonomously, with safety-override protection. Data acquisition will also be automatic. The data will be stored on board and transmitted to ground once per day. It will be possible to change operational programmes by reloading from the ground by telecommand during periods of ground contact.

The performance characteristics of the RITA 10 space test are summarised in Table 2 .

Status of the FEEP system

In the FEEP system, the ions are not created by electron bombardment of a gas or a metallic vapour, but are derived directly from the surface of a liquid metal exposed to vacuum, by means of a strong electric field resulting from suitable voltages applied to an emitting unit and

Figure 4 — RITA experiment arrangement on a Eureca Equipment Support Panel



the consequent shaping of the liquid surface into a series of sharp cones (Taylor cones). This process does not require the transitional vapour phase which is common for metal propellants used in the more classical technologies of other ion engines. The liquid metal is directly converted into an ion beam, with an extremely high power efficiency. Because the radius of curvature at the tips of the cusps is very small (of the order to 1 micron or less), applied voltages of the order of 10 kV are sufficient to create the required strong electric fields.

Ion beams can be created from wetted needles (or arrays of needles) or from capillaries into which liquid metal is allowed to flow. The FEEP emitter has been progressively developed from a simple, single-pin emitter, through linear arrays of stacked needles, to an 'infinite' stack of needles which is the solid slit emitter described above. This provides precise control over the hydrodynamic flow and permits easy modularisation of the system and precise characterisation of the emitted beam (Fig. 5).

A FEEP system consists of the following components:

— single or a cluster of solid emitters
— cesium propellant storage and feed system
— power-supply unit
— neutraliser.

This simple system can be extended to fulfil the needs of any space mission.

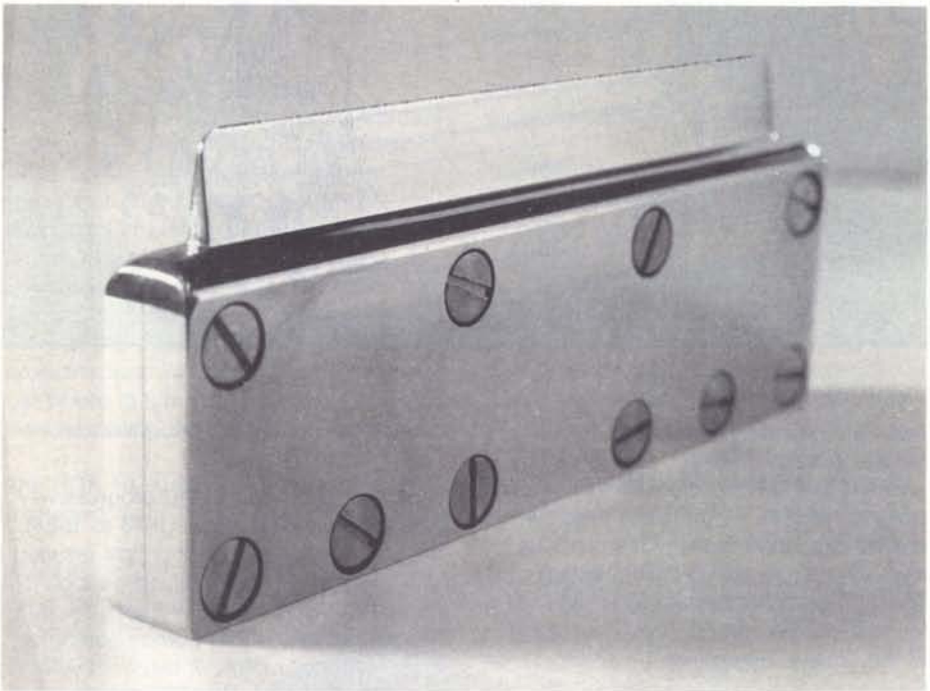
FEEP has been developed progressively over a period of 11 years (1973 to 1984). This long period of development resulted primarily from the small investment of about 100 thousand dollars per year for the programme, with a correspondingly small manpower effort of two man-years per year at ESTEC. By 1980, it had been developed to the point where the basic physics were understood and the major engineering problems for the manufacture of the emitter had been solved. This allowed initiation of the industrial development phase, by a progressive transfer of the technology to European industry. SEP in France was selected as the Prime Contractor for the industrial development, because of their considerable experience and facilities acquired during the development of the SEP cesium-bombardment and CNES cesium-contact ionisation systems up to their termination in 1977. Since 1981, SEP has formulated the system architecture for FEEP, set up and commissioned a comprehensive vacuum test facility, engineered and life-tested a pair of 8 cm clustered emitters, refurbished and life-tested a neutraliser derived from their previous cesium-bombardment-system development and, with MATRA, have performed a comprehensive FEEP application study.

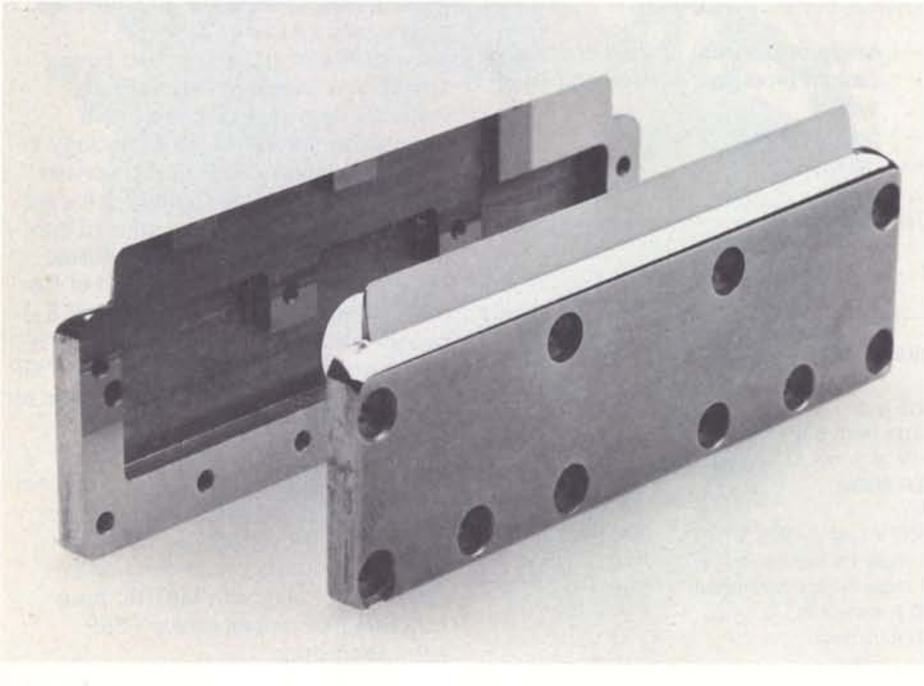
Table 2 — Performance data for the RITA 10 space test on the Eureca-1 spacecraft

Propellant	Xenon gas
Thrust	Variable from 5 to 10 mN
Power input	270 W at 5 mN to 440 W at 10 mN
Specific impulse	35000 Ns/kg
Experiment mass	35 kg
Applied high voltages	+1500 V and —1500 V
Propellant flow rates	0.36 mg/s for the thruster
	0.04 mg/s for the neutraliser
Life test duration	2000 h minimum
Life test start/stop cycles	3000 minimum

Figure 5 — An 8 cm long FEEP emitter module assembled and disassembled

To complement the SEP work, the Agency placed contracts in 1984 with FIAR (Italy) for the development of the thruster-dedicated power supply module (TDPSM) and with Fulmer Research Institute in England for the industrial development of the emitter module.





To explore further the capabilities of the FEEP system, a collaboration between ESA/ESTEC and Pisa University was established in 1984 to develop an annular slit emitter combining the advantages of the slit with the simplicity of an axi-symmetric geometry and the absence of end effects, which seems to hold potential for a wide variety of applications.

The current performance of the FEEP emitter is shown in Table 3.

A future programme for the development of FEEP has been prepared and is under review for financing by the Agency's Member States. This programme will be the final development phase, with the end objective of making the FEEP system available to commercial users. To achieve this, the programme has been constructed to complete discrete component developments, followed by the preparation of a FEEP technology demonstration space test in early 1989. The results of this space test will then be used to update the design of FEEP and to prepare it for an operational north-south stationkeeping flight on the Agency's AOTS spacecraft in 1992. In parallel with this activity, the FEEP system will be ground-qualified to meet the specific requirements of the AOTS test flight. This programme would make FEEP available as a flight-proven propulsion system by 1994, by which time at least two years of operational experience on AOTS should have been achieved.

Status of the MPD system

MPD systems are a large family of related devices which all operate on the same physical principle, but are variable in their design. The major variations are in the type of propellant (solid or gas phase) and their mode of operation (pulsed, quasi-steady or continuous modes). From the initial study of MPD propulsion systems performed for the Agency by SNIA-BPD (Italy) in 1981, the Agency

Table 3 — FEEP emitter module performance data

Emitter length (cm)	8.0
Emitter depth (cm)	2.4
Emitter thickness (cm)	0.6
Slit width (micron)	1.1
Thrust per unit length (mN/cm)	0.3
Power-to-thrust ratio (W/mN)	55
Specific impulse (Ns/kg)	60000
Mass efficiency (%)	60
Transmission efficiency (%)	99
Power efficiency (%)	98

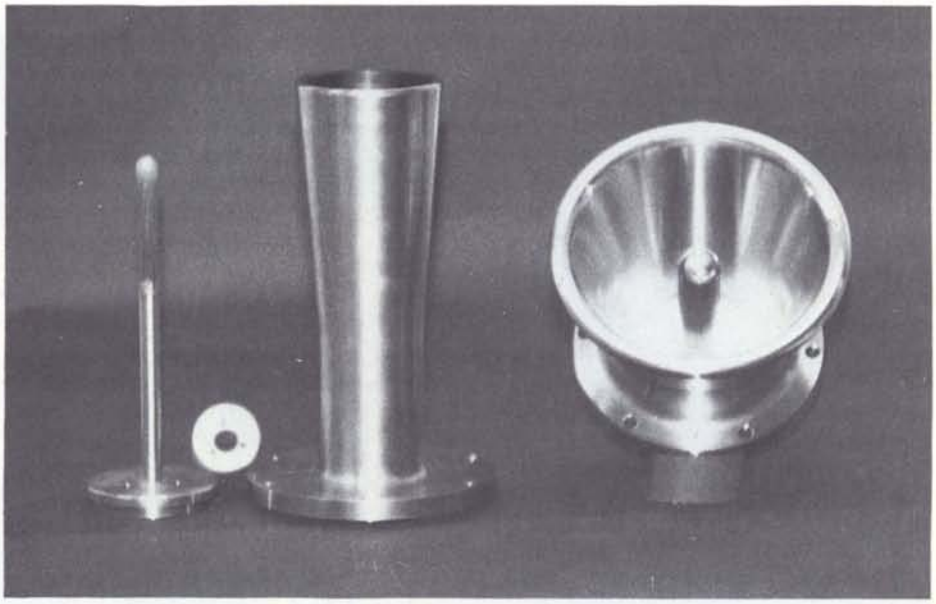


Figure 6 — Laboratory prototype MPD thruster.
Left: cathode, teflon block and anode of one thruster
Right: assembled second thruster

identified the solid-propellant (teflon) quasi-steady thruster as the best of the options which was worth investigating in an experimental programme. The successful development and subsequent flight applications of the generally similar teflon, pulsed micro-thrusters developed in the USA provided confidence in the potential of the solid-propellant type. The Agency therefore selected this concept for experimental development at SNIA-BPD in 1982 in a follow-on contract, as a starting point for a programme on MPD propulsion. The main differences from the successful USA system was to be the thrust level, which was an order of magnitude higher at a nominal value of 10 mN, and the quasi-steady (1 ms) operating mode.

In the MPD system, the solid propellant is fed in bar form into the discharge chamber and accurately positioned by an automatic mechanical feed system. A high-energy arc discharge is struck between the anode and cathode of the thruster, which ablates and ionises the teflon propellant. The ionised electrically conducting plasma permits the current to flow between cathode and anode and simultaneously induces an orthogonal magnetic field. The interaction between the electric and magnetic fields induces a force along the thruster axis which accelerates the plasma out of the thruster to provide a reaction thrust.

The work conducted by SNIA-BPD, with scientific support from Pisa University and exhaust beam plasma diagnostics support from Rome University, has just been completed. It included an extensive testing programme on thruster prototypes to explore the effects of configuration on thruster performance (variation of anode and cathode lengths and diameters) and the effects of scale variations, for a given thruster geometry. The highest efficiencies achieved were 40 %. Figure 6 shows one of the prototype thrusters.

The baseline characteristics of the best system resulting from the parametric study are summarised in Table 4.

A tentative configuration has subsequently been defined for north-south station-keeping featuring four thruster subassemblies placed at the NE, NW, SE and SW edges of the satellite, with two thrusters per subassembly (Fig. 7). The total mass of 110 kg is highly competitive with those of the RITA 10 and FEEP systems for a similar mission.

The continuation of the teflon quasi-steady plasma development programme has been proposed by ESA and its contractor, SNIA-BPD. This is now under discussion between the Agency and the Italian space authorities, to seek further funding from the Italian sponsored ASTP programme or to associate the Agency with the future programme if this is to be financed further within the Italian national space plan. The main future activities planned are to:

- broaden the mission scenario to other types of mission
- deepen the subsystem aspects and develop breadboard models
- extend the experimental activities to second-generation prototypes in order to improve the understanding of scale-effects and assess alternative feed arrangements
- develop in detail electrode material aspects
- develop direct thrust measurements
- perform endurance tests.

Table 4 — MPD performance data

Specific impulse	3000 s
Thrust efficiency	45%
Thrusting time per node	1.5 h
Equivalent steady thrust	15 mN
Total equivalent steady power	576 W
Propellant mass (10 years)	53 kg

Status of the RITA 35 system

ESA became associated with the development of this 'high thrust' (150—200 mN) system in 1983, triggered by the future scientific programme of the Agency, which identified the study of primitive bodies in the solar system as being of primary interest. The first such mission study was undertaken by the Agency in 1983, to examine the feasibility of a rendezvous mission to the asteroids, with a launch date in the 1992 to 1994 time frame. This mission was named AGORA (Asteroid Gravity, Optical and Radar Analysis).

The consideration of electric propulsion for this mission was made possible, in a European context, by the availability of a laboratory model of the RIT 35 thruster at Giessen University. Development of this thruster was started in 1972, based on a scaling of the RIT 10 thruster which had just been transferred to MBB for

Figure 7 — General concept of an MPD thruster module for north-south stationkeeping

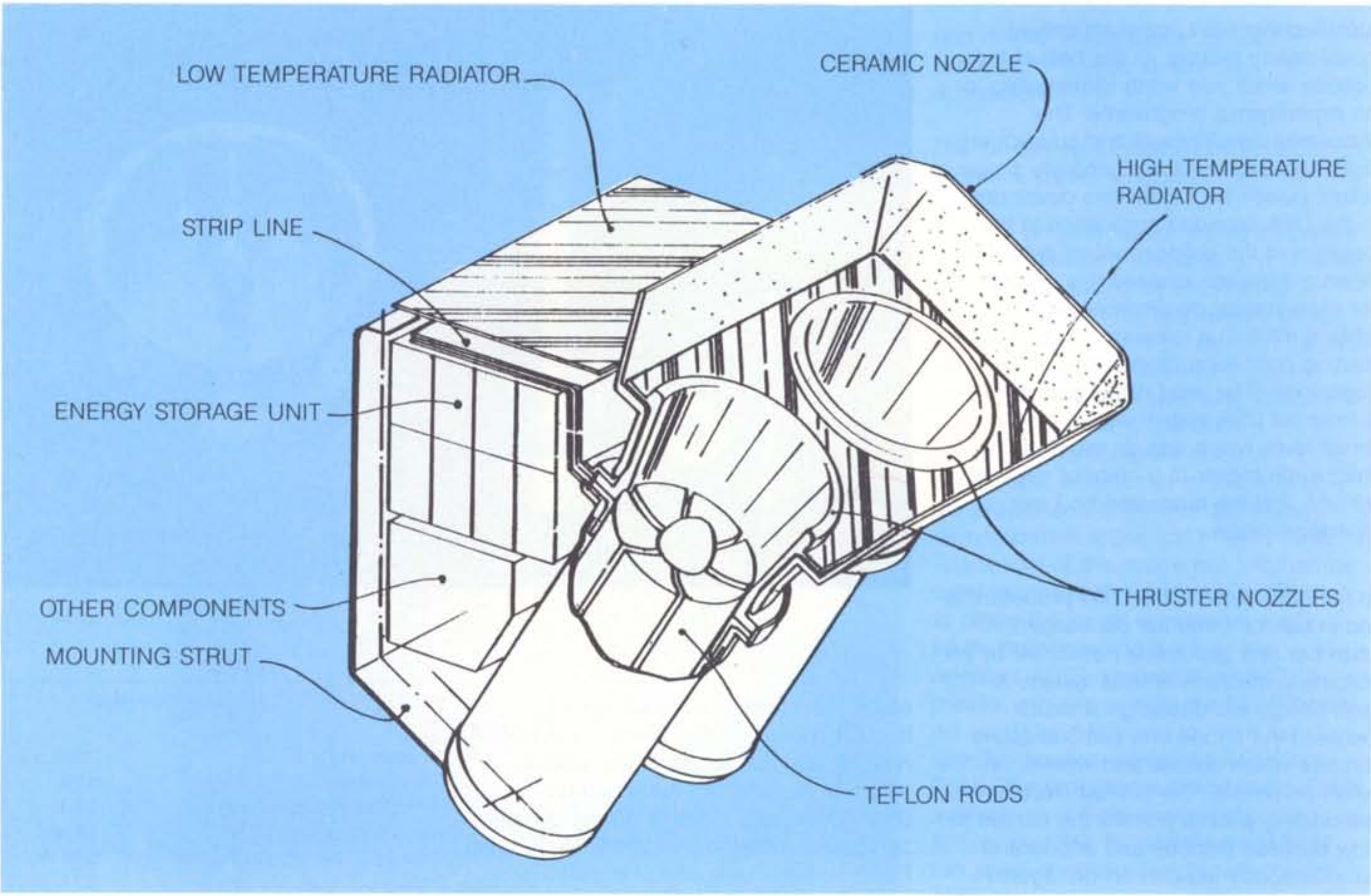


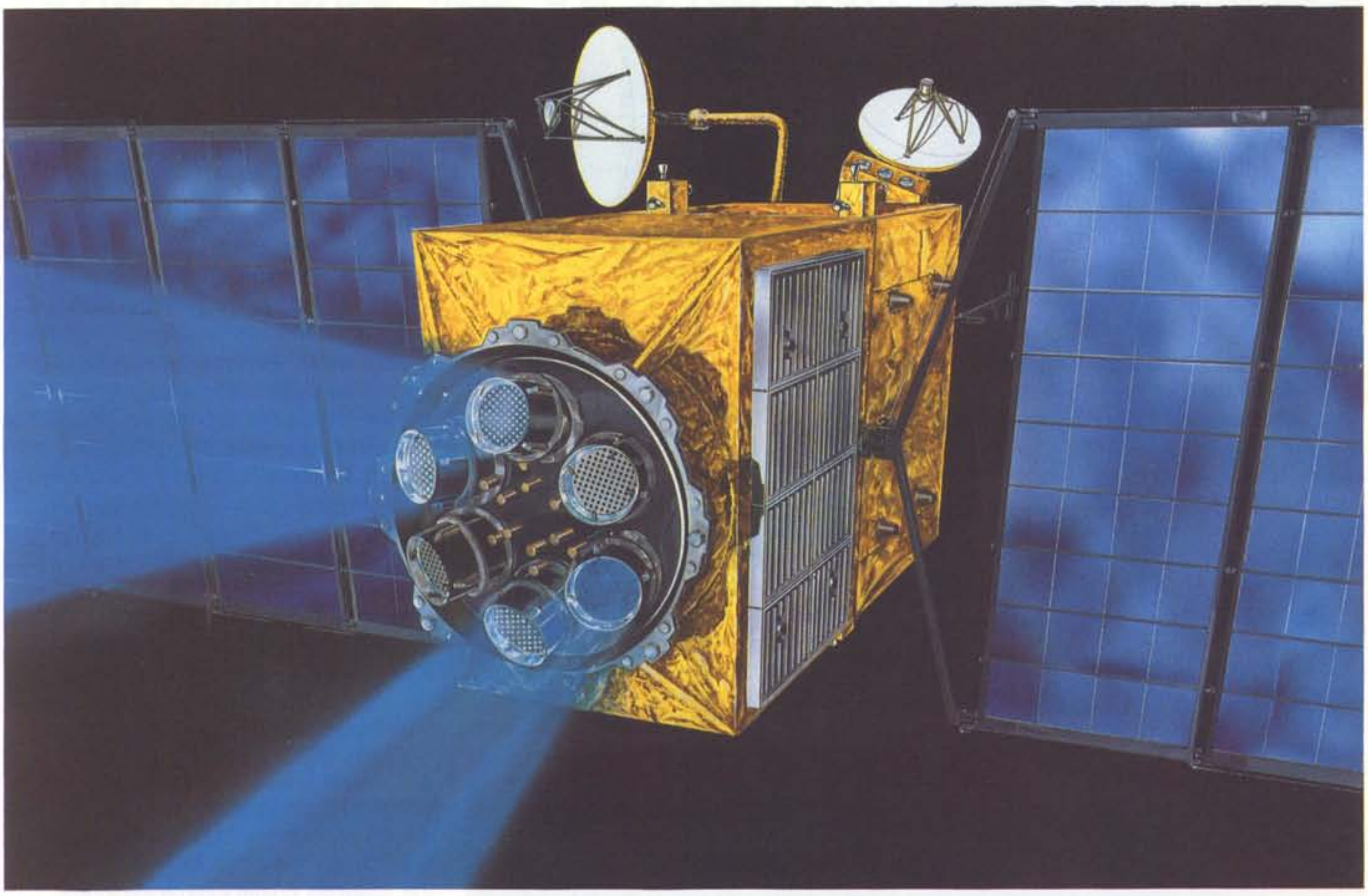
Table 5 — EPM performance data

Masses	
Module dry mass	1498 kg
Propellant mass	850 kg
Payload mass	465 kg
Total spacecraft mass BOL	2813 kg
Power	
Power source	Two fold-up solar arrays
Total power output at 1 AU	27.6 kW
Total power output at 2.5 AU	6.0 kW
Specific power BOL at 1 AU	86.5 W/kg
Specific power EOL at 2.5 AU	18.7 W/kg
Propulsion	
Thruster type	RITA 35
Propellant	Mercury
Total number of thrusters	6
Simultaneously operable thrusters	1 to 4
Thrust at BOL at 1 AU	4x200 mN
Thrust at EOL at 2.5 AU	1x150 mN
Specific impulse	31250 Ns/kg
Propellant flow rate	6.4 mg/s per thruster max.
Maximum thrust duration	11000 h per thruster

industrialisation. A diagnostic model was investigated up to 1976 and two laboratory models were built and operated at Giessen from 1977 to 1980 and at DFVLR in Stuttgart from 1979 to 1981. The ESA interest in high-energy interplanetary missions prompted the redesign of RIT 35 by Giessen University in 1983. This redesign made use of the results of the successfully qualified RIT 10 thruster and adopted some of its features: the mercury feed and vaporiser-isolator system and the neutraliser. This redesigned laboratory prototype thruster was designated RIT 35 LP.

Following the AGORA assessment study in 1983, the Agency embarked on a programme in January 1984 for the further development of RIT 35 and the simultaneous study of an Electric Propulsion Module (EPM) using AGORA as a reference mission. A contract was placed with MBB as prime contractor

Figure 8 — Conceptual drawing of the Electric Propulsion Module attached to the AGORA spacecraft



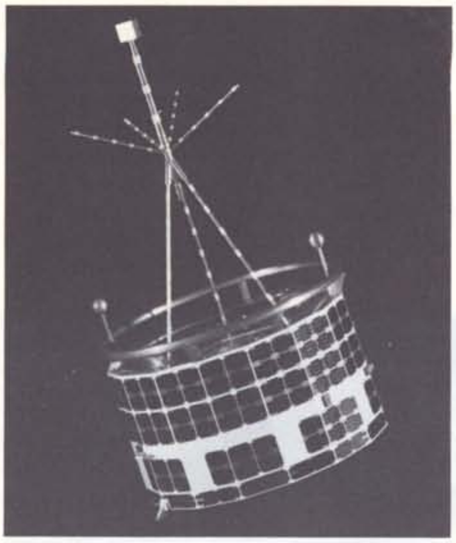
and Giessen University as subcontractor.

This EPM system study has now been completed and the module proposed uses a cluster of six RITA 35 systems, each with its dedicated power supply and thermal-control system, and a single mercury propellant tank and feed system, housed in a box structure (Fig. 8). An interface to the launcher is provided at the lower end of the module and an interface for the AGORA spacecraft is provided at the top end. Electrical power is derived from a pair of solar arrays, unfurlable from opposite sides of the module.

The major characteristics of the EPM are summarised in Table 5.

The EPM study will form a good basis for the further definition of key technologies, having confirmed the feasibility of the module, which has been developed by drawing on European experience in all areas.

Since completion of the EPM study in June 1985, interest in the use of electric propulsion for other high-energy interplanetary missions has increased. The notable mission of interest for ESA is the Comet Nucleus Sample Return (CNSR). This has been designated as one of the 'Cornerstones' of the Agency's future Scientific Programme, the objective of which is to return to Earth samples from a comet's nucleus, whilst preserving their physical and chemical integrity during acquisition and return. ESA is currently seeking cooperation with NASA for this mission, to be launched in the 1997 time frame.



How Long Do Our Satellites Live?

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Satellites, like most man-made objects, do not last indefinitely. One has, however, to differentiate between two elements of a satellite's lifetime:
(i) operational lifetime: the period during which the satellite performs its planned mission
(ii) orbital lifetime: the time until the satellite burns up in the Earth's atmosphere.

Our considerable experience with geostationary satellites allows a good estimate to be made of a particular spacecraft's lifetime, with actual lifetimes usually confirming the much earlier estimations.

The operational lifetime of a satellite depends on the reliability of its hardware and the use of its propellant for manoeuvres. Even if all satellite systems continue to function correctly, a certain reduction in hardware performance is unavoidable, such as reduced battery recharging capability, lower solar-cell efficiency, etc., leading to an overall degradation in the satellite's functions. On the other hand, manoeuvres are necessary to maintain the proper orbit and attitude for the satellite. After a certain number of manoeuvres, the available propellant will be depleted and the satellite will no longer be controllable.

These and other considerations lead to an operational lifetime of limited duration. The first question to be answered is: 'Can this duration be predicted? In the early 1970s, operational lifetimes were of the order of 2 to 3 years; now they are two to three times longer.

Scientific satellites involve a wide variety of hardware and orbits, and their operational lifetimes depend strongly on the satellite's mission. They can range from a few months (e.g. for an infrared space observatory, whose instrument is cooled by an evaporating supply of liquid helium), to more than a decade (for some deep-space probes powered by a nuclear reactor).

The usual policy for operational-lifetime estimation for scientific satellites is to foresee two periods: the nominal lifetime and a so-called 'extended lifetime'. All systems are expected to work long enough for the basic scientific observation programme to be completed. The subsequent 'extended lifetime' is a kind of bonus, during which one has to expect some performance degradation, but where there is still a good chance of receiving useful scientific data. Propellant and other expendable supplies are usually sufficient to cover this extended operational lifetime.

Once a satellite is no longer operational, it will still continue to orbit the Earth, but until when? This is the problem of the orbital lifetime, which we will now examine in greater detail.

Orbital-lifetime predictions

Firstly, it should be emphasised that orbital-lifetime estimations are not performed just to satisfy our curiosity, but are an important part of mission analysis. It is a major concern, for instance, that the satellite's orbital lifetime be longer than its operational lifetime, so that the satellite will not decay before its nominal mission has been completed. For near-Earth or high-eccentricity orbits, this leads to a fundamental mission constraint.

Heavy satellites may not completely burn up during atmospheric re-entry and some solid parts may hit the Earth's surface. The exact time and place of re-entry has therefore to be predicted accurately in order to warn the inhabitants of the areas concerned of any possible danger. This need has been illustrated spectacularly by the re-entries of Cosmos 954 (January 1978), Skylab (July 1979) and Cosmos 1402 (February 1983).

Even for a planetary orbiter, orbital lifetime has to be considered. In order to limit possible contamination of a planet's surface by Earth-based bacteria, the international Committee for Space Research (COSPAR) has recommended a quarantine period of several decades for

Figure 1 — Main Control Room at ESOC, Darmstadt, from which ESA's satellites are controlled

planetary orbiters before they should be allowed to hit the planetary surface.

Perturbations on the orbit
Orbital lifetimes are estimated by means of an orbit propagator. This is a mathematical tool which, given an initial satellite position and velocity, will propagate this state for future times, taking orbital perturbations into account. Without perturbations, the orbit would remain unchanged forever and orbit propagation would be a trivial exercise. However, in practice the perturbative effects on the trajectory are strong and have to be taken into account. The dominant perturbations are due to:

- the nonspherical shape of the Earth
- atmospheric drag
- the gravitational pulls of the Moon and the Sun.

The nonsphericity of the Earth results basically in a change in orbit orientation. The atmospheric drag is an important perturbation for near-Earth satellites, resulting in a decrease in orbital energy and therefore a reduction in satellite height, which may lead ultimately to the satellite's decay.

The gravitational disturbance by the Moon and the Sun influences the eccentricity of elliptic orbits, leading to a change in perigee height. The latter may decrease so much that the satellite hits the dense atmosphere or even strikes the Earth's surface itself.

The lunar and solar disturbances depend on the configuration of these celestial bodies with respect to the satellite's orbit. To prevent the occurrence of a geometry or configuration leading to a reduction in perigee, satellites in a high-eccentricity orbit, such as scientific satellites aimed at observing regions far from the Earth, have to be launched on specific dates and at specific hours defining a launch window.

Other perturbations, such as solar radiation pressure, play no significant role in decay prediction. Orbital changes due to satellite manoeuvres, executed by means of small onboard thrusters, may however introduce an additional uncertainty into the decay prediction.

Orbit propagation
Mathematical tools for orbit propagation are of three types:
- analytical
- semi-analytical and
- numerical.

In an analytical orbit propagator, the orbital state of the satellite for any future time is given in terms of an initial state by a formula. This formula may be rather complicated and laborious to develop. Only the main perturbations can be taken into account and a given formula is valid only for a particular type of orbit. The main advantage of an analytical formulation is that it allows estimation of the orbital state at a future time in one step and requires only a short computing time.

Should the validity of the analytical formula be restricted to a short time interval, for instance along one revolution of the satellite, the same formula can be reapplied for the next revolution after updating the parameters. This can be repeated revolution by revolution. Such a method is called 'semi-analytical' because it involves a step-by-step procedure. At ESOC, the late E.A. Roth developed such a semi-analytical method, called the 'stroboscopic method' because it provides a kind of stroboscopic view of the trajectory.

Semi-analytical methods are frequently used. They are sufficiently accurate for lifetime prediction and sufficiently fast to allow the calculation of the large number of cases needed, for instance, for launch-window calculation.

Numerical orbit propagation consists of integrating the satellite equations of motion directly with a step-by-step numerical integration scheme. The perturbation model can be made as realistic as desired. Such a method is very accurate but slow, and is therefore used only in cases where a particularly high precision is required.

Decay prediction
For routine predictions, an analytical formulation or at most a semi-analytical method, is sufficient. This allows the estimation of a large number of cases with limited computing effort. For accurate re-entry predictions, a numerical integration including a detailed perturbation model containing all the available information on the satellite and the physics of the atmosphere is usually required.

Even when using the most sophisticated method, the decay prediction will be subject to a certain error due to uncertainties in:
— the actual orbital state of the satellite
— the manoeuvres to which the satellite will be subjected
— the air-drag perturbation.

The orbital state of an operational satellite is usually well known, with range or range-rate measurements being performed regularly from ground stations and processed at the Control Centre with an orbit-determination program. When the satellite is no longer operational, however, the only means of determining its orbit are optical observation or radar tracking.

Satellites in high-eccentricity orbits undergo perturbations due mainly to the attractions of the Moon and the Sun. Such perturbations can be accurately estimated and the main uncertainties for lifetime predictions therefore stem from the initial orbital state of the satellite and the subsequent in-orbit manoeuvres.

Two ESRO satellites, HEOS-A1 and HEOS-A2, serve as good examples of decay prediction for satellites in high-eccentricity orbits (see accompanying box).

Several ESA scientific satellites are currently orbiting in highly eccentric orbits. The next of these to re-enter will be Exosat, an X-ray observatory launched on 26 May 1983 into a 0.9 eccentricity orbit. If no orbital manoeuvres were performed, Exosat would decay in April 1986. However, there is sufficient on-board propellant still available for perigee-height-increase manoeuvres to be performed that will allow an orbital-lifetime extension of up to 12 months.

Figure 2 shows the perigee history of Cos-B, ESA's gamma-ray observatory launched on 9 August 1975 into a 0.88 eccentricity orbit. This satellite decayed in January 1986.

ISEE-2, another ESA scientific satellite, designed for magnetospheric exploration and launched on 22 October 1977 into a 0.91 eccentricity orbit, is predicted to decay on 25 September 1987. Its perigee history, as estimated shortly after the launch, is also shown in Figure 2.

The Geostationary Transfer Orbit (GTO) is also of rather high eccentricity (e=0.73). Objects in this orbit, such as launcher third stages, have lifetimes varying from a few months to more than 10 years, depending on the luni-solar configuration at launch time. Estimation of the re-entry date for such objects is less accurate than for scientific satellites because of the increased influence of air drag at perigee due to their large size.

During the last phase of the re-entry of a high-orbit satellite, and throughout the lifetime of near-Earth satellites, air drag due to the Earth's atmosphere is the dominant perturbation. Its magnitude depends on the satellite's cross-sectional area and the ambient air density.

The cross-sectional area varies depending on the satellite's attitude. If the satellite is still operational, its attitude will be known at all times; if on the other hand, the satellite's attitude is no longer known — it may even be tumbling — one has to rely on a mean cross-sectional area. If radar observations are available, the signature of the return signal provides clues as to the satellite's attitude.

It is known from extensive observations of near-Earth satellites that the air density at a given altitude can show considerable

The Decay of HEOS-A1 and HEOS-A2

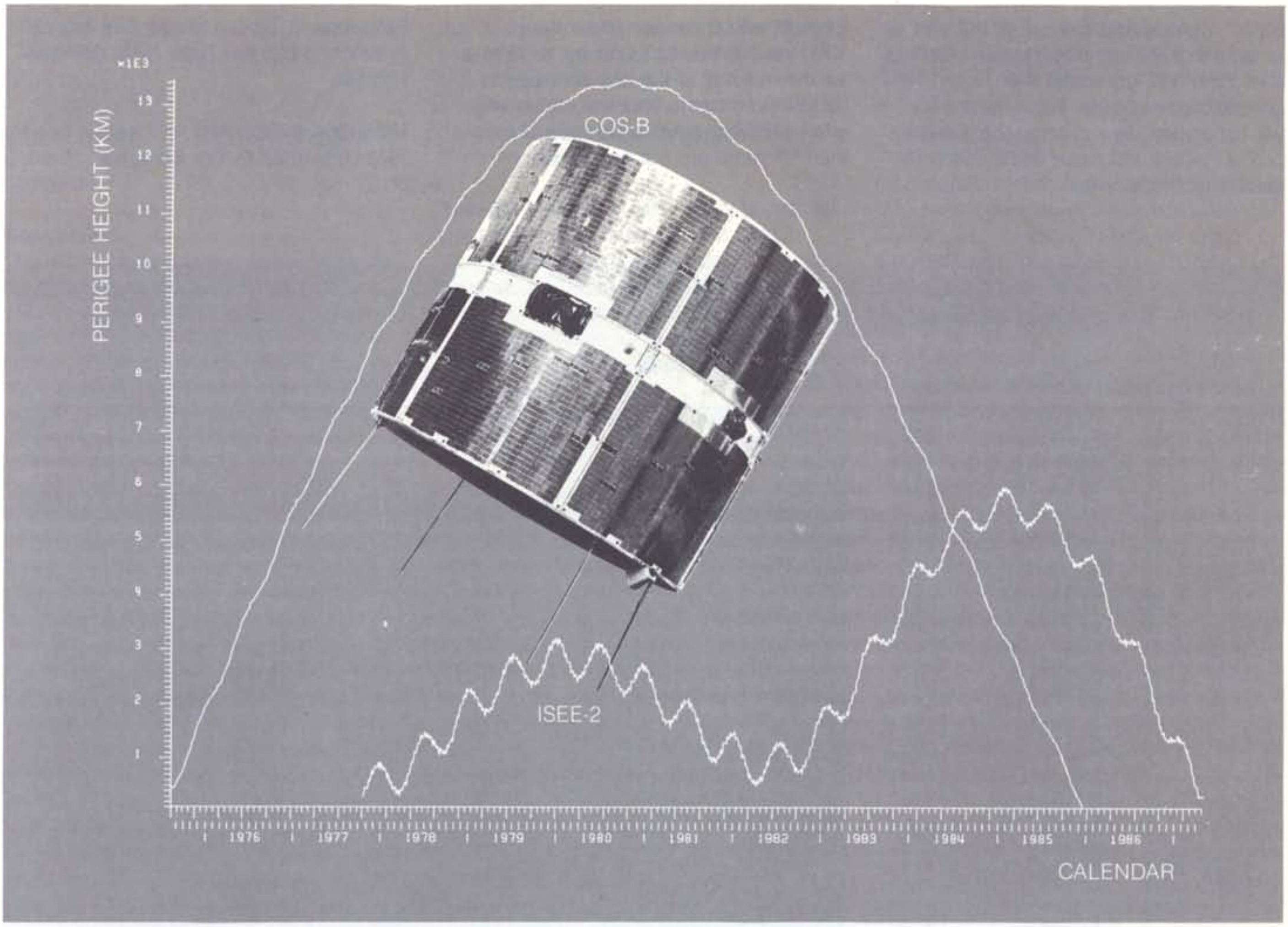
HEOS-A1 and HEOS-A2 were two scientific satellites built by ESRO/ESA to investigate the Earth's magnetosphere. They were launched by a US Thor-Delta rocket into an orbit with an apogee two-thirds of the way to the Moon and a perigee of 400 km, resulting in an eccentricity of 0.95.

HEOS-A1 was launched on 5 December 1968. About two weeks after launch, the satellite's orbit was determined with sufficient accuracy to predict its re-entry date as 31 October 1975, after 542 revolutions. In March 1974, a new prediction was made, leading to a forecast re-entry on 28 October 1975. The three-day shift in the re-entry date resulted from slight changes in the orbital elements due to attitude manoeuvres performed on the satellite. The actual re-entry did indeed occur on 28 October 1975, at 18 h UT. The re-entry point was located above the Weddell Sea in Antarctica. The event occurred in daytime, and could therefore not be observed.

HEOS-A2 was launched on 31 January 1972. The predicted re-entry date was 5 August 1974, after 176 revolutions. This prediction was updated to 2 August in March 1974. The actual re-entry did occur on 2 August at 11 h UT, above the Ross ice shelf in Antarctica. As the re-entry occurred at night, observation was attempted by informing the Amundsen-Scott South Pole Station of the event, but a light cloud cover and driving snow precluded observation.

For both satellites, uncertainty in the initial orbital elements and subsequent orbital perturbations due to attitude manoeuvres altered the initially predicted re-entry dates by about three days. The initially predicted number of revolutions was however confirmed as correct in both cases.

Figure 2 — Perigee histories of Cos-B and ISEE-2



and often unpredictable variations due to solar activity. At an altitude of 240 km, for example, it can vary by a factor of 3; at 500 km altitude, this factor can reach more than 20! Consequently, estimation of the air-drag perturbation is a difficult problem and the re-entry predictions for near-Earth satellites are subject to large inaccuracies, sometimes of several years, as was the case for Skylab. Even with the most sophisticated prediction methods, lifetime estimates for near-Earth satellites are accurate to only 10% at best.

The last phase of a re-entry

When a satellite decays and begins to enter the Earth's dense atmosphere, it experiences an increasing amount of drag, leading to a gradual reduction in its horizontal forward velocity. The point at which the satellite begins this deceleration phase is called the 're-entry point'. For most satellites, the re-entry point is about 130 km above the Earth's surface.

This deceleration phase is illustrated in Figure 3 for the ESRO satellite HEOS-A1. During the descent from a height of 100 km to 60 km, the satellite experiences a very high deceleration and consequently also a high heat loading. It is therefore during this period that the satellite is most likely to disintegrate and burn up. Any remaining debris will follow individual paths, depending on its cross-section to mass ratio.

Lifetime estimation for satellites and associated launch items

A list of all ESRO/ESA objects that have been put into space is given in Table 1, which indicates the situation on 1 November 1985. Such a table is updated at ESOC at regular intervals.

The satellite orbital element data are obtained from the latest orbit-determination results for satellites operated by ESOC, and from the NASA Prediction Bulletin for the other objects.

Satellites in geostationary orbits can have very long lifetimes, of the order of 10 million years. Geostationary satellites such as Meteosat-1 which has completed its mission, are no longer controlled and do not remain geostationary because they are subject to a periodic drift in longitude and a change in orbital inclination.

In order to reduce the number of 'dead' objects sited along the geostationary ring, ESOC manoeuvred Geos-2 at the end of its operational lifetime in January 1984 to a position 350 km above the geostationary altitude. This manoeuvre will not appreciably change the satellite's orbital lifetime, but freed this location for another active satellite.

Objects with a perigee lower than 1000 km are bound to decay, as is true for the majority of the objects listed in Table 1. In order to limit the computing effort involved, satellite lifetimes of more than 10 years are not predicted.

Reference to Table 1 shows that objects in similar orbits can have quite different lifetimes:

1968-109A (HEOS-A1): 7 years
1972-005A (HEOS-A2): 4.5 years
or

Table 1 — List of ESRO/ESA catalogued objects per 1 November 1985

COSPAR designation	name	NORAD no.	launcher		launch date	apogee (km)	perigee (km)	incl. (deg)	period (hour)	re-entry date
1968-041A	ESRO-2	3233	scout		68/05/17	1086	326	97.20	1.648	71/05/08
1968-084A	ESRO-1A	3459	scout		68/10/03	1538	258	93.76	1.717	70/06/26
1968-109A	HEOS-A1	3595	TD		68/12/05	223440	418	28.28	112.493	75/10/28
1969-083A	ESRO-1B	4114	scout		69/10/01	389	291	85.11	1.523	69/11/23
1972-005A	HEOS-A2	5814	TD		72/01/31	245380	396	89.81	128.480	74/08/02
1972-014A	TD-1A	5879	TD		72/03/12	551	524	97.55	1.590	80/01/09
1972-092A	ESRO-4	6285	scout		72/11/22	1173	245	91.11	1.650	74/04/15
1974-070A	ANS	7427	scout		74/08/30	1173	258	98.03	1.652	77/06/14
1975-072A	COSB	8062	TD		75/08/09	99873	342	90.13	37.112	86/01/20?
1977-029A	GEOS-1	9931	TD		77/04/20	38357	2110	26.25	12.001	indef.
1977-102B	ISEE-2	10423	TD		77/10/22	132718	5503	31.11	57.341	87/09/25?
1977-108A	MET-1	10489	TD		77/11/23	--------	geostationary		--------	indef.
1978-012A	IUE	10637	TD		78/01/26	45888	25669	28.63	23.928	indef.
1978-044A	OTS-2	10855	TD		78/05/11	--------	geostationary		--------	indef.
1978-071A	GEOS-2	10981	TD		78/07/14	--------	geostationary		--------	indef.
1979-104A	CAT-1	11645	AR-1	L01	79/12/24	23717	140	17.8	6.849	91/10?
- B	3rd st.	11659	-	-	-	36000	202	17.6	10.558	82/11/14
1981-057A	MET-2	12544	AR-1	L03	81/06/19	--------	geostationary		--------	indef.
- C	3rd st.	12546	-	-	-	33227	253	10.87	9.854	>1995
- D	CAT-3	12562	-	-	-	24946	229	10.46	7.216	92/11?
- E	adapt.	14125	-	-	-	28123	245	10.26	8.151	92/11?
1981-122A	MARECS-A	13010	AR-1	L04	81/12/20	--------	geostationary		--------	indef.
- B	CAT-4	13011	-	-	-	34325	238	9.90	10.065	>1995
- C	3rd st.	13025	-	-	-	19726	227	10.33	5.766	88/04?
1983-051A	EXOSAT	14095	TD		83/05/26	191581	356	72.5	90.517	86?
1983-058A	ECS-1	14128	AR-1	L06	83/06/16	--------	geostationary		--------	indef.
- C	3rd st.	14130	-	-	-	32002	232	8.44	9.329	>1995
- D	sylda	14151	-	-	-	16233	196	8.49	4.876	86/07?
1983-105B	3rd st.	14423	AR-1	L07	83/10/19	15943	163	8.44	4.783	86/10?
1984-023B	3rd st.	14787	AR-1	L08	84/03/05	31628	295	10.95	9.234	>1995
1984-081A	ECS-2	15158	AR-3	V10	84/08/04	--------	geostationary		--------	indef.
- C	Sylda	15165	-	-	-	31867	238	6.63	9.290	86/09?
- D	3rd st.	15166	-	-	-	33707	662	6.63	10.003	>1995
1984-114B	MARECS-B2	15386	AR-3	V11	84/11/10	--------	geostationary		--------	indef.
- C	3rd st.	15388	-	-	-	35912	346	7.13	10.604	>1995
- D	Sylda	15389	-	-	-	24331	175	6.95	7.032	86/01?
1985-056A	GIOTTO		AR-1	V14	85/07/02	--------	heliocentric		---------	indef.
- B	3rd st.	15876	-	-	-	35393	206	7.02	10.394	>1995

Column designations

1. *COSPAR designation:* Usual Committee on Space Research way of defining a space object. For instance, *1968-041A* means launch year 1968; number of launch in 1968 041, and the A designates the first object for this launch (A is usually the main object (spacecraft) and B, C, etc. rocket stages, attachments, fragments, etc.).
2. *Name:* This is the satellite or object name.
3. *NORAD number:* NORAD is a US-organisation (North American Aerospace Defense Command) monitoring all objects of a certain minimum size orbiting the Earth below a certain height. Each space object monitored by NORAD is given a number.
4. *Launcher:* Scout and TD (Thor-Delta) are US launchers used by ESRO/ESA before Ariane (AR) was available. The Ariane launchers are numbered L01 to L08 for the 8 promotional launches under ESA supervision and V09, V10, ... for the subsequent launches under Arianespace responsibility.
5. *Launch date.*
6. *Apogee, perigee, inclination, period:* These data are currently available orbital elements. If the satellite has already decayed, they are initial orbital elements.
7. *Re-entry date:* This is the actual re-entry date for objects already decayed, or the predicted re-entry date for objects still in orbit (date followed by a questionmark).

Figure 3 — Calculated velocity and altitude of HEOS-A1 in terms of the time measured in seconds since re-entry point crossing (at a height of 130 km)

1979-104B (AR-1 third stage): 3 years
1985-056B (AR-1 third stage): more than 10 years.

making it clear that lifetimes cannot be guessed, but need to be carefully computed.

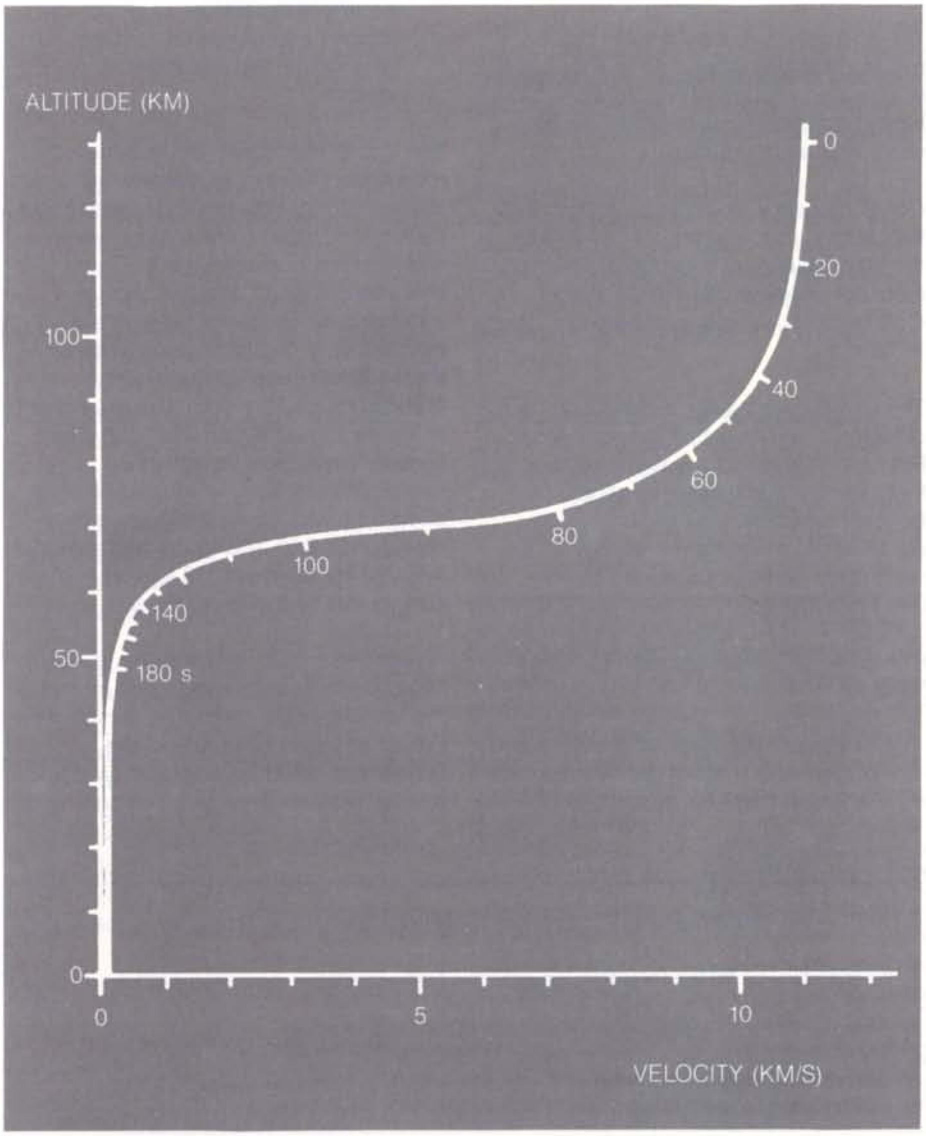
Conclusion

The orbital lifetime of a satellite has to be predicted in order to guarantee that it is not shorter than the foreseen operational lifetime. This leads to a possible launch-window constraint. For a satellite in a high-eccentricity orbit, such as scientific satellites designed to explore the Earth's magnetosphere, the main perturbation is due to the gravitational pull by the Moon and the Sun and can be computed precisely. The decay prediction for such a satellite is therefore accurate to a few days, as illustrated by the two ESRO scientific satellites.

Near-Earth satellites are mainly subjected to air-drag perturbation by the high atmosphere. The high-altitude air density depends on the solar activity, which cannot be predicted accurately. The lifetime estimation for such a satellite is therefore reliable to within about 10%.

Objects in geostationary transfer orbit have irregular lifetimes, varying from a few months to more than 10 years. Satellites in geostationary orbits, on the other hand, have very long lifetimes extending to several million years.

Thirty-eight catalogued objects (spacecraft, rocket third stages, adapters, etc.) have been launched successfully by ESRO/ESA, of which 26 are still orbiting the Earth and one (Giotto) is orbiting the Sun. Eleven have already decayed.



Cos-B — A Mission Fully Accomplished

K. Bennett, Astrophysics Division, ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

On 27 September 1985 the scientific database of the gamma-ray astronomy satellite Cos-B was formally released to the scientific community. At a ceremony hosted by the University of Palermo and the Regional Government of Sicily, the Project Scientist (KB) handed the database to the Director General of ESA, who coincidentally was a founder member of the Cos-B Collaboration.

Cos-B was launched from NASA's Western Test Range by a Thor-Delta vehicle on 9 August 1975. Its scientific mission was to study in detail the sources of extraterrestrial gamma radiation at energies above about 30 MeV.

The originally foreseen duration of the mission was two years, but in fact Cos-B was finally switched off on 25 April 1982, having functioned successfully for six years and eight months.

Cos-B carried a single large experiment, the design and provision of which was the responsibility of a group of research laboratories known as the Caravane Collaboration, whose members are listed in Table 1.

The Cos-B gamma-ray experiment detector is shown within the spacecraft in Figure 1. It featured a spark chamber, triggered by a counter telescope, beneath which was a caesium-iodide scintillator to measure the energy of the secondary particles produced by the incident photons.

The principal objectives of the mission were to:

- investigate the angular structure and energy spectrum of gamma-ray emission from the galactic plane
- measure the flux and energy spectrum of the isotropic radiation from high galactic latitudes, believed to be of extragalactic origin
- examine known or postulated point sources of the radiation, to determine the energy spectrum of all detected sources and to search for time variations in the intensities of sources.

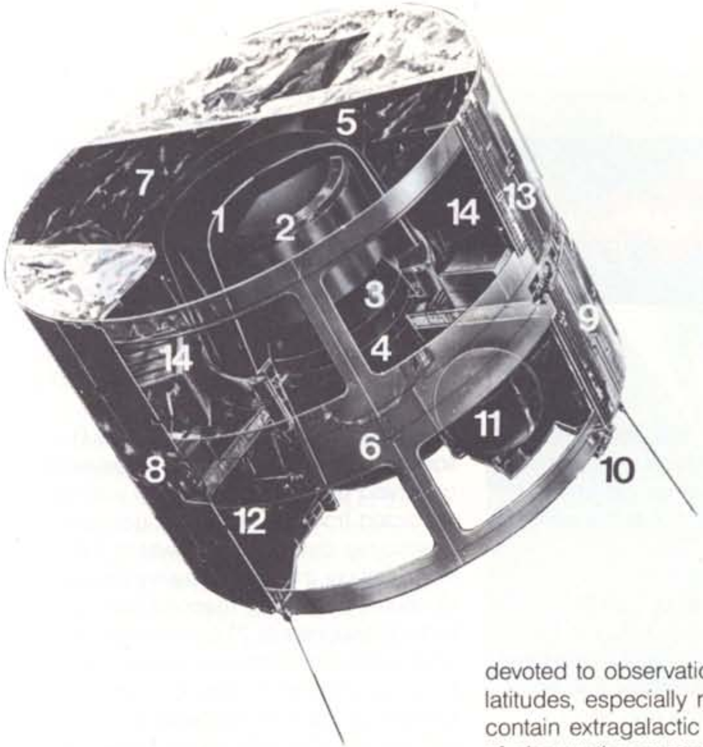
The Cos-B spacecraft was configured as a cylinder 1400 mm in diameter and 1130 mm long, with the main experiment package occupying the central region as shown in the cutaway view in Figure 1. It was spin-stabilised about its axis of symmetry, which coincided with the optical axis of the gamma-ray detector. A simple nitrogen-gas attitude-control system was used to point the experiment in the desired direction. Sun and Earth sensors were used for attitude measurements, from which the pointing direction could be reconstituted with a precision of 0.5°. The total mass at launch was 278 kg, of which 118 kg was contributed by the experiment.

An eccentric orbit with apogee at about 100 000 km was chosen to ensure that the satellite would mainly be outside the Earth's radiation belts, where the experiment could be operated safely. The satellite was operated in a pointing mode

Table 1 — Membership of the 'Caravane Collaboration'

1. Laboratory for Space Research, Leiden, The Netherlands
2. Istituto di Fisica Cosmica del CNR, Milan, Italy
3. Istituto di Fisica Cosmica e Informatica del CNR, Palermo, Italy
4. Max-Plank-Institut für Extraterrestrische Physik, Garching, Germany
5. Service d'Electronique Physique, Centre d'Etudes Nucleaires de Saclay, France
6. ESA Space Science Department, ESTEC, Noordwijk, The Netherlands

Figure 1 — Cutaway view of the Cos-B satellite showing the Anticoincidence Counter (1), Spark Chamber (2), Triggering Telescope (3), Energy Calorimeter (4), Pulsar Synchroniser (5), Structure (6), Superinsulation (7), Sun and Earth Albedo Sensors (8), Spin Thrusters (9), Precession Thrusters (10), Nitrogen Tank (11), Neon Tank (12), Solar Array (13), and Electronics (14)



with its spin axis directed towards fixed points in the sky for periods of between 30 and 75 days.

The advances in sensitivity achieved by the Cos-B mission can be ascribed to a number of factors:
- the outstanding in-orbit technical performance: very few component failures occurred and those that did were overcome by the built-in redundancy and operational flexibility
- the high fraction of live time of the telescope (about 65%) during which it could view selected regions of the sky without being obscured by the Earth
- the long mission lifetime of 6.8 years, compared with a design life of two years, finally curtailed by the depletion of the spark-chamber and attitude-control gases
- the significant efforts of the Caravane Collaboration scientists in careful pre-launch calibration
- the diligent operation of the spacecraft by ESOC personnel.

The sky coverage achieved with Cos-B is shown in Figure 2. A broad band along the galactic equator was studied in detail by means of repeated or overlapped observations. About one quarter of the observing time was devoted to observations at higher galactic latitudes, especially regions expected to contain extragalactic sources. Scheduling of observations was constrained by limitations on solar-aspect angle, attitude-sensor coverage and entry of the Earth into the field of view, but took account of scientific priorities and, where possible, the known plans of other satellite-, balloon- or ground-based astronomy experiments.

Cos-B's major achievements during its almost seven years in orbit can be summarised as follows:
- first complete galactic survey in high-energy gamma rays (see Fig. 3)
- observations of the Crab and Vela pulsars with unprecedented statistical precision between 50 MeV and 10 GeV
- discovery of numerous point-like sources in the galactic disc
- relatively precise (plus or minus 0.5°) location of the gamma-ray source CG195+4, Geminga
- first observation of gamma-ray emission from an extragalactic source: 3C273.

Many of these results were illustrated in an earlier article in ESA Bulletin No. 28, in November 1981.

In 1984, a reduced version of all Cos-B data was compiled into a single data set. This Final Agreed Database (FAD) provided the basis for the final consolidated analyses being conducted by the Cos-B Data Reduction Group. The database was also the prototype of that which has now been made available to the scientific community at large.

It is interesting to note briefly here how the treatment of the data has evolved with availability of the total data set. Of the 26 high-energy gamma-ray sources of the second Cos-B catalogue, only four have been positively identified: the Quasar 3C273 by a positional overlap with CG289+64, the Rho Ophiuchi cloud

Figure 2 — Approximate sky coverage achieved by Cos-B. The crosses indicate the pointing directions of the 64 observation periods

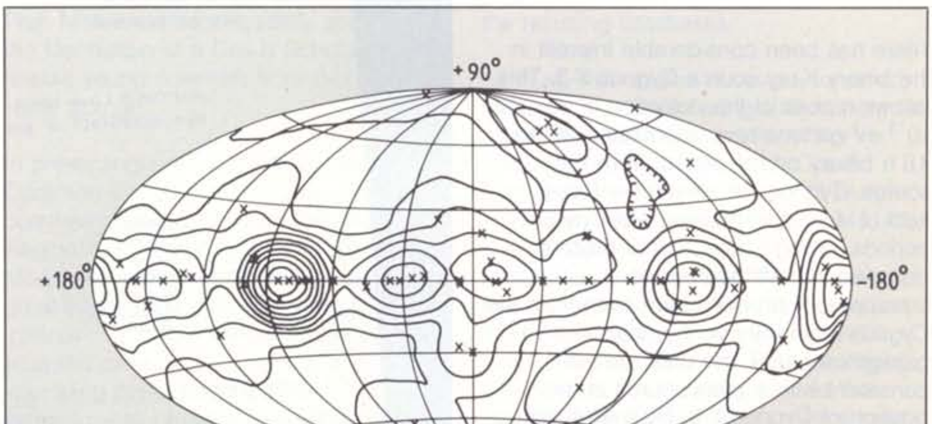
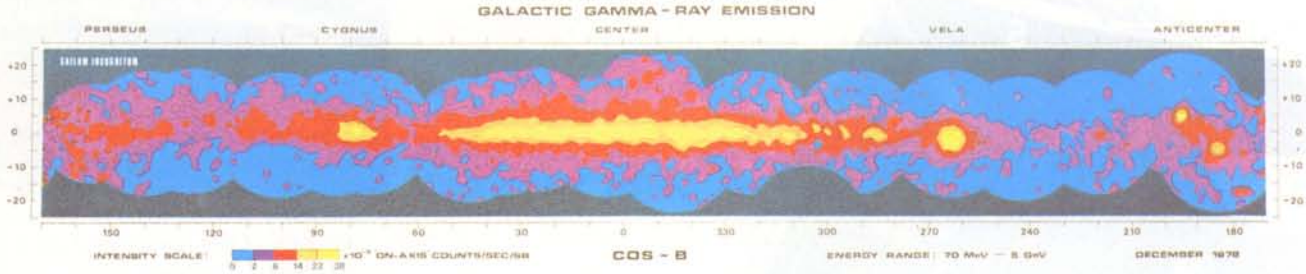


Figure 3 — The gamma-ray emission from the Galaxy as observed by Cos-B

Figure 4 — The commemorative silver plaque presented to ESA Space Science Department by the Regional Government of Sicily



complex with GT353 + 16, and the Crab and Vela pulsars by their timing signatures. For the remaining sources there has been much speculation about their identity.

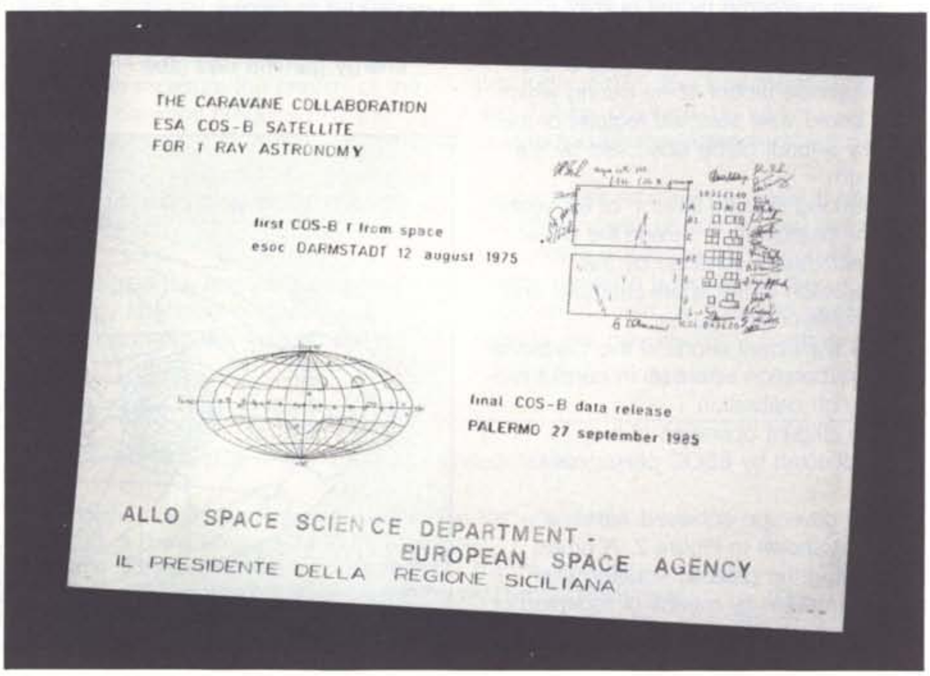
There has in particular been much speculation about the nature of the source CG195 + 4 (Geminga), which is the brightest of the unidentified Cos-B sources. Earlier results from the Sas-II satellite's experiment indicated a possible 59 s periodicity with a low statistical significance. Subsequently searches were made at other energies for possible counterparts. In particular, a strong case was made for identification of Geminga with the X-ray source IE0630+178 on the basis of the period. However, more recently an analysis of the *complete* Cos-B data set from this object has been made. The results show that there is absolutely no evidence for a 59 s periodicity from Geminga. Clearly, the absolute determination of a counterpart is of great importance in understanding the nature of this source.

There has been considerable interest in the binary X-ray source Cygnus X-3. This follows reports of the detection of 10^{15} eV gamma rays, modulated at the 4.8 h binary orbital period, from the source. Cygnus X-3 was in the Cos-B field of view during seven observation periods, giving a total of 300 days of observations. Although there is considerable structured emission from the Cygnus region above the diffuse background level, the data are not consistent with a point source at the position of Cygnus X-3. By overlaying successive data samples with 4.8 h orbital periods, a search has been made for periodic emission as reported at other energies. The resulting 'light curve' has been found to be flat, indicating that there is no evidence whatsoever in the Cos-B data for high-energy gamma-ray emission from Cygnus X-3 in the period 1975 to 1982.

This apparent null-result of Cos-B is extremely important when taken in the context of the other positive observations. Indeed if Cygnus X-3 continued to emit ultra-high-energy gamma-rays at its presently observed rate, then this object would be one of the most powerful sources in the Galaxy, contributing a sizeable fraction (if not all) of the galactic cosmic rays. The Cos-B result therefore allows the production model to be constrained and it may not be ignored.

Cosmic gamma rays are produced by cosmic-ray bombardment of the interstellar gas and hence the Cos-B scientists have attempted to correlate the observed gamma-ray emission with that predicted from the observed gas and cosmic-ray distributions. Towards the inner Galaxy the gas is mainly comprised of neutral hydrogen, mapped out with radio telescopes at 21 cm wavelength, and molecular hydrogen, which is traced by observing the millimetre radio waves emitted by carbon monoxide (CO) in its vicinity. The CO data has only recently been acquired for the large-scale regions of the Galaxy and was provided for the Cos-B correlation studies by the University of Columbia.

The predicted emission was seen to fit the observed emission over large angular extents and in localised regions some of the excesses previously reported as point-sources in the Cos-B catalogue



were found to be adequately explained by the gas. However, of the nine sources in the region under study, there remain five still unexplained by the gas and their nature continues to be a mystery.

In the near future the CO data for the remainder of the Galaxy (two quadrants) will be made available to the Cos-B team and this will permit a complete revision of the Cos-B source catalogue.

The map of the gamma-ray sky that has been made with the assistance of Cos-B shows an abundance of detail. On the small scale there are localised sources, while on a medium scale galactic arms interleave with and contrast against weak interarm regions. The larger scale features are hinted at by the apparent wobbling of the centre of the gamma-ray emission around the galactic equator throughout the Galaxy. The most recent findings of the Cos-B data are in fact concerned with the large-scale emission of the Galaxy. The gas data contain information that hints at its position within the Galaxy: namely the Doppler shift of the observed emission. Using this information, the gas may be apportioned into various distance bands, in effect several galactic annular rings. The shape of the emission is sufficiently different in the annuli that the observed gamma-ray emission may be fitted to each component simultaneously. The best fit indicates the most likely value for the gamma-ray emissivity in each annular ring or, as the amount of gas is known, the cosmic-ray content of each ring. Furthermore, as the spectrum of the gamma rays would be different if they were produced from cosmic-ray electrons or from cosmic-ray nuclei (mostly protons), the contribution of each component may be further determined in each radius interval.

The most surprising, and possibly the most controversial, result of the Cos-B analysis is that, while the data show evidence for a fall-off in the number of electrons in the Galaxy away from the centre, the protons appear to be roughly constant out to the furthest reaches. This result confirms the reasonable galactic origin of the cosmic-ray electrons, while hinting at an extragalactic origin for the protons, or at least an extension beyond the visible Galaxy.

Figure 5 — Prof. Reimar Lüst receiving the Cos-B data tape from the current Project Scientist Dr. Kevin Bennett (left)

The Seminar to celebrate the release of the Cos-B data to the scientific community was held just ten years after the launch of Cos-B. Those assembled for the ceremony, in the Palazza Steri of the University of Palermo, were addressed by Prof. Melisenda, Rector of the University, who presented medals (Silver Seals of the University) to the founding fathers of Cos-B, namely Prof. Beppo Ochialini, Prof. J. Labeyrie, Prof. Henk van der Hulst, Dr. Ernst Trendelenburg and Prof. Reimar Lüst. Prof. Melisenda subsequently announced the foundation of a Cos-B Scholarship, to enable young scientists from Sicily to study abroad.

In presenting each Institute of the Caravane Collaboration with a commemorative plaque on behalf of the Regional Government of Sicily (Fig. 4), Mr. R. Nicolosi, its President, spoke of the great importance attached there to international collaboration in major scientific projects as a means of improving the academic and technological infrastructure within Sicily. Continuing this theme, Dr. P. Cavaliere, Vice-President of the National Committee of Physical Science of CNR, assured the audience that a number of new scientific grants would be made available to Sicilian projects in the near future.

Following the formal handing over of the database to ESA (Fig. 5), the Director General, Prof. Lüst spoke of the important role scientific institutes had to play in the Agency's future Science Programme. He noted that during the last 20 years the scientific community concerned with space research in Europe had grown from about 300 to about 3000 members. Prof. Lüst also pointed out how essential it is that this community be kept involved, both in providing payloads for ESA's scientific missions as well as in exploiting the resulting databases.

All in all, this unique occasion, for which the team members had gathered from far afield, was a fitting reminder of the unique spirit surrounding the Cos-B mission, referred to in the recent Bulletin article by Prof. Lüst (ESA Bulletin No. 42, May 1985). The cordiality of the proceedings showed that those present, many of whom had been contributors to the Cos-B mission over a period of 20 years, felt that their hard work had been beneficial to the Collaboration, to the Agency and, last but by no means least, to the European scientific community at large.

ESA's New Ground Station at Carnarvon, Australia

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By virtue of its orbital coverage, the Carnarvon site in Western Australia has always been a prime element of the Agency's Geostationary Transfer Orbit (GTO) and stations network. Originally equipped with VHF facilities, the station has recently been extended to cover satellite operations in both S- and X-band. The Carnarvon station has thus become the first ESA ground facility able to operate simultaneously in three frequency bands, and in particular the first ESA station equipped with X-band reception facilities.

Introduction

In view of the establishment of the European launcher programme (Ariane) due to become operational in the eighties, ESA took the decision during the second half of the seventies to set up a network of ground stations specifically designed to support satellites during their launch and early orbit phase.

Network-configuration studies demonstrated the need for a station located in the far east, preferably at equatorial/tropical latitudes, whose orbital coverage would overlap that of ESA's African facility located at Malindi in Kenya. The location of Carnarvon (Australia) met the above requirements (Fig. 2) and the site operated there by the OTC (Overseas Telecommunication Commission) was selected for the installation of ESA's VHF* TTC ground facilities. The setting up of the Agency's VHF station at Carnarvon dates back to 1980.

Following the recommendation of the World Administrative Radio Conference, in Geneva in 1979, to discontinue the use of the VHF band for space operations and to allocate frequencies in the S-band for this purpose, the ESA Council decided to extend its VHF GTO (Geostationary Transfer Orbit) network to S-band** and to phase out the existing VHF operational capabilities by 1990.

The initial studies for the upgrading to S-band of the Carnarvon station (1982)

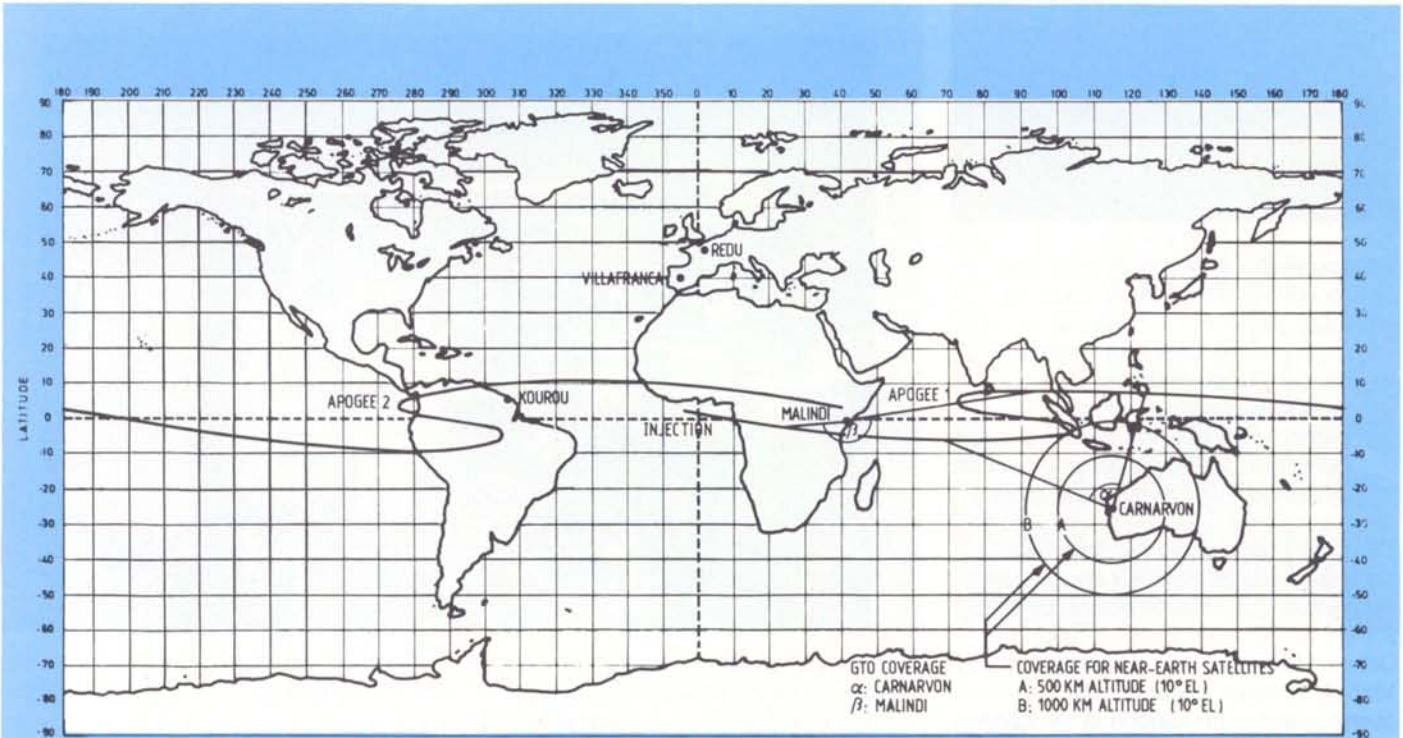
* VHF = ITU band 8 (VHF), i.e. space-to-Earth 136—138 MHz (space operation), Earth-to-space 148—149.9 MHz (space operation).

** S-band = ITU band 9 (UHF), i.e. space-to-Earth 2200–2290 MHz (space research, near-Earth-space operation), 2290–2300 MHz (space research, deep space), Earth-to-space 2025–2110 MHz (space research, near-Earth-space operation), 2110–2120 MHz (space research, deep space).

Figure 1 — An aerial view of the Carnarvon station: top left, the 15 m ESA S/X-band antenna and the containers housing the station's mains supply system; bottom left, the ESA VHF telemetry antenna

Figure 2 — The orbital coverage of the Carnarvon station

Figure 3 — Carnarvon station block diagram



were based on a 15 m diameter fast-moving antenna similar in design to the antenna previously procured by the Agency for its ground station at Villafranca del Castillo in Spain (see ESA Bulletin No. 30, May 1982, 'ESA's New Standard 15 m S/X Band Antenna – First installation at Villafranca').

Late in the same year, for orbital coverage reasons, the Carnarvon station was selected as the prime ground station for the operation of ESA's Giotto spacecraft during its cruise phase to Halley's Comet, and as the prime telecommand station during the encounter with the comet.

This new requirement led to:
— expansion of reception and antenna angular tracking capabilities to X-band***

*** X-band = ITU band 10 (SHF), i.e. space-to-Earth 8000–8400 MHz (Earth exploration), 8400–8450 MHz (space research, deep space), 8450–8500 MHz (space research, near-Earth).

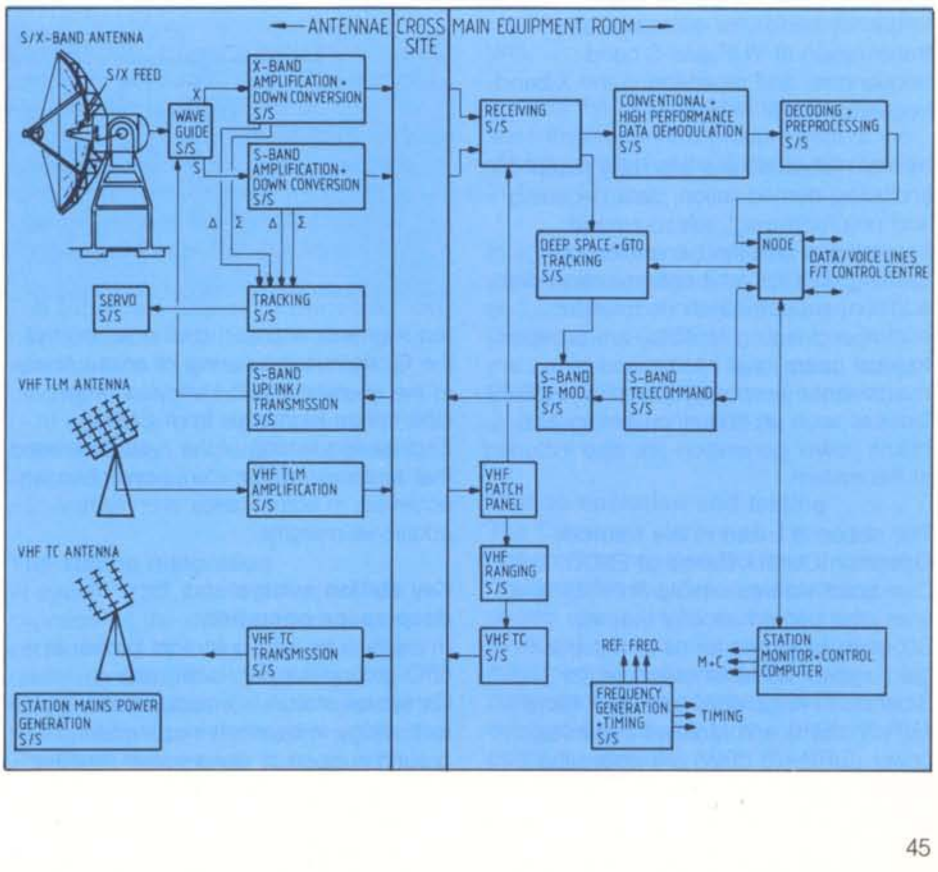


Figure 4 — The 15 m ESA S/X-band antenna at Carnarvon

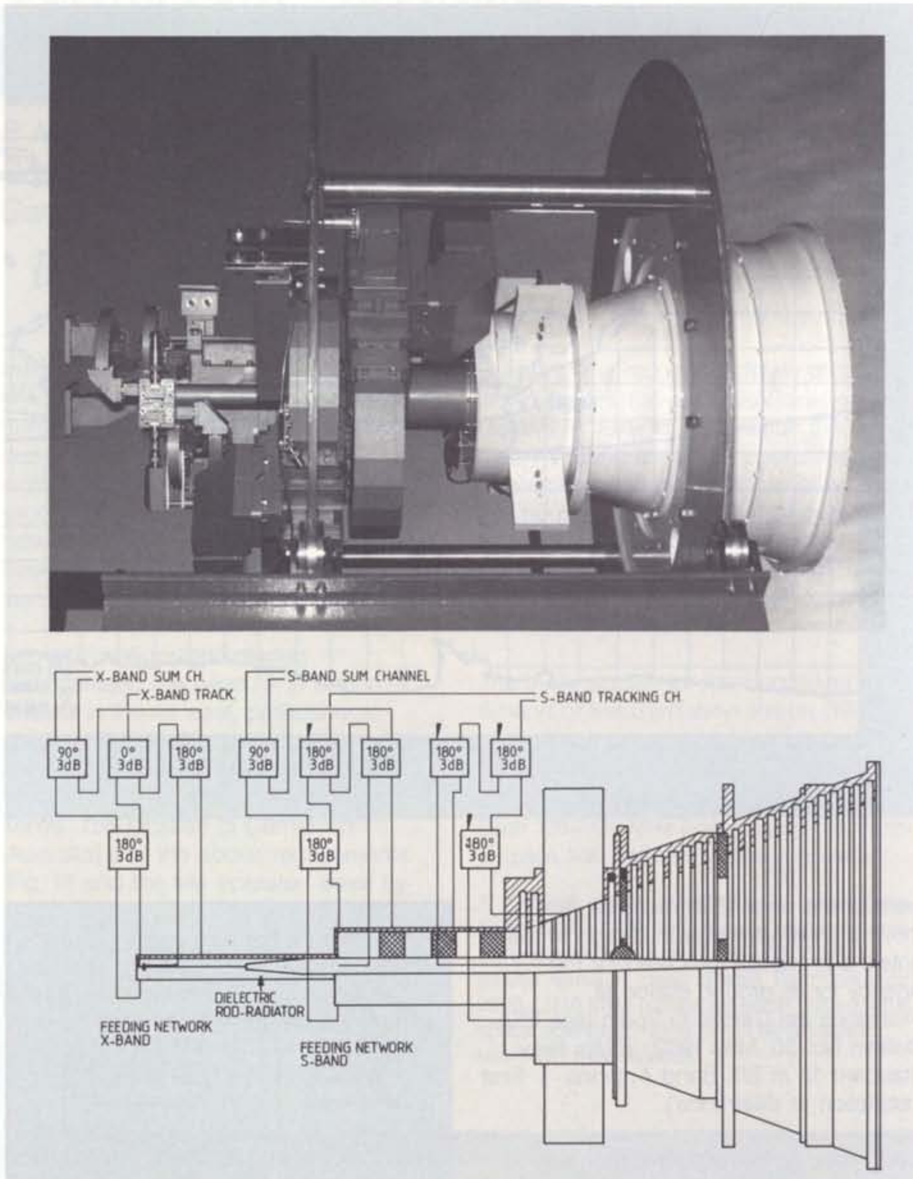


Figure 5 — The S/X-band antenna feed, mounted on a test support structure at the premises of MBB, in Germany. The accompanying schematic summarises the feed's main technical features

- improvement of transmission and reception capabilities to meet the more demanding spacecraft — ground-station link performance needed for deep-space distances
- the incorporation of a high-performance tracking system to meet the orbital-determination requirements associated with deep-space probes.

The main procurement contracts with European industry for the new S/X-band station subsystems were placed by 1983. Station integration started at the end of October 1983 and was completed in May 1985. The station became fully operational, for the support of the Giotto mission, on 2 July 1985.

The new station system and its performance

The new station is designed to provide satellite ground support in three frequency bands, i.e. reception and transmission at VHF and S-band frequencies, and reception in the X-band frequency range (Fig. 3).

Its main functions are telemetry reception (including demodulation, data decoding and preprocessing), telecommand transmission and the generation of tracking data for orbit determination. In addition, support functions (monitor control and testing facilities) are provided to ease operational control and for maintenance purposes. Essential ancillary facilities such as frequency, timing and mains power generation are also included in the system.

The station is linked to the Network Operation Control Centre at ESOC Darmstadt via two satellite (Intelsat) data lines. The performance of the new S/X-band system in terms of reception gain, system noise temperature (for S-band G/T=27.2 dB/K and for X-band G/T=37 dB/K) and radiated transmission power (EIRP=78 dBW) are above the requirements imposed by the support of the Giotto mission during its cruise phase to the encounter with Halley's Comet (150 million kilometres from Earth). Engineering testing of the system showed that all design parameters have been well achieved, in some cases even with additional margins.

Key station subsystems for deep-space operation

In addition to the equipment proper of a GTO ground-support facility, the Carnarvon station is equipped with high-technology subsystems required for TTC ground support of deep-space satellites.

The extension of the station reception capabilities to X-band has been achieved by fitting the 15 m antenna (Fig. 4) with an S/X-band feed newly developed by MBB (Germany) to ESA's specifications. The feed consists of an outer corrugated horn, the S-band radiator, and a dielectric rod mounted on the axis of the corrugated horn, the X-band radiator. The two radiators are equipped with mode couplers from which error signals are derived proportional to the misalignment of the antenna from the source (satellite) with respect to the antenna electrical axis. These signals are used for antenna pointing correction in autotrack mode. A

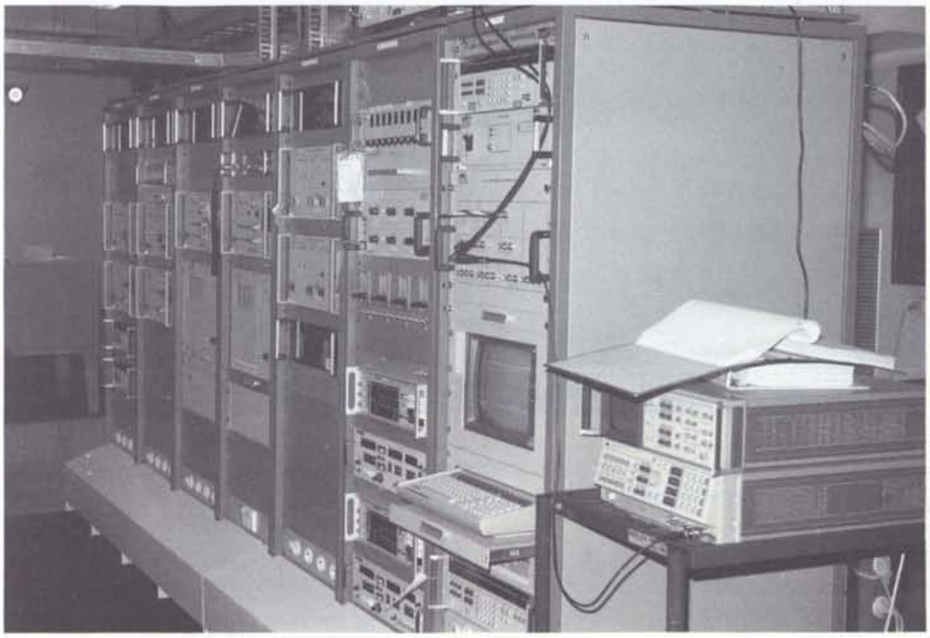


Figure 6 — The High Performance Demodulator at Carnarvon during station commissioning (first rack from the left)

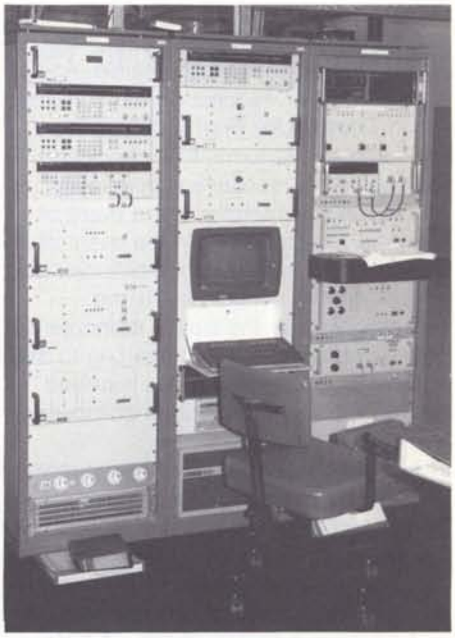


Figure 7 — The GTO Tone Ranging System (first rack from the left) and the Deep-Space Tracking System (last two racks from the left) at Carnarvon during station testing

schematic of the S/X-band feed is shown in Figure 5.

The improvement in the station's telemetry reception capabilities for deep-space probes has been achieved by the addition of a new low-loss demodulation subsystem, the High Performance Demodulator (HPD) developed by Bell Telephone Manufacturing Company (Belgium) (Fig. 6). Compared with commercially available conventional data demodulated subsystems (PSK demodulator and bit conditioner), the main advantages of the HPD, aside from the lower unlock threshold, is the negligible subsystem degradation of the received signal. In engineering terms, this represents a system performance gain of 1 to 2 dB, a useful improvement for the ground support of deep-space missions.

After demodulation, coded data are decoded in the station's decoder before being assembled in messages to be transmitted to the control centre. The decoder is a new development made necessary by the choice of Giotto's onboard coding scheme, in order to optimise the satellite–ground-station link. The unit was designed by Computer Resources International (Denmark), with consultancy from the Technical University of Denmark.

For deep-space satellite tracking, the Carnarvon station has been equipped with a new Deep-Space Tracking System (DSTS) developed by ATNE (France) to ESA's specifications (Fig. 7). The tracking data provided by the subsystem are accurate satellite range and integrated Doppler measurements. The range measurement, i.e. the measurement of the station–satellite distance, is performed in a conventional manner using a transponded sinusoidal tone (for ambiguity resolution, square-wave codes are modulated onto the tone). The integrated Doppler measurements provide accurate quantitative knowledge of the range variation with time. The DSTS is able to measure this variation with an accuracy of better than 0.1 mm/s.

The subsystem design solutions that have been adopted meet the demanding specifications in terms of minimum ranging tone signal-to-noise density (−10 dBHz), and of signal round-trip time between station and satellite at deep-space distances, which can be some ten minutes.

The station integration

At system level, the multi-support role imposed on the station system was implemented by integrating interfaces (switching units) into the station configuration which allow the operator to rapidly reconfigure the station signal flow. The basic concept has been to optimise the maintenance of the system by standardising the interfaces as far as possible at rack level and to equip the racks with interface panels from which all the rack functions can be tested. Whenever feasible, redundant equipment has been installed in different racks to provide the possibility of locally testing equipment items while providing undisturbed operation via the redundant unit.

A list of the industrial companies who were involved in the procurement of the different station subsystems is presented in Table 1.

Integration of the subsystems into the station was managed by ESOC's Stations and Communications Engineering Department (SCED). Wiring and rack mechanical assembly was carried out at ESOC by Elintech (Germany) under the direct supervision of SCED.

Station operation and testing

The Carnarvon station has been designed to be operated from a central position from the station monitor and control computer. From the computer keyboard the operator can select the station configuration required for a particular satellite and program the different subsystems for the support of a particular mission.

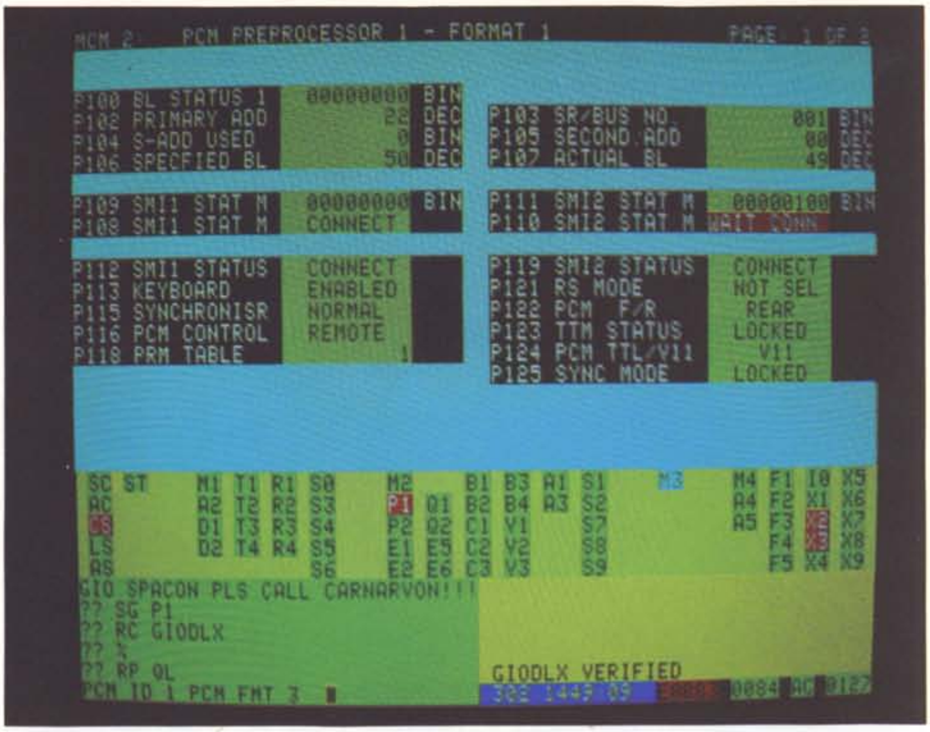


Figure 8 — The station Monitor and Control Computer Video Display Unit (VDU). The organisation of the different fields within the VDU allows the operator to monitor a particular item of equipment (upper field) while maintaining the overall view of system operability (middle field). The bottom field shows operator-generated control and other functions (operator-to-operator messaging, back-up telecommanding, etc.)

All the station monitoring parameters can be displayed on request on the computer Video Display Unit (Fig. 8). In addition, the computer performs limit checks on the equipment monitoring parameters and warns the operator in the event of an equipment malfunction. In the event of a breakdown in the data lines between the station and the control centre, the operator can use the station computer to generate backup telecommanding to the spacecraft and to display the received telemetry data for verification purposes.

The Carnarvon station is also equipped with integrated testing facilities which can be activated at the operator's request via the station node by the monitor and control computer. This facility not only represents a useful maintenance tool, but also provides a means of pre- or post-pass calibrating station performance. The station is maintained and operated by the Overseas Telecommunication Commission (OTC) of Australia, under contract to ESOC's Network Operations Division.

Conclusion

The system performance of the new Carnarvon station and its configurational flexibility allow it to cope with a wide range of ground-support requirements, from geostationary-transfer-orbit needs to deep-space missions. This has been achieved by the integration of high-technology subsystems specially developed for ESA by European industry, the S/X-band feed developed in conjunction with MBB being a good example.

The system's operation requires a minimum of effort in the sense that the station can be operated from one single position, via a centralised monitor and control computer. Station maintenance is facilitated by the provision of semi-automatic testing facilities which can be activated by the station operator via the monitor and control computer and by the implementation of well-defined integration standards, which allow maintenance of a particular unit with minimal interference to operational equipment.

The integrity of the station design concept and the system's ability to meet or exceed all performance specifications has been demonstrated by extensive validation testing and is now being proven by the successful operation of ESA's Giotto probe in deep space as it heads for its March encounter with Comet Halley.

Table 1 — The European companies involved in the provision of subsystems/equipment/services for the ESA ground station at Carnarvon

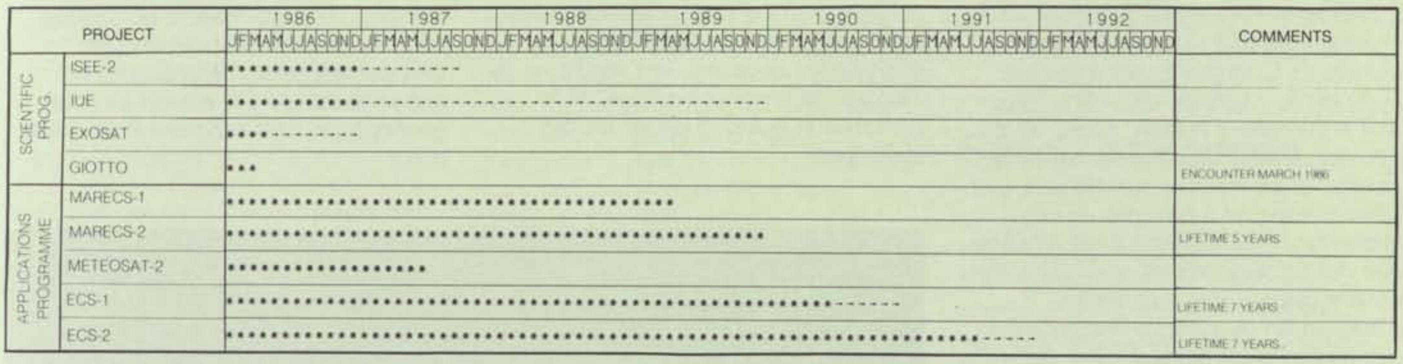
Company	Subsystem/Service
AEG (D)	Mains power generation
ATNE (F)	Interfaces (switching units), receivers, deep-space tracking subsystem
Bell Telephone Manufacturing Co. (B)	High-performance demodulator, tracking receiver
CERME (F)	Time generation and distribution
Continental Microwave Ltd. (UK)	Up-converter
Computer Resources International (DK)	Reed Solomon/convolutional decoder
Dateno (F)	High-power amplifiers
Dornier (D)	Baseband subsystem (TLM, TC, MCM)
Elintech (D)	Station wiring and general services
Honeywell Bull (D)	Station computer
Krupp (D)	S/X-band antenna structure; Servo and drive
LCT (F)	Parametric amplifiers and tone-ranging subsystem
Marcol (UK)	Front-end controller software development
MBB (D)	S/X-band antenna feed; RF and tracking design
Oscilloquartz (CH)	Frequency generation and distribution
Overseas Telecommunication Commission (Aus)	Site facilities (roads, civil works, mains power distribution etc.)
SESA (F)	Communications node
Softlab (D)	Station computer software development
Spinner (D)	S/X-band feed waveguide network, diplexers and waveguide subsystem

Acknowledgement

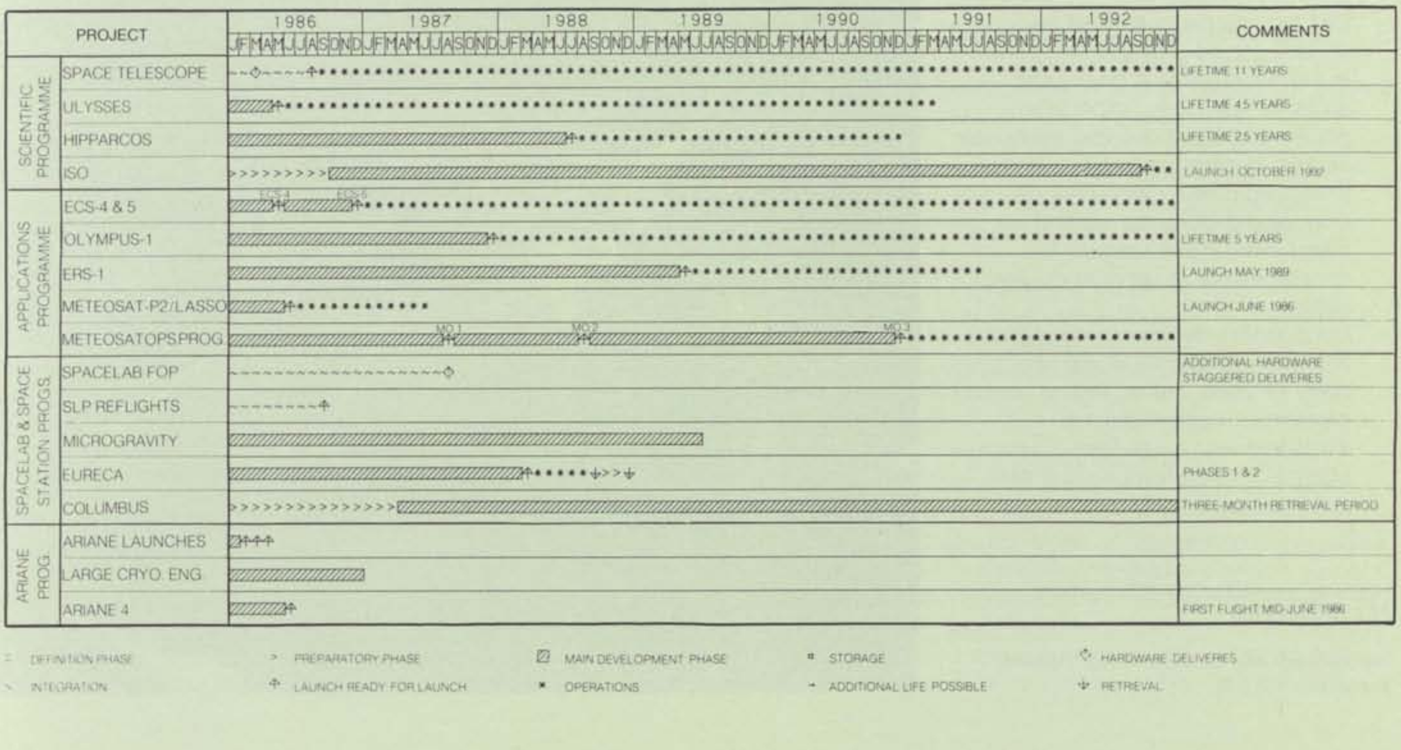
The author wishes to thank Mr. D. Runhaar of ESOC for his contribution to the success of this project, and Mr. A. Badrick of OTC-Carnarvon for the station staff's contribution to the installation and commissioning of the system.

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

In Orbit / En orbite



Under Development / En cours de réalisation



Geos-2

La dernière des quatre périodes de saisie de données de Geos-2, financée dans le cadre d'un programme spécial par l'Allemagne et la Suisse, a duré du 22 juillet au 24 août 1985. La saisie quotidienne de données a été possible pendant 12 heures sur 24. Cette réduction à 50% du temps théoriquement disponible provient du fait que l'attitude du satellite est optimisée en vue d'un éclairement maximal des panneaux solaires, avec cette conséquence que l'antenne en bande S à faisceau étroit n'est pas constamment orientée vers la station sol. A la fin de cette dernière période, on peut conclure que chacune de ces quatre périodes, sauf la première, a été fructueuse et a donné les résultats requis.

ISEE

Un événement majeur est intervenu dans ce programme le 11 septembre 1985 quand ISEE-3, rebaptisé 'Explorateur cométaire international' (ICE), a frôlé la comète de Giacobini-Zinner à environ 8000 km du noyau du côté de la queue (voir le précédent Bulletin, pages 32 à 39). Aucun dommage n'a été causé au satellite, et les résultats scientifiques sont remarquables, et à bien des égards inattendus. Il est également remarquable que des renseignements aussi bons aient pu être obtenus des instruments d'observation du plasma, des ondes et des particules de haute énergie qui étaient conçus à l'origine pour des explorations du vent solaire.

Certains des points les plus importants sont résumés ci-dessous:

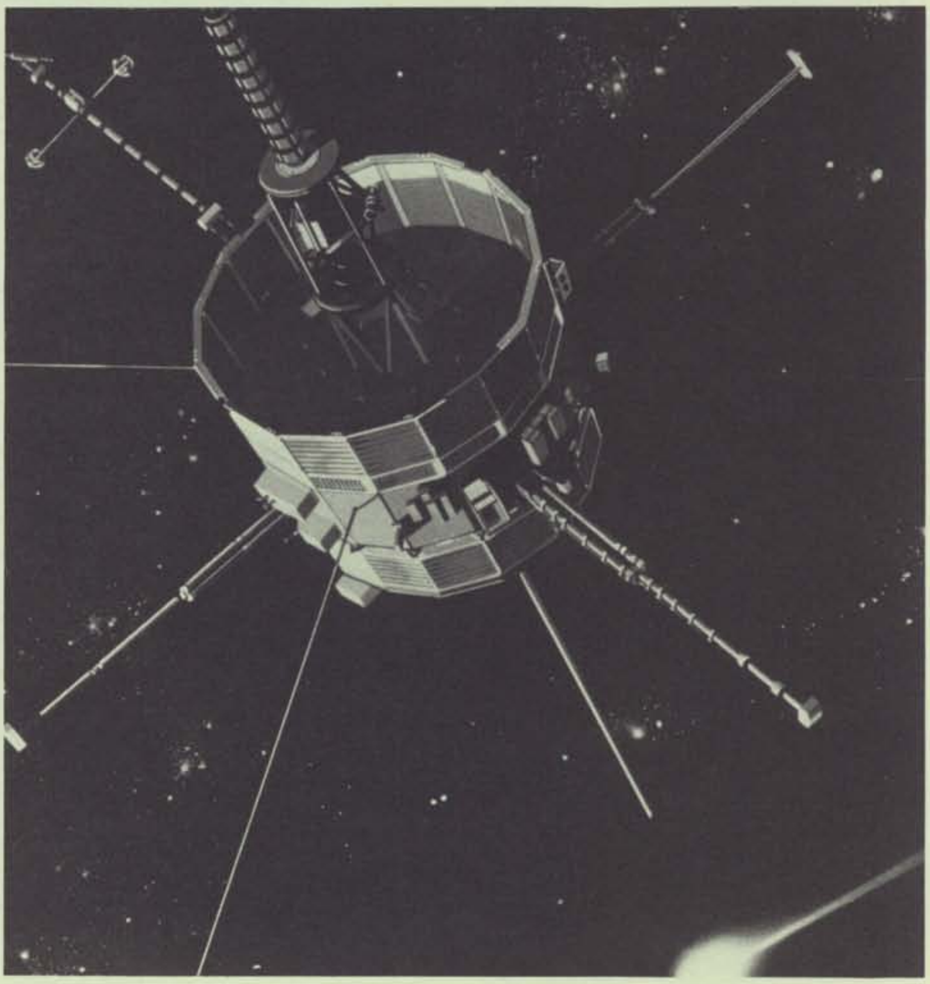
- *Des ions de haute énergie (plus de 30 keV) ont été détectés environ un jour avant et jusqu'à deux jours après la rencontre. L'explication vraisemblable est que des molécules neutres lourdes, probablement des molécules d'eau, parcourent de longues distances par rapport au noyau avant d'être ionisées et accélérées par le captage du vent solaire.*
- *Les données de champ magnétique ont révélé l'existence d'une structure claire de zone neutre dans la queue, exactement comme dans la magnétoqueue de la Terre. L'activité plasma-onde correspondante était très importante.*
- *La densité du plasma de faible énergie présentait un maximum étroit de l'ordre de 600 cm^{-3} dans la queue.*
- *H_2O^+ et CO^+ ont été identifiés comme les espèces les plus abondantes.*
- *Le compte d'impact de poussière, détectée par une antenne plasma-onde, était beaucoup plus faible que prévu.*

Ces résultats permettent d'espérer encore davantage de la rencontre de Giotto avec la comète de Halley le 13 mars.

Le satellite ISEE/ICE et sa charge utile scientifique avaient fonctionné pendant plus de six ans avant que ces excellentes mesures cométaires soient faites, ce qui est en soi un exploit notable. Les efforts de recueil de données de routine d'ISEE-1 et ISEE-2 et les efforts continus d'analyse des données scientifiques sont pour le moment éclipsés par les observations d'ICE. Cette partie du programme est néanmoins importante et continue d'être soutenue financièrement par la NASA en vue d'études scientifiques et de réunions régulières de 'l'équipe de travail scientifique', et la participation européenne est encore importante.

IUE

En octobre 1985, le programme scientifique européen d'IUE a été remis en route après une 'suspension' de deux mois due à la défaillance du gyroscope No. 3 le 17 août. Cette défaillance a laissé IUE avec seulement deux gyroscopes opérationnels. Une telle situation avait été prévue, et un logiciel de commande du satellite à deux gyroscopes, mis au point par le GSFC, a été mis en service aux deux stations sol d'IUE sans difficultés majeures. La stabilisation trois axes a été obtenue pas plus de 48 heures après la défaillance du gyroscope No. 3. La période de remise en service de deux mois s'est déroulée régulièrement. En effet, pendant cette période, 45% des observations programmées à l'origine ont été faites pour les cas présentant une urgence scientifique suffisante, par exemple observations coordonnées avec Exosat, mission ICE et autres. La mise en service du système à deux gyroscopes n'a provoqué qu'une dégradation tout à fait mineure des performances du satellite pour les observations scientifiques. Globalement, le seul effet a été une augmentation de 5% environ des frais généraux pour les expositions de courte durée.



Artist's impression of the ICE (formerly ISEE-3)spacecraft

Vue conceptuelle de satellite ICE (appelé auparavant ISEE-3)

Geos-2

The last of four data-acquisition periods of Geos-2, funded in the framework of a special programme by Germany and Switzerland, occurred from 22 July to 24 August 1985. Daily data acquisition was possible for 12 h out of 24 h. This reduction to 50% of the time theoretically available arises because spacecraft attitude is optimised for maximum solar-array illumination, with the consequence that the narrow beam S-band antenna is not pointing to the ground station continuously. At the end of this last acquisition period, it can be concluded that all but the first of the four such periods agreed in the framework of the special programme were successful and gave the required output.

ISEE

A major event occurred in this programme on 11 September 1985 when ISEE-3, renamed the International Cometary Explorer (ICE), passed Comet Giacobini-Zinner about 8000 km from the nucleus on the tailward side, as reported in the last issue of the Bulletin (pp. 32-39). No damage occurred to the spacecraft, and the scientific results are remarkable, and in many ways unexpected. It is also remarkable that such good information could be obtained from plasma, wave and high-energy particle instruments originally designed for solar-wind investigations.

Some of the highlights are summarised below:

- High-energy (larger than 30 keV) ions were detected approximately one day before and up to two days after the encounter. The likely explanation is that heavy neutral molecules, probably H_2O, travel long distances relative to the nucleus before being ionised and accelerated by solar-wind pick-up.
- The magnetic-field data showed a clear neutral-sheet structure in the tail, just like that in the Earth's magnetotail. Associated plasma-wave activity was very high.
- The low-energy plasma density had a narrow maximum of the order of 600 cm^{-3} in the tail.
- H_2O^+ and CO^+ were identified as the most abundant species.
- The dust-impact count, sensed by a plasma-wave antenna, was much lower than expected.

These results clearly enhance the expectations for the Giotto encounter with Comet Halley on 13 March.

The routine ISEE-1/ISEE-2 data taking and continued scientific data analysis efforts are at this moment overshadowed by the ICE observations. This part of the programme is, nevertheless, important and continues to be supported by NASA in terms of money for scientific studies and regular Science Working Team meetings and the European involvement is still high.

IUE

In October 1985 the European science programme for IUE was restarted after a 'suspension' of two months caused by the failure of gyro no. 3 on 17 August. This failure left IUE with only two operational gyros. Such an occurrence had been anticipated and two-gyro spacecraft control software developed by GSFC was implemented at both IUE ground stations without major difficulties. Three-axis stabilisation was achieved only 48 h after the failure of gyro no. 3. The recommissioning period of two months has proceeded smoothly. Indeed, during this time, 45% of the originally scheduled observations were made for those cases with sufficient scientific urgency, e.g. coordinated observations with Exosat, the ICE mission and others. Very little degradation of the spacecraft performance for science observations has resulted from the implementation of the two-gyro system. Overall, the only effect has been an increase of about 5% in the overhead for short exposures.

The lifetime estimate for IUE has not been affected by the gyro failure and, in anticipation of further gyro failures, a one-gyro control system has been conceptually accepted and work has started on it. The projected end of life for IUE, in the absence of a catastrophic failure, remains around 1990.

Exosat

Exosat, launched at the end of May 1983, has now been operational for almost three years. In August 1985, one of the eight detectors from the medium-energy (ME) experiment failed, but this has had little impact on the observation programme. The demand to use the observatory from the scientific community continues at a high level, far exceeding the actual time available. Exosat continues to provide an excellent and unique scientific return.

A significant fraction of Exosat's results have been obtained while the observatory was coordinated with IUE or ground-based facilities. In fact, a major success has been the continuing flexibility displayed by the observatory in performing coordinated observations. The multi-frequency results so far published in the literature and at conferences clearly indicate the worth of such observations. The number of coordinated observations will, however, be reduced in 1986, as a result of lifetime uncertainties and orbit modifications.

The observatory has continued to upgrade both the on-board application programmes and the ground-based scientific analysis software. These upgrades, mainly associated with the ME experiment, are a direct result of the high speed variability discovered in a number of compact X-ray sources and illustrate the flexibility of the on-board data handling system. The interactive analysis system made available to Exosat users from the beginning of 1985 has provided an additional service to observers, particularly those without major Exosat software facilities in their home institutes. It has usually been fully booked.

Space Telescope

NASA

The integration and test phase is proceeding, with some problems emerging in the test equipment and hardware. The launch date is currently 8 August 1986, but any serious problems during the forthcoming thermal-vacuum test in January 1986 could jeopardise the planning.

Solar array

Flight-wing 1 has been delivered to Lockheed/MSC, before completion of environmental tests in Europe, to allow an acoustic test of the complete Hubble Space Telescope to take place. The wing will be mounted in late December 1985 and the acoustic test will take place in the second half of January 1986.

Flight-wing 2 problems have been rectified and building up is proceeding. The blankets are due to be fitted in December 1985, and delivery is scheduled for May 1986.

Faint Object Camera

After reintegration of the FOC it was discovered that the performance of a photon detector assembly had degraded. Subsequent checks have shown further degradation and so the decision has been taken to replace the assembly with a spare during the period December 1985 — January 1986.

L'estimation de durée de vie l'IUE n'a pas été affectée par la défaillance du gyroscope et, en prévision d'autres défaillances de gyroscope, le concept d'un système de commande à un seul gyroscope a été accepté, et on a commencé à travailler sur ce système. La fin de la vie prévue pour IUE, en l'absence de défaillance catastrophique, reste aux alentours de 1990.

Exosat

Exosat, lancé à la fin du mois de mai 1983, est maintenant opérationnel depuis près de trois ans. En août 1985, un des huit détecteurs de l'expérience à moyenne énergie (ME) est tombé en panne, mais cela a eu peu d'incidence sur le programme d'observation. La demande d'utilisation de l'observatoire par les milieux scientifiques continue de se situer à un niveau élevé, dépassant de loin le temps réellement disponible. Exosat continue d'avoir un rendement scientifique excellent et unique.

Une fraction significative des résultats d'Exosat a été obtenue tandis que l'observatoire était coordonné avec l'IUE ou des installations basées au sol. En fait, un succès majeur a été représenté par la souplesse permanente dont a fait preuve Exosat dans l'exécution d'observations coordonnées. Les résultats multifréquence qui ont été jusqu'à présent publiés dans la littérature et lors de conférences indiquent clairement l'intérêt de telles observations. Le nombre des observations coordonées sera cependant réduit en 1986, par suite d'incertitudes sur la durée de vie et de modifications d'orbite.

L'observatoire a continué à perfectionner aussi bien les programmes d'application embarqués que le logiciel d'analyse scientifique basé au sol. Ces perfectionnements, associés principalement à l'expérience ME, sont un résultat direct des variations à grande vitesse découvertes dans un certain nombre de sources compactes de rayons X et illustrent la souplesse du système de traitement de données embarqué. Le système d'analyse interactive qui a été mis à la disposition des utilisateurs d'Exosat à partir du début de 1985 a fourni un service supplémentaire aux observateurs, en particulier à ceux qui ne disposent pas d'installations majeures de logiciel d'Exosat dans leurs instituts locaux. Il a habituellement été loué à sa pleine capacité.

Télescope spatial

Activités NASA

La phase d'intégration et d'essai progresse, avec quelques problèmes dans l'appareillage et le matériel d'essai. La date de lancement prévue est actuellement le 8 août 1986, mais des problèmes sérieux qui se poseraient pendant le prochain essai de vide thermique en janvier 1986 pourraient compromettre ce calendrier.

Générateur solaire

L'aile de vol No. 1 a été livrée à Lockheed/MSC, avant l'achèvement des essais d'ambiance en Europe, pour permettre d'effectuer un essai acoustique du télescope spatial Hubble complet. L'aile sera montée fin décembre 1985, et l'essai acoustique aura lieu dans la seconde moitié de janvier 1986.

Les problèmes de l'aile de vol No. 2 ont été résolus, et la construction est en cours. Les couvertures doivent être montées en décembre 1985, et la livraison est prévue pour mai 1986.

Caméra pour objets faibles (FOC)

Après réintégration de la FOC, on a découvert que les performances d'un ensemble détecteur de photons s'étaient dégradées. Des contrôles ultérieurs ont montré une nouvelle dégradation, aussi la décision a t-elle été prise de remplacer cet ensemble par un ensemble de rechange pendant la période décembre 1985–janvier 1986.

Hipparcos

Le programme d'essai et de vérification du modèle optique-structurel-thermique (OSTM) de charge utile s'est poursuivi de la façon la plus fructueuse. Suite à l'essai d'étude modale à Toulouse, la charge utile de l'OSTM a été expédiée en Belgique, pour y subir des essais de vide thermique dans l'installation FOCAL de l'Institut d'Astrophysique de Liège.

La chambre FOCAL est une installation totalement nouvelle qui n'a été achevée que juste avant la date de démarrage prévue de l'essai d'Hipparcos, et certains problèmes se sont posés avec la régulation thermique de la chambre, nécessitant un travail de réparation qui a retardé les préparatifs d'environ deux semaines. L'essai de vide thermique qui a en fait commencé le 25 octobre, a été mené efficacement, permettant de rattraper une partie du retard; il s'est terminé le 10 novembre. L'analyse préliminaire des résultats des essais a indiqué des performances satisfaisantes du système optique et de la régulation thermique de la charge utile.

Celle-ci a ensuite été expédiée à Toulouse, où elle subit actuellement des préparatifs pour de nouveaux essais optiques et mécaniques en même temps que le satellite.

Scale model of the Hipparcos satellite

Modèle à l'échelle du satellite Hipparcos

Hipparcos

The test and verification programme for the payload optical/structural/thermal model has continued quite successfully. Following the modal-survey test in Toulouse, the OSTM payload was shipped to Liège, Belgium, for thermal-vacuum testing in the FOCAL facility of the Liège Institute of Astrophysics.

The FOCAL chamber is a completely new facility completed only just prior to the planned start date of the Hipparcos test, and some problems arose with the chamber's thermal control necessitating repair work which delayed its readiness by about two weeks. The thermal-vacuum test actually started on 25 October 1985 and was conducted efficiently, enabling some recovery of the delay. The test was concluded on 10 November. Preliminary post-test analysis of results has indicated satisfactory performances of the spacecraft payload's optics and thermal control.

The payload was subsequently shipped to Toulouse, where it is being prepared for further optical and mechanical tests in combination with the spacecraft.

Activities have commenced on the payload engineering model with some of the payload electronic units already being successfully integrated. Integration and test activities on this model are scheduled to continue until late in 1986.

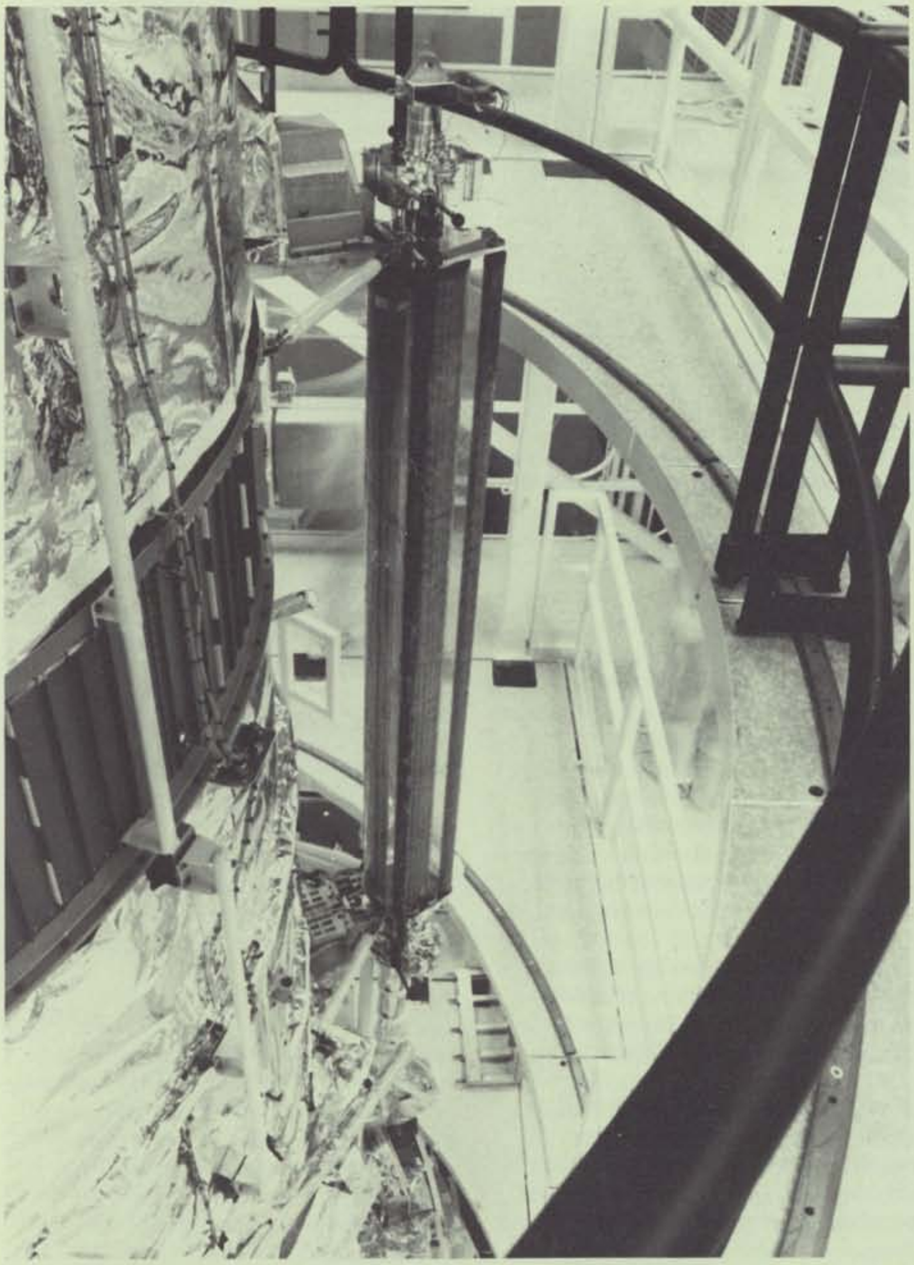
Spacecraft structural/thermal model test activities are underway, the spacecraft modal-survey and acceleration tests being successfully accomplished. This model is currently being prepared for coupled testing together with the payload model.

Preparations for the integration of the engineering-model spacecraft are in hand. The hardware and software activities are advancing well and should permit spacecraft integration to commence in January 1986 as planned.

Giotto

Giotto carries a scientific payload of 10 experiments. Since launch all experiments have been switched on and tested, starting with the Magnetometer and the Energetic Particles Experiment on 22 August, and finishing with the testing of the Dust Mass Spectrometer on 13 October. All experiments are functioning nominally. As the Magnetometer and the Energetic Particles Experiment both have memories, they remain switched on with memory data dumps every few days, and will in the end provide nearly continuous data from 22 August 1985 until 14 March 1986. The two Plasma Analysers and the Ion Mass Spectrometer have obtained measurements of the solar wind and its composition. They have been operated several times per week for many hours in the cruise science mode. Perhaps the most exciting results to date have been obtained from the Camera which has made observations of the star Vega, of Jupiter and, on 18 and 23 October, of the Earth (see cover and pages 96 and 97 of ESA Bulletin No. 44). The quality and resolution of the images showed that the Camera is functioning according to its design specifications.

The first formal Encounter Rehearsals were held on 14 and 16 October 1985, with all experiments operating in simulated encounter mode. The encounter time line was demonstrated and all relevant spacecraft and ground-system modes were successfully exercised according to the encounter scenario. Weekly payload operations are planned until the end of this year, with somewhat more intensive operations from January 1986 onwards, including six more formal rehearsals.



L'aile du générateur solaire du Télescope spatial au cours de vérification chez Lockheed/MSC en décembre 1985

Space Telescope solar-array wing (flight unit 1) being fit-checked at Lockheed/MSC in December 1985

Les activités sur le modèle d'identification de la charge utile ont commencé, certaines des unités électroniques ayant déjà été intégrées avec succès. Il est prévu que des activités d'intégration et d'essai sur ce modèle continueront jusqu'à la fin de 1986.

Les activités d'essai du modèle structurel-thermique du satellite sont en cours, les essais d'étude modale et d'accélération ayant été menés à bien. Ce modèle subit actuellement des préparatifs d'essais couplés avec le modèle de charge utile.

Les préparatifs d'intégration du modèle d'identification du satellite sont en cours. Les activités sur le matériel et le logiciel progressent bien et devraient permettre à l'intégration du satellite de commencer en janvier 1986 comme prévu.

The Giotto Main Control Room at ESOC, in Darmstadt

La Salle de contrôle Giotto à l'ESOC, Darmstadt

Giotto

Giotto emporte une charge utile scientifique de 10 expériences. Depuis le lancement, toutes les expériences ont été déclenchées et essayées, en commençant par le magnétomètre et l'expérience concernant les particules énergétiques, le 22 août, et en finissant par les essais du spectromètre de masse de poussière le 13 octobre. Toutes les expériences fonctionnent nominalement. Comme le magnétomètre et l'expérience concernant les particules énergétiques disposent tous deux de mémoires, ils restent en fonctionnement, les données contenues dans les mémoires étant vidées à quelques jours d'intervalle, et en fin de compte ils fourniront des données pratiquement continues du 22 août 1985 au 14 mars 1986. Les deux analyseurs de plasma et le spectromètre de masse d'ions ont obtenu des mesures du vent solaire et de sa composition. On les a fait fonctionner plusieurs fois par semaine pendant plusieurs heures dans le mode scientifique de croisière. Les résultats les plus stimulants qui ont été obtenues à ce jour sont peut-être ceux de la caméra, qui a réalisé des observations de l'étoile Vega, de Jupiter et, les 18 et 23 octobre, de la Terre (voir la page de couverture et les pages 96 et 97 du Bulletin No. 44). La qualité et la finesse des images ont montré que la caméra fonctionnait selon les spécifications.

Les premières répétitions formelles de la 'rencontre' ont eu lieu les 14 et 16 octobre 1985, toutes les expériences fonctionnant en mode de rencontre simulée. La chronologie de la rencontre a été démontrée, et tous les modes pertinents de fonctionnement du satellite et du système basé au sol ont été mis en oeuvre avec succès selon le scénario de la rencontre. Des opérations hebdomadaires de la charge utile sont programmées jusqu'à la fin de cette année, des opérations un peu plus intensives étant prévues à partir de janvier 1986, y compris six nouvelles répétitions formelles.

Olympus

Des revues de conception critiques permettant de revoir la conception de vol ont été complétées de manière satisfaisante pour la plupart des sous-systèmes de la plate-forme et de la charge utile.

Les deux séries d'esais de vibration sinusoïdale et aléatoire sur le modèle structurel de satellite, l'une avec la charge minimale de propergols factices et l'autre avec une charge maximale, correspondant respectivement à la mission minimale et à la mission maximale, ont été complétées avec succès. Ces essais ont mis en jeu près de 70 expériences séparées pendant la période d'essai de huit semaines et ont été suivis par des essais acoustiques du satellite. Il est prévu que de nouveaux essais, dans le programme d'essais dynamiques de ce satellite, seront complétés avant la fin de 1985.

La préparation du modèle thermique de satellite et de l'appareil fixe d'essai spécial est presque achevée pour l'essai infrarouge en différé au début de 1986. Les essais en temps réel du programme Olympus-1 ont été complétés il y a un an.

Les essais de base de tous les répéteurs de charge utile du modèle d'identification sont achevés. Une fois terminés les essais thermiques ultérieurs et les essais sur les panneaux, le module de communications sera adapté sur le module d'intervention et sera prêt pour les esais de système du modèle d'identification du satellite complet au cours de l'année 1986.

Les livraisons de matériel de vol ont continué. La structure du module de propulsion pour le prototype de modèle de vol de satellite a été livrée en octobre et l'intégration des éléments du matériel de propulsion a commencé. La structure du module d'intervention a reçu son équipement thermique et les faisceaux de câbles électriques ont été montés sur les panneaux du module de communications et sont prêts pour de nouvelles activités d'intégration.

Les contractants, qui ont été choisis après une phase d'offres concurrentielles, ont commencé la fabrication des stations sol destinées aux opérations d'Olympus en orbite. Le groupe de travail des stations terriennes s'est réuni en septembre pour échanger des informations techniques et discuter des expériences.

Olympus

Critical Design Reviews have been completed satisfactorily for more of the platform and payload subsystems.

The two series of sine and random vibration tests on the structural model spacecraft, one with the minimum loading of simulated propellants and the other with a maximum loading, corresponding to minimum and maximum missions, have been completed successfully. These tests involved nearly seventy separate runs during the eight-week test period and were followed by acoustic testing of the spacecraft. Further tests in the dynamic test programme with this spacecraft are planned to be completed before the end of 1985.

Preparation of the thermal model spacecraft and the special test fixture are nearing completion for the offline infrared test early in 1986. The online tests for the Olympus-1 programme were completed a year ago.

Baseline testing of all the engineering-model payload repeaters has finished. On completion of the subsequent thermal and panel-level testing, the communications module will be mated with the service module ready for system testing of the complete engineering-model spacecraft during 1986.

Deliveries of flight hardware have continued. The propulsion module structure for the protoflight model spacecraft was delivered in October 1985 and integration of the propulsion equipment items has started. The service-module structure has been thermally equipped and the electrical harnesses have been fitted to the panels of the communications module ready for further integration activities.

The successful contractors selected after a competitive proposal phase have started manufacture of the ground stations to be used for Olympus in-orbit operations. The Olympus earth-station working group met in September 1985 to exchange technical information and to discuss experiments.

ERS-1

The spacecraft's design was thoroughly reviewed during the Development Baseline Review, first at instrument and subsystem level, and finally at system level in October and November 1985. During the Review a number of areas were identified where further work is required to establish the system fully, but no major critical items were found. As a result, engineering-model manufacture can gradually be commenced.

The Ariane launch of the spacecraft has been scheduled for the period May/June 1989, and negotiations on the associated launch contract have been initiated.

A comparative assessment has been made of the various alternative ground-station configurations for low-bit-rate data acquisition. On the basis of this assessment, the Remote-Sensing Programme Board selected the option comprising Kiruna (Sweden), Maspalomas (Spain), and Gatineau (Canada). Fucino (Italy) can also be used.

Spacelab and IPS

After the successful completion of the Spacelab-2 mission on 6 August 1985, the European obligations towards NASA, as defined in the Cooperative Agreement signed in 1973, have virtually been completed. However, there are still several open work items in the process of being completed. These include the investigation and correction of the small number of anomalies observed in the Spacelab and IPS systems during the Spacelab-2 flight and the closeout of formal exceptions recorded during the customer acceptance of the hardware and software from ESA's contractors.

Problems encountered during the Spacelab-2 mission and currently being worked upon in Europe are as follows:

- The pre-flight failure of one experiment computer has been traced to a component inside the unit. This computer is with the supplier (CIMSA) for repair and retest, for completion in December 1985.
- The in-flight anomalous working of the IPS optical sensor package has been traced to one of the three Fixed Head Star Trackers (FHST). The unit has been returned to Dornier System for further investigative testing. The purpose of these tests is to reproduce the failure and isolate the exact cause, to determine the necessary repair.
- On one of the Data Display Units (DDU) of the Spacelab System, shutdown was observed during the mission at a certain temperature level at which the DDU was expected to continue operation. The supplier is preparing recommendations.

Development and qualification of a Payload Interface Adaptor (PIA) to enhance Spacelab's experiment capabilities is in progress. The flight units of this device are expected to be available in mid-1986, the Eureca project being the first identified user of this new adaptor.

Follow-on Production
The FOP activities for Spacelab and IPS hardware are continuing on schedule. Deliveries of spares to NASA are being made on the planned dates. Four Experiment Racks and other hardware, with a total value of about 15 million German marks, have been added to the Spacelab FOP contract through negotiations conducted by the Agency with NASA/MSFC and MBB/ERNO. This extends the FOP spares delivery schedule for MBB/ERNO into August 1987.

Dornier System's FOP delivery schedule for IPS spares is planned to be completed in June 1985.

Microgravity

D1 mission
Three ESA payloads, representing about one third of the critical resources for experiments (mass, energy and crew time), were flown on the German D1 Spacelab Mission, launched on 30 October 1985. These payloads were:

- Vestibular Sled
- Fluid Physics Module
- Biorack.

Vestibular sled
The Sled is a reusable multi-user Spacelab facility intended to support research under weightless conditions in the general field of neuro-physiology. During this mission, the emphasis was placed on the investigation of the behaviour of the human vestibular system.

The Sled and all supporting equipment worked to the full satisfaction of the investigators, who followed the experiments from the Control Center at Johnson Space Center (USA). Before and after the flight an extensive measurement programme has been carried out on the crew in order to obtain a reference basis for comparison.

Fluid Physics Module (FPM)
The FPM is a multi-user facility dedicated to the study of basic fluid phenomena in space. Experiments on Marangoni convection, fluid motion, floating zone by aerodynamics, capillary effects, etc., were performed. The FPM worked very

ERS-1

La conception du satellite a été revue dans le détail pendant la 'Revue de référence du développement', d'abord au niveau instruments et sous-systèmes, et enfin au niveau système, en octobre et novembre. Pendant cette revue, il est apparu qu'un certain nombre de secteurs exigent des travaux complémentaires pour établir totalement le système, mais aucun élément critique majeur n'a été découvert. Par suite, la fabrication du modèle d'identification peut être entreprise progressivement.

Le lancement du satellite par Ariane a été programmé pour la période de mai-juin 1989, et les négociations sur le contrat de lancement correspondant ont été entamées.

Il a été procédé à une évaluation comparative des diverses configurations de rechange possibles de stations sol pour la saisie de données à faible débit binaire. A partir de cette évaluation, le Conseil directeur du Programme de Télédétection a choisi l'option comprenant Kiruna (Suède), Maspalomas (Espagne) et Gatineau (Canada). Fucino (Italie) pourra également être utilisée.

Spacelab et IPS

Après le succès de la mission Spacelab-2, achevée le 6 août 1985, les obligations européennes envers la NASA, telles qu'elles sont définies dans l'accord de coopération signé en 1973, sont pratiquement terminées. Il reste cependant encore plusieurs tâches ponctuelles en cours d'achèvement. Elles comprennent l'examen et la correction de quelques anomalies observées dans les systèmes Spacelab et IPS pendant le vol de Spacelab-2 et la liquidation des procédures d'exception prévues lors de l'acceptation par les clients du matériel et du logiciel fournis par les contractants de l'ESA.

Les problèmes rencontrés pendant la mission Spacelab-2 et sur lesquels on est en train de travailler en Europe sont les suivants:

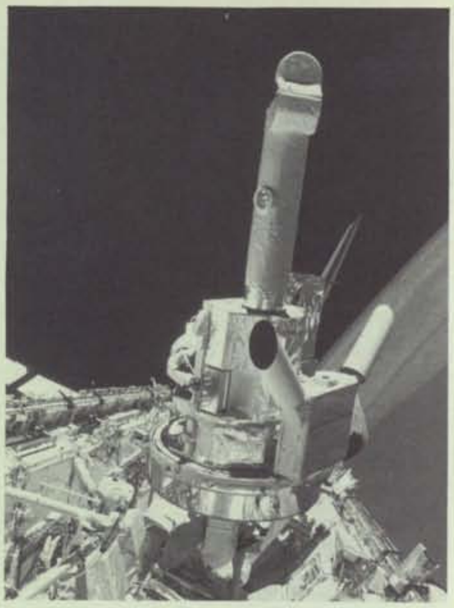
- *La défaillance avant le vol d'un ordinateur d'expérience a été attribuée à un composant situé à l'intérieur de cette unité. Cet ordinateur est chez le fournisseur (CIMSA) pour réparation et nouvel essai, qui doivent être terminés en décembre 1985.*
- *Le fonctionnement anormal en vol du groupe de capteurs optiques de l'IPS a pu être attribué à l'un des trois suiveurs stellaires à tête fixe (FHST). Cette unité a été renvoyée à Dornier System pour de nouveaux essais exploratoires. Le but de ces essais est de reproduire la défaillance et d'en isoler la cause exacte, pour déterminer la réparation nécessaire.*
- *Sur l'une des unités d'affichage de données (DDU) du système Spacelab, un arrêt de fonctionnement a été observé pendant la mission à un certain niveau de température auquel la DDU est censée continuer à fonctionner. Des recommandations sont en cours de préparation par le fournisseur.*

La mise au point et la qualification d'un adaptateur d'interface de charge utile (PIA) permettant d'améliorer les capacités d'expérience de Spacelab sont en cours. Les unités de vol de ce dispositif devaient être disponibles à la mi-1986, le projet Eureca étant le premier utilisateur prévu pour ce nouvel adaptateur.

Production ultérieure (FOP)

Les activités FOP concernant le matériel Spacelab et l'IPS se poursuivent comme prévu. Les livraisons de pièces de rechange à la NASA s'effectuent aux dates prévues. Quatre porte-expériences et autres matériels, d'une valeur totale d'environ 15 millions de DM, ont été ajoutés au contrat FOP, grâce à des négociations menées par l'Agence avec NASA/MSFC et MBB/ERNO. Cela prolonge jusqu'à août 1987 le calendrier de livraison de pièces de rechange de FOP par MBB/ERNO.

Le calendrier de livraison de FOP de Dornier System pour les pièces de rechange de l'IPS devrait prendre fin, selon les prévisions, en juin 1986.



IPS in orbit aboard the Shuttle/Spacelab-2 in August 1985

IPS à bord du Spacelab-2 en août 1985

Microgravité

Mission D1

Trois charges utiles de l'ESA, représentant environ le tiers des ressources critiques pour les expériences (masse, énergie et emploi du temps de l'équipage) ont été embarquées sur la mission Spacelab D1 allemande, lancée le 30 octobre 1985. Ces charges utiles étaient:

- *le Traîneau vestibulaire*
- *le Module de physique des fluides*
- *Biorack.*

Traîneau vestibulaire

Ce Traîneau est une installation multi-utilisateur réutilisable de Spacelab destinée à permettre des recherches, dans des conditions d'apesanteur, dans le domaine général de la neurophysiologie. Pendant cette mission, l'accent a été mis sur l'étude du comportement du système vestibulaire humain.

Le Traîneau et tout le matériel de soutien ont fonctionné à la pleine satisfaction des expérimentateurs, qui ont suivi les expériences depuis le Centre de direction des opérations au Centre Spatial Johnson (Etats-Unis). Avant et pendant le vol, un programme très complet de mesure a été mené à bien sur les sujets d'essai, c'est-à-dire sur l'équipage, afin d'obtenir une base de référence à des fins de comparaison.

Module de physique des fluides (FPM)

Le FPM est une installation multi-utilisateur consacrée à l'étude des phénomènes fluidiques fondamentaux dans l'espace. Des expériences sur la convection de Marangoni, le mouvement des fluides, la zone flottante par aérodynamique, les effets capillaires, etc., ont été effectuées. Le FPM a fonctionné de manière très satisfaisante. Les expérimentateurs ont pu suivre leurs expériences depuis le Centre de direction des opérations situé à Oberpfaffenhofen en Allemagne, et avoir des échanges avec l'équipage pendant les périodes de couverture par les télécommunications.

Biorack

Au cours du dernier mois précédant le vol de Biorack sur la mission allemande D1 en novembre, les derniers préparatifs de ce vol ont été complétés au Centre satisfactorily. The investigators could follow their experiments from the German Control Centre in Oberpfaffenhofen and interact with the crew during periods of telecommunications coverage.

Biorack
During the last month prior to Biorack's flight on D1 the final preparations were completed at Kennedy Space Center (KSC), including in particular:
- installation of the 'ground-truth' laboratory equipment at KSC
- a complete flight simulation with the Principal Investigators present
- simulation of the late access to the Space Shuttle
- a final overall review of launch readiness (including the organisation of the flight/ground cooperative operations during the flight).

Preparation of the biological samples and their handover to the NASA ground crew ran very smoothly. The samples were stored in the Passive Thermal Conditioning Units (PTCUs) for transfer to the Orbiter mid-deck locker 11 h prior to the actual launch.

During the mission, all Biorack activities were performed as scheduled, both in Spacelab itself and on the ground-based Biorack thermal model, installed at KSC in the Life Science Support Facility (LSSF).

The Biorack system, which includes the Biorack flight model, the Biorack thermal model, the LSSF for preparation and analysis of biological samples, and the communication lines between the German Space Operations Centre (GSOC) and KSC all performed as expected.

A preliminary review of the scientific results was held at KSC on 9 November 1985. There is already some evidence that some cell biological processes are affected by gravity forces. Detailed evaluation of the scientific results will require several months.

Anthrorack
The definition study (Phase-B) is proceeding according to plan and the mid-term presentation was held in December 1985. In parallel, more than 50 experiment proposals are being evaluated.

Fluid Physics Double Rack
Definition work is currently in progress. Two competitive offers for Phase-B of the Bubble, Drop and Particle Unit (BDPU) are under evaluation. The Request for Experiment Proposals for the Critical Point Facility and Fluid Physics Module for flight on the Spacelab D2 mission has been released.

Microgravity Core Payloads on Eureca
The main development (Phase-C/D) of the five core payload facilities is well underway. The Preliminary Design Reviews, resulting in the start of manufacture of the engineering models, have been completed.

Biorack

IML-1 mission
Advantage has been taken of the presence of the Biorack D1 team in the US to hold a number of coordination and interface meetings with NASA/MSFC, the centre responsible for the integration of the International Microgravity Laboratory (IML) payload.

These meetings have been very useful for the preparation of the Biorack IML activities. In particular, safety aspects associated with the new Biorack experiments on IML have been discussed.

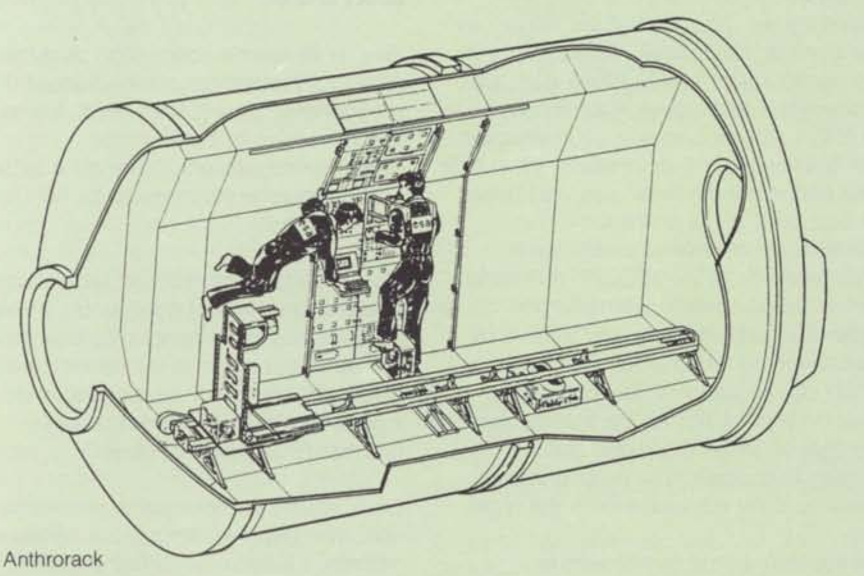
The contracts for refurbishing and extending the Biorack hardware have been placed with industry and the work is progressing at full speed in order to meet the IML-1 schedule, which requires the refurbished Biorack to be delivered to NASA during September 1986 for integration into the IML-1 Spacelab.

Space Station/Columbus

Phase-B1 study work has progressed steadily and two more significant project reviews have been successfully conducted. The first, the Mid-Term Review, concentrated on the establishment of an updated Reference Configuration compliant with the previously established System Requirements Report. This configuration definition was used in extensive technical discussions with NASA to agree on module operating pressure, hatch sizes, safe-haven approaches, Environmental Control and Life Support System (ECLSS) philosophy within the US/International Space Station, platform sizing, platform operating altitude and propellant-option selection. The Station's power-distribution characteristics were also scheduled for resolution, but this item is still outstanding.

The second of the reviews, the Programmatics Review, focussed on the implementation and planning of the future design and main development phases (C/D), to make a first estimate of the associated costs, to estimate the costs for the operational/utilisation phase and the associated European ground control infrastructure. Eleven different combinations of programme hardware content and operational scenarios were costed in this exercise. The synthesis of the data evaluated at this review was presented to the Columbus Programme Board in readiness for the conduct of a level-1 Memorandum of Understanding (MOU) milestone meeting, to be held in December 1985, at which ESA will indicate to NASA the currently proposed participation of Europe in the international Space Station.

Meetings have been held with Ariane-5 and Hermes representatives and specific compatability studies and utilisation studies have been initiated with


Anthrorack

Spatial Kennedy (KSC), comprenant en particulier:
- *l'installation du matériel de laboratoire 'réalité de terrain' au KSC;*
- *une simulation de vol complète en présence des 'chercheurs principaux';*
- *simulation de 'l'accès au dernier moment' à la Navette spatiale;*
- *une revue d'ensemble finale des préparatifs de lancement (y compris la coordination des opérations entre l'équipage en vol et le personnel au sol).*

La préparation des échantillons biologiques et leur remise à l'équipage de la NASA au sol, se sont déroulées sans encombre. Les échantillons ont été stockés dans les 'unités de conditionnement thermique passif' (PTCU) en vue de leur transfert dans le coffre du pont intermédiaire de l'Orbiteur 11 heures avant le lancement réel.

Pendant la mission, toutes les activités de Biorack ont été exécutées comme prévu, aussi bien dans le Spacelab lui-même que dans le modèle thermique de Biorack installé au KSC dans l''installation de soutien des sciences de la vie' (LSSF).

L'ensemble du système Biorack – qui comprend le modèle de vol, le modèle thermique, la LSSF pour la préparation et l'analyse des échantillons biologiques, et les lignes de communications entre le 'Centre allemand des opérations spatiales' (GSOC) et le KSC – s'est comporté de façon entièrement satisfaisante.

Une revue préliminaire des résultats scientifiques a eu lieu au KSC le 9 novembre 1985. Un premier examen montre déjà que certains processus biologiques cellulaires sont influencés par les forces de gravité. Une évaluation détailllée des résultasts scientifiques demandera plusieurs mois.

Anthrorack
L'étude de définition (phase B) se déroule selon les prévisions, et la présentation de mi-projet a eu lieu en décembre 1985. Parallèlement, plus de 50 propositions d'expérience sont en cours d'évaluation.

Double support de physique des fluides
Le travail de définition est actuellement en cours. Deux offres compétitives concernant la phase B de l''Unité Bulles, Gouttes et Particules' (BDPU) sont en cours d'évaluation. L'appel aux propositions d'expérience pour l'Installation de Point Critique et le Module de Physique des Fluides en vue de leur vol sur la mission Spacelab D2 a été lancée.

Charges utiles principales de microgravité sur Eureca
Le développement (phase C/D) des cinq installations de charge utile principales est bien avancée. Les revues de conception préliminaires, conduissant au démarrage de la fabrication des modèles d'identification, ont été complétées.

Biorack

Mission IML-1
On a tiré parti de la présence de l'équipe de Biorack D1 aux Etats-Unis pour tenir un certain nombre de réunions de coordination et de liaison avec le MSFC de la NASA, qui est le centre responsable de l'intégration de la charge utile du 'Laboratoire international de Microgravité' (IML).

Ces réunions ont été très utiles pour la préparation des activités Biorack relatives à l'IML. En particulier, les aspects concernant la sécurité qui sont associés aux nouvelles expériences Biorack ont été discutés.

Les contrats de remise à neuf et d'extension du matériel Biorack ont été passés avec l'industrie, et les travaux avancent à grande vitesse afin de respecter le calendrier d'IML-1, qui exige que le nouveau Biorack soit livré à la NASA pendant le mois de septembre 1986 en vue de son intégration dans le Spacelab d'IML-1.

Station spatiale/Columbus

Le travail d'étude de la Phase-B1 a progressé régulièrement et deux revues de projet plus importantes ont été menées avec succès. La première, c'est-à-dire la 'Revue à mi-projet', s'est concentrée sur l'établissement d'une configuration de référence mise à jour conforme au 'Rapport sur les exigences du système' déjà établi. Cette définition de configuration a été utilisée dans des discussions techniques approfondies avec la NASA afin de convenir de la pression de fonctionnement du module, de la taille des panneaux ouvrants, des approches 'à bon port', de la philosophie du 'système de contrôle d'ambiance et d'entretien de la vie' (ECLSS) à l'intérieur de la Station spatiale internationale, de la taille des plates-formes, de l'altitude de fonctionnement des plates-formes et du choix des propergols. La solution du problème posé par les caractéristiques de l'altimentation électrique dans la Station était également programmée, mais ce point n'a pas encore été réglé.

La seconde revue ou 'Revue de programmatique', s'est concentrée sur la mise en oeuvre et la planification des phases futures de conception et de développement principale (C/D), afin de procéder à une première estimation des coûts correspondants, et d'estimer les coûts de la phase opérationnelle et d'utilisation ainsi que de l'infrastructure européenne correspondante de commande au sol. Dans ce travail, le coût de onze combinaisons différentes de contenu du matériel de programme et de scénarios opérationnels a été évalué. La synthèse des données évaluées lors de cette revue a été présentée au Conseil directeur du Programme Columbus en préparation d'une réunion intermédiaire de niveau 1 sur un Protocole d'Accord (MOU) prévue pour le mois de décembre 1985, lors de laquelle l'ESA indiquera à la NASA la part que l'Europe se propose alors de prendre la Station spatiale internationale.

Des réunions ont eu lieu avec les représentants d'Ariane-5 et d'Hermes, et des études spécifiques sur les aspects compatibilité et utilisation ont été entamées avec les contractants de Columbus pour compléter la définition des interfaces techniques et opérationnels potentiels entre les trois projets.

La mise en oeuvre du 'Programme de soutien technologique' est maintenant en cours avec le lancement d'un certain nombre d'appels d'offres et l'évaluation des réponses correspondantes. L'autorisation de mise en route de onze contrats a déjà été donnée, seize propositions sont en train d'être examinées activement, et dix contrats sont au stade de la rédaction des appels d'offres ou attendent que leur date de commencement soit fixée.

Eureca

Avec la Revue de conception du système (ESDR) d'Eureca qui est maintenant programmée pour janvier 1986, la phase de conception et de montage expérimental parviendra bientôt à sa fin, et la production du matériel de vol commencera.

Une importante réunion de liaison avec l'ensemble des responsables de la mise au point des instruments d'Eureca a eu lieu au début du mois de décembre pour établir définitivement les exigences de logiciel et d'opérations en vue des phases d'intégration et de vol.

Deux études d'implantation de charge utile type pour le 'télescope à rayons gamma d'Eureca (GRETEL) et pour l'appareillage d'adaptation de la physique

Columbus contractors to further the definition of potential technical and operational interfaces between the Columbus project and the Ariane-5/Hermes programmes.

The Supporting Technology Programme's implementation is now underway with the issuing of a number of Invitations to Tender (ITTs)/ Statements of Work (SOWs) and evaluation of the associated responses. Authorisation to proceed on eleven contracts has been given, sixteen proposals are under active review, and ten contracts are at the ITT draft stage.

Eureca

With the Eureca System Design Review (ESDR) now scheduled for January 1986, the design and breadboarding phase will soon come to an end and the production of flight hardware will commence.

A major interface meeting with all Eureca instrument developers was held in early December to finalise the software and operations requirements for the integration and flight phases.

Two model-payload-accommodation studies for the Gamma-Ray Eureca Telescope (GRETEL) and Solar-Physics Adaptation (SOPHYA) missions in support of ESA's Science Programme were completed in October 1985.

In response to a Call for Proposals, the Science Directorate have received numerous experiment proposals, which together would fill at least five Eureca platforms. On the basis of these responses, the ESA Executive intends, within the Implementation Plan for Space Science Horizon 2000, to request approval for a Eureca Utilisation Programme. If this approval is forthcoming, an Announcement of Opportunity for scientific experiments will be issued in early 1986.

With the anticipated new flights for microgravity and space-technology demonstrations, the total number of potential flights identified so far is approximately 10. Consideration is therefore being given to the employment of a second Eureca, suitably adapted to scientific needs.

The studies of in-orbit re-fuelling and exchange of equipment by the use of so-called 'Orbit Replaceable Units' (ORUs), proximity operations and extended Eureca flight durations are proceeding well and the results will become available in February 1986.

Ariane

The work carried out following the failure of the Ariane-3 V15 launch (with ECS-3 and Spacenet F3) on 12 September 1985 has been conducted in accordance with the recommendations of the Board of Enquiry, namely:

- alteration of the design of the third stage LH_2/LOX injection valves
- definition of a new, more stringent qualification and acceptance test programme
- improvement of the flight-data processing procedure
- review of the configuration of five critical launcher elements.

The injection valve design has been modified, reverting to an improved version of the original design used up until the L07 launch which has proved more reliably leak-free in a transient cold environment. This technical change, based on a thermal/mechanical model analysis of the combined valve core and seal holder, was validated through development of the process for seal preforming before assembly; analysis of the sealing material (KEL'F) has also led to better understanding and control of the overall behaviour of the valve under all conditions of use.

The qualification programme was performed on two valves (LH_2/LOX) in order to simulate every operational cycle at equipment, engine and stage level. In addition to ambient temperature running tests, the valves were subjected to repeated cooling down sequences on an inert engine plus four test firings on a functional engine. They were also subjected to vibration testing at qualification levels, both at ambient and cryogenic temperatures.

All the tests were successfully conducted:

- during ambient and cryogenic temperature testing (including vibration testing);any leaks have remained well within the newly specified criteria
- cooling-down cycles using LH_2/LOX revealed no detectable leakage
- test firings confirmed the correct functioning of the engine.

This qualification programme was completed in mid-December 1985 and will be followed up in the first half of 1986 by a life and ageing test programme on two more valves.

Acceptance testing has also been tightened, in particular through the introduction of additional cooling down sequences (LH_2/LOX) on the inert engine.

Flight-model valves for V16, V17 and V18 successfully completed this last screening before installation on the respective engines. Production of the valves for later flights has also begun.

The flight-data processing procedure has been improved in two respects:

- by systematic use of the flight data computer system ('EAGLE') developed by CNES under ESA contract
- by establishing the working procedure of specialist teams to cover the analysis of all launcher systems.

Under this new scheme, all the results for preliminary flight processing are submitted before the next flight to the Steering Committee for flight readiness reviews.

Finally, the review of the configuration of five critical items at launcher level has made it possible to evaluate their qualification status after the above modifications. Certain protective measures (further analysis) were taken to confirm the validation of the items under consideration.

solaire (SOPHYA), à l'appui du programme scientifique de l'ESA, ont été complétées en octobre 1985.

En réponse à un appel à propositions, la Direction des programmes scientifiques a reçu de nombreuses propositions d'expérience, qui occuperaient ensemble au moins cinq plates-formes Eureca. A partir ces réponses, l'Exécutif de l'ESA a l'intention, dans le cadre du plan de mise en oeuvre de la science spatiale à l'horizon 2000, de solliciter l'approbation d'un programme d'utilisation d'Eureca. Si cette approbation ne se fait pas trop attendre, un appel aux expériences scientifiques sera lancée au début de 1986.

Avec les nouveaux vols qui sont prévus pour les démonstrations de microgravité et de technologie spatiale, le nombre total de vols potentiels identifiés jusqu'à présent est de 10 environ. C'est pourquoi on envisage actuellement d'utiliser une seconde plate-forme Eureca, adaptée de manière appropriée aux besoins scientifiques.

Les études sur le ravitaillement en vol, l'échange de matériel à l'aide d''unités remplaçables en orbite' (ORU), les opérations en phase de proximité et les durées de vol prolongées d'Eureca se déroulent bien, et les résultats en seront disponibles en février 1986.

Ariane

Les travaux menés suite à l'échec, le 12 septembre 1985, du lanceur Ariane 3-V15 (ECS-3–Spacenet F3) ont été définis conformément aux recommandations de la Commission d'Enquête. Ils ont essentiellement porté sur:
- *la modification de conception des vannes d'injection d'hydrogène et d'oxygène liquides (vannes identiques) du moteur du 3ème étage,*
- *la définition d'un nouveau programme de qualification et d'essais de recette plus sévères*
- *l'amélioration de la procédure d'exploitation des résultats de vol*
- *la revue de configuration de cinq éléments critiques du lanceur.*

La conception des vannes d'injection a été modifiée pour revenir à une version améliorée de celle utilisée jusqu'au lancement L7, pour laquelle l'étanchéité en froid transitoire s'avérait être plus fiable. Cette modification, établie à partir de modélisation thermo-mécaniques de l'ensemble boisseau-porte joint, a été validée par la mise au point du procédé de préformage du joint avant montage; un programme de caractérisation du matériau constituant le joint (KEL'F) a également permis de mieux comprendre et de maîtriser le comportement de l'ensemble pour toutes les conditions d'utilisation.

Le programme de qualification a été effectué sur deux vannes (LH_2 et LOX) de façon à simuler tous les cycles d'opérations aux niveaux équipement, moteur et étage. Outre les opérations à température ambiante, le programme comportait une des séquences répétées de mise en froid réelle des vannes sur un moteur maquette et d'essais au banc à feu sur un moteur fonctionnel. Les vannes ont également été soumis aux essais de qualification en vibrations, tant à la température ambiante qu'en froid.

Toutes les épreuves ont été effectuées avec succès:
- *pour les essais à température ambiante et à froid (dont les vibrations), les fuites sont restées très inférieures au nouveau critère spécifié*
- *les mises en froid réelles à l'hydrogène et l'oxygène liquides n'ont pas révélé de fuites détectables*
- *les essais à feu ont confirmé le bon fonctionnement du moteur.*

Ce programme de qualification s'est achevé en mi-décembre 1985; il sera prolongé au cours du premier semestre 86 par un programme compléntaire d'endurance et de vieillissement qui sera effectué sur deux vannes supplémentaires.

Les essais de recette ont également été renforcés, avec en particulier l'introduction des épreuves supplémentaires de mises en froid réelles (LH_2 et LOX) sur le moteur-maquette. Les vannes de vol pour V16-V17 et V18 ont subi avec succès ce dernier 'filtre' avant d'être montées sur leur moteur respectif. Le cycle de production est en cours pour les vannes de vols ultérieurs.

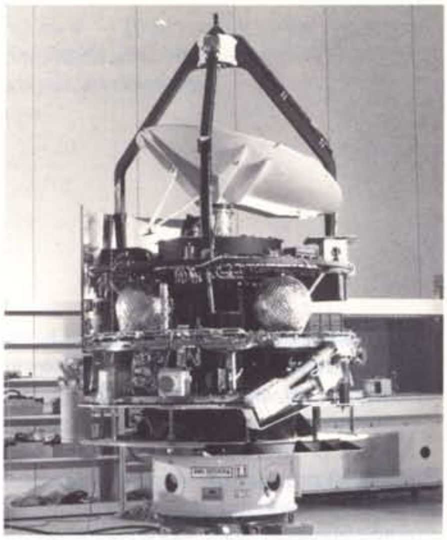
Le procédure d'exploitation des résultats de vol a été améliorée:
- *d'une part par l'utilisation systématique du système informatique de traitement des données de vol (système 'AIGLE') développé par le CNES sous contrat ESA,*
- *d'autre part par l'organisation de la procédure de travail des groupes d'experts couvrant l'analyse de tous les systèmes du lanceur.*

Selon ces nouveaux moyens tous les résultats de l'exploitation préliminaire d'un vol sont présentés avant le vol suivant au Comité Directeur des revues d'aptitude au vol.

Aerial view of the ELA-2 launch facility

Vue aérienne des installations ELA-2

La revue de configuration de cinq éléments critiques sélectionnés au niveau du lanceur à permis d'évaluer leur état de qualification suite aux modifications introduites. Certaines mesures conservatoires ont été apportées (analyses complémentaires) pour justifier la validation des éléments concernés.



The Giotto Assembly, Integration and Verification Programme

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The Assembly, Integration and Verification (AIV) programme for the Agency's Giotto satellite, now nearing its encounter with Comet Halley, was designed to provide the maximum possible confidence in the spacecraft system's ability to survive the launch phase and to meet all of the mission goals within the imposed programme and cost constraints. A programme like Giotto, with its unique launch window in July 1985, and an encounter possibility only every 76 years, has to be made as immune as possible to the normal project problems of late delivery or malfunctioning of units (both ground support and spacecraft), etc. Alternative work flows and schedules had therefore to be pre-defined to provide flexibility and enable work-around solutions to be incorporated whenever necessary to maintain the overall programme schedule.

Figure 1 — Structural-model vibration testing in progress at IABG in Munich

The choice of model philosophy for the Giotto project was based on five principal factors:

- a 'once and for all' launch window in July 1985
- delivery of the flight spacecraft to ESA in January 1985
- the need to develop and prove new items alongside the procurement or modification of existing units
- the system-level verification requirements
- the need to minimise cost and risk.

The time and cost constraints of the programme prohibited the inclusion of a thermal development model, and the model philosophy selected was therefore primarily based on two early development models plus a proto-flight model. The development spacecraft system models selected were a structural model (SM) and an electrical model (EM). An additional 'configuration model' was subsequently employed at the Prime Contractor's premises (BAe). This full-scale three-dimensional layout of the spacecraft provided a model on which the locations of the platform-mounted units could be finalised, particularly the fuel tanks and pipework for the reaction-control subsystem and the harness layouts.

The primary role of the structural model (Fig. 1) was to complete a dynamic test programme to verify the spacecraft's structural design. The structural tests also confirmed that the design of the onboard units, including the scientific payload, was adequate to withstand the specified environmental test levels.

The integration of the structural model took place at Dornier System in Friedrichshafen and the test programme was carried out at IABG, Ottobrunn, and CESTA, Bordeaux.

The main purposes of the electrical model (Fig. 2) were to:

- verify electrical interfaces
- measure and verify system electrical and functional performance, including limited electromagnetic and RF compatibility
- prove and develop integration and test procedures and methods
- develop and prove checkout software, including test software for the system test programme
- establish techniques for checking antenna despin pointing performance
- train personnel in preparation for the proto-flight model programme

Figure 2 — Electrical model during EMC testing at BAe's facilities in Bristol (UK)

Figure 3 — Proto-flight model during solar-simulation testing at the SIMLES facility in Toulouse

A representative structure was used for the electrical model. This allowed the mounting of a representative harness and the integration of the spacecraft units and experiments.

The electrical-model activities took place in the Space System Integration areas at BAe (Bristol), where the electromagnetic-compatibility and radio-frequency interference tests were also performed.

A comprehensive system-level test programme was derived for the proto-flight model spacecraft (Fig. 3) to demonstrate that the design met the system requirements, which can be summarised as follows:

- satisfactory spacecraft operations during each of the mission phases including launch
- satisfactory compatibility of the overall system in all operating modes
- satisfactory operation of all subsystems in the predicted thermal environment and demonstration of satisfactory thermal balance
- launch-vehicle interface compatibility, via mechanical inspection and fit checks.

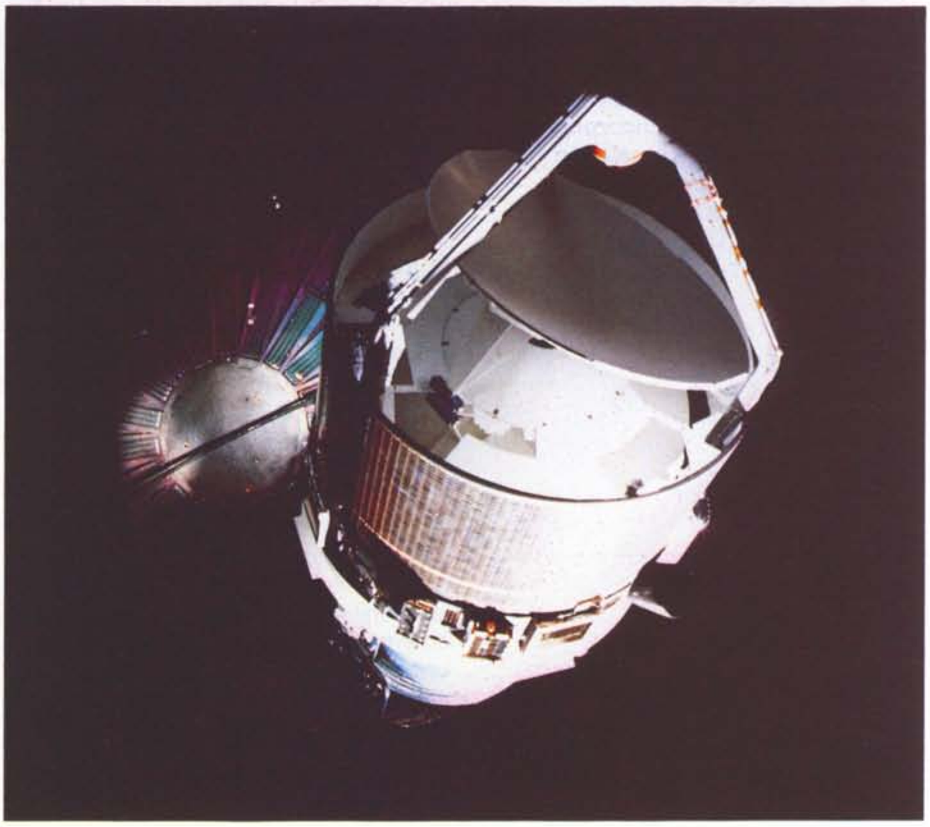
The overall AIV programme

The planned programme relationship between the early development models and the proto-flight spacecraft — which is the one that was actually launched on 2 July 1985 — is shown in Figure 4, together with the phasing of the major reviews. The major milestones shown are:

- structural-model (SM) tests to start nine months into the main development phase (Phase-C/D) with confirmation of the unit and subsystem environmental test levels to be available after 13 to 14 months
- electrical-model (EM) unit integration to start 14 months into Phase-C/D, with confirmation of compatibility of the units and subsystems, including experiments, being obtained after 20 months
- proto-flight-model (PFM) unit integration to start 22 months into Phase-C/D, with the environmental test phase to start after 29 months.

The overall programme requirements for the units and subsystems, including the scientific payload units, were as follows:

- electrically representative units to be delivered for the EM integration 14 months (for spacecraft units) and 15 months (for payload units) after the start of Phase-C/D
- qualification of all units of new design, or involving major design changes not later than the start of the proto-flight model's environmental test programme, 27 months after the start of Phase-C/D
- acceptance/performance verification of all flight units prior to delivery for proto-flight-model integration, 24 months after the start of Phase-C/D
- flight-spare units to be available prior to the proto-flight model's environmental test programme 28 months after the start of Phase-C/D.



Structural-model AIV programme

All of the tasks planned for the SM programme were successfully completed in the time foreseen. However, some small problems did arise during the programme, which made it necessary to modify some of the spacecraft hardware for the PFM programme. The completion of the programme confirmed the design qualification of the primary and secondary structures, together with the predicted mechanical loads used for subsystem and system design. Subsequent testing of the PFM spacecraft showed satisfactory operation of all modifications incorporated.

Electrical-model AIV programme

The EM system AIV programme started in February 1983 and was planned to be completed by the end of December 1983 with successful performance of the System Functional Test. Although integration and testing produced no major problems with either the spacecraft subsystems, payload units or electrical ground-support equipment, enough small problems occurred to extend the EM schedule beyond the anticipated baseline planning. The main reasons for the schedule delays were small technical incompatibilities across the unit interfaces, and delays in deliveries of spacecraft and payload units.

During the EM programme, two important system performance tests, of electromagnetic-compatibility and system-pointing, were successfully completed.

Proto-flight-model AIV programme

Although, like the EM programme, no major problems were encountered, other than with the validation of the thermal analytical model discussed later, several delays manifested themselves. For example, due to the extension of the EM schedule, the start of electrical integration had to be delayed until late February 1984. Eventually at the end of May 1984, it became necessary to move the spacecraft from Bristol to Intespace in Toulouse before the spacecraft build-up for environmental testing could be completed. Before the spacecraft was moved to Toulouse the electromagnetic compatibility test and a system pointing test were completed.

The environmental test phase did in fact begin in mid-August 1984, the delay being caused by the extended preparation activities prior to the solar-simulation test (Fig. 5). In order to have the possibility of selecting the payload prime flight units as late as possible in the programme, it was necessary to introduce additional exchange periods into the programme in order to test both flight and flight-spare units, and to allow last-minute instrument calibration to be performed at the scientific institutes.

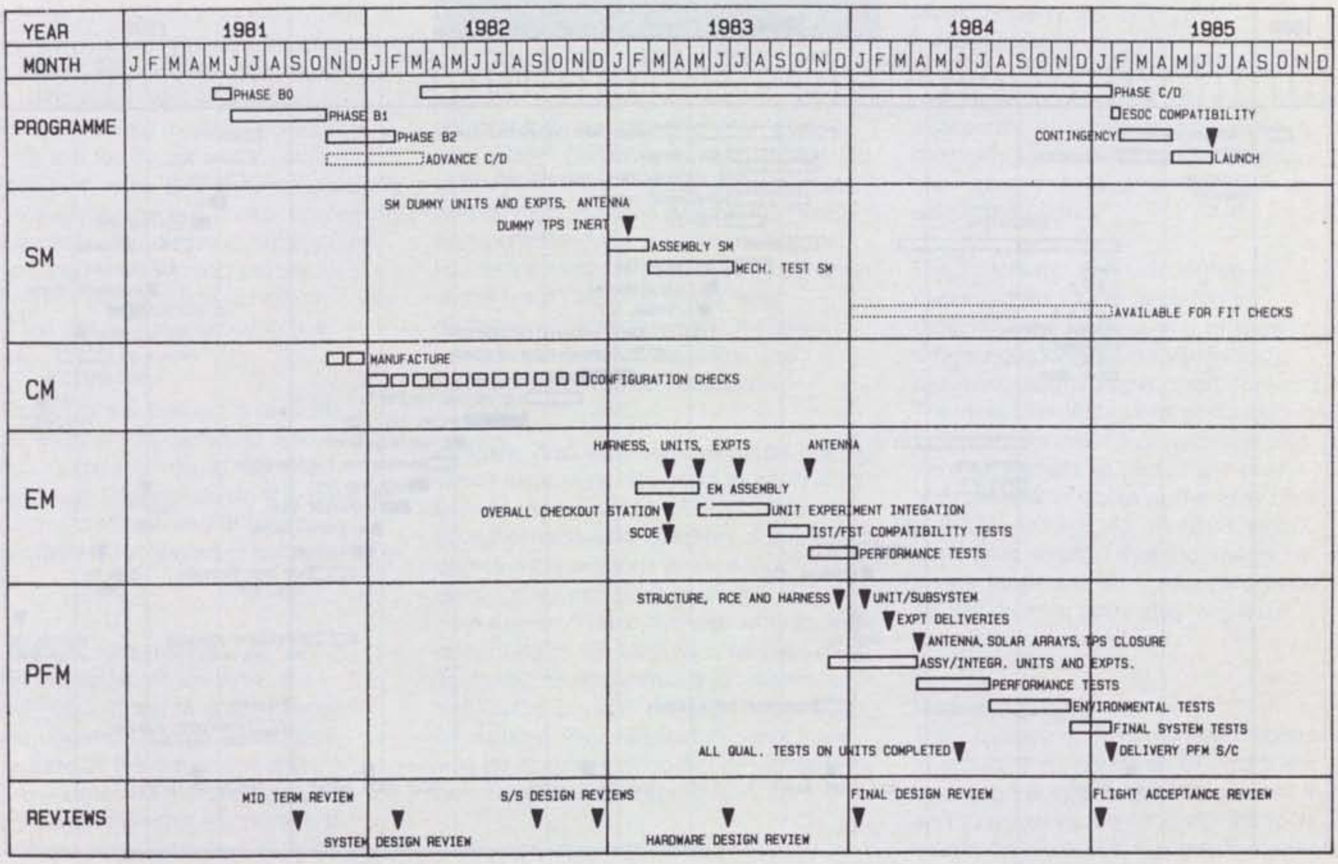


Figure 4 — Giotto system-level Assembly, Integration and Verification (AIV) programme overview

Integration and electrical-system testing

The aim of the planned integration activities was to ensure that the electrical and mechanical interfaces of the spacecraft units and experiments were correct. Each unit delivered was subject to detailed mechanical inspection, and electrical-interface checks were carried out on units and the spacecraft harness prior to fitting the units into the structure. The integration activity was followed by a short functional test of the subsystem/experiment via telecommand and telemetry, with all instrumentation and test aids removed.

The system electrical testing was intended to verify correct operation of units, subsystems and payload when integrated into the system. In the Giotto programme, three types of electrical system tests were performed:

— a Integrated System Test (IST), in which all modes of operation of each subsystem and experiment, telemetry and command functions were verified in detail. During this test only the subsystem or experiment concerned was active together with those subsystems necessary for supplying interfaces.
An IST was performed after each unit integration or exchange and prior to and after the environmental test programme, and varied from 4 to 48 h in duration, depending on the complexity of the subsystem or experiment concerned.

— a System Functional Test (SFT), performed to demonstrate that all spacecraft subsystems and experiments operated together in the correct manner. The SFT was designed to test each mission phase (launch, GTO, NEP, cruise and encounter) in a representative manner. Subsets of the IST tests were used during the SFT.
An SFT was performed before, during and after major environmental tests and as a final test at the launch site. The automated SFT lasted 48 h, additional time being required for manual testing of the radio-frequency subsystem.

— an Abbreviated Function Test (AFT), used to confirm that the spacecraft subsystem and experiments were still functioning in their main modes of operation after local movements of the spacecraft. The AFT was therefore performed as a 'quick-look' check after transportation and installation of the spacecraft in a test facility and between axes-of-vibration tests.

The majority of system electrical testing was software-controlled by sequences from the electrical ground-support equipment.

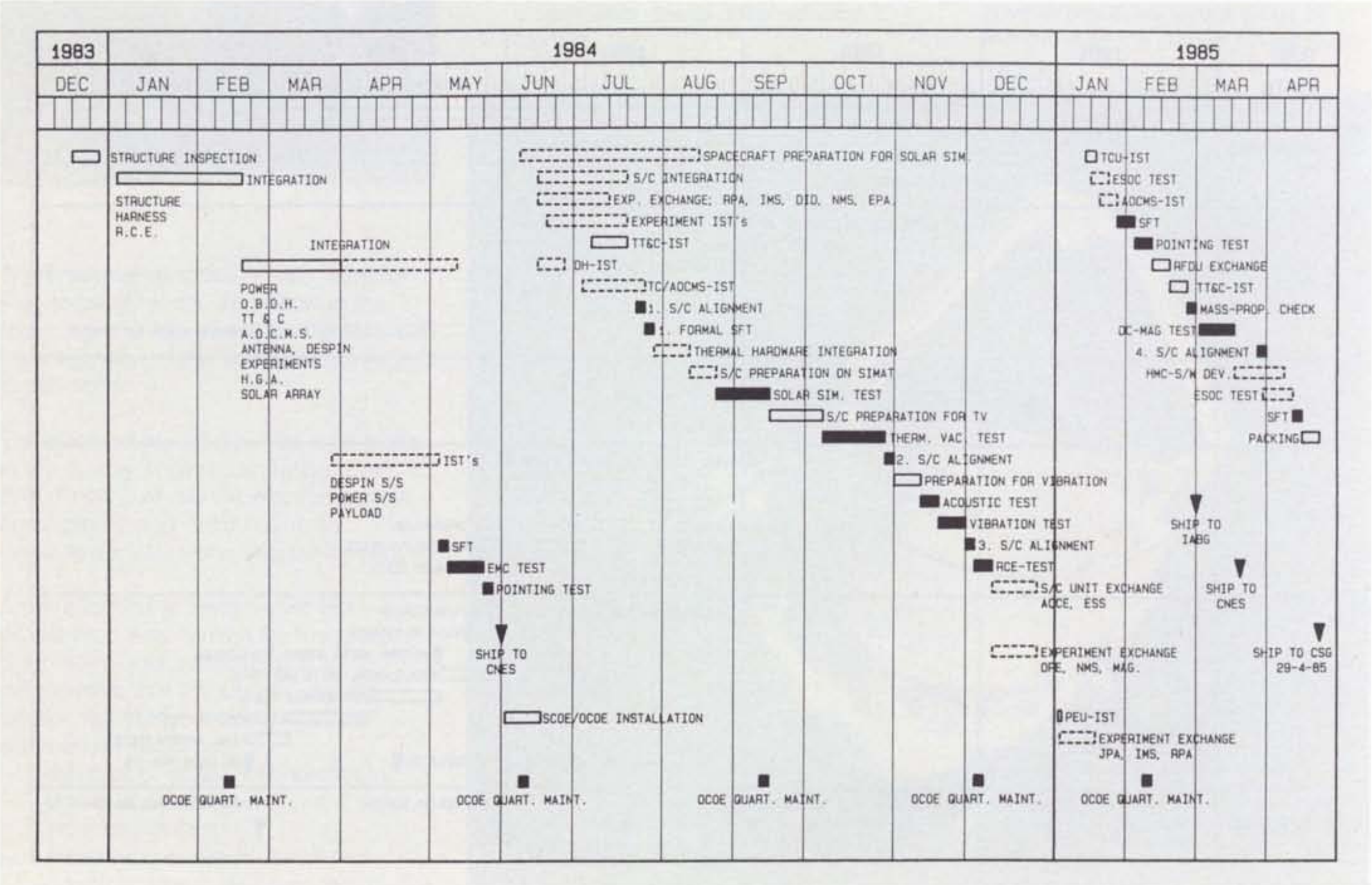


Figure 5 — Giotto proto-flight model (flight spacecraft) programme as actually performed

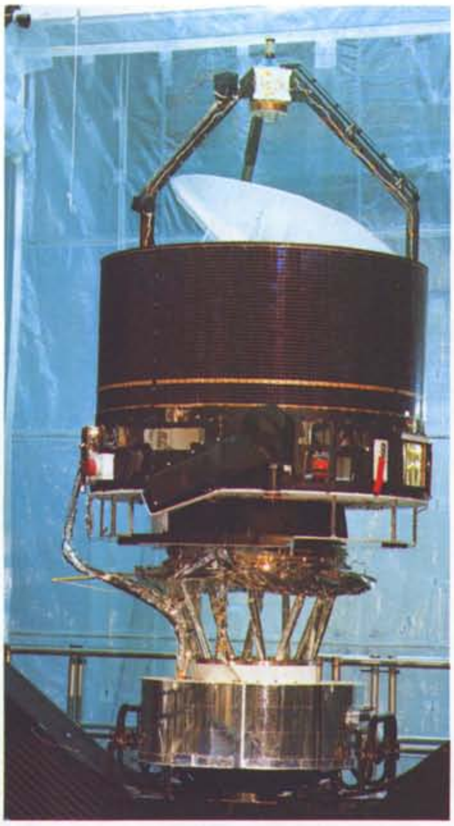


Figure 6 — Proto-flight model ready for thermal-vacuum testing at Intespace in Toulouse

The environmental test programme

Electro-Magnetic Compatibility (EMC) tests

The EMC tests on the proto-flight model spacecraft were performed at BAe in Bristol before shipment to Toulouse. The objectives of this test were to determine subsystem and system compatibility, system EMC performance and spacecraft compatibility with Ariane frequencies. The levels measured were satisfactory for the spacecraft to meet the system objectives.

Solar-simulation testing

The objective of this test was to submit the fully operational PFM spacecraft to a solar-simulation test in order to verify the analytical model used to predict the spacecraft's thermal behaviour during the mission. Due to the deletion of the thermal model, the test had to be performed at the beginning of the environmental programme, with a contingency test phase three months later in case of major modifications to the thermal hardware.

During the solar-simulation test, a total of 18 test cases were studied with different solar aspect angles and solar intensities up to 1800 W/m^2, which was the maximum possible intensity achievable with the test facility. Two successful payload tests were also performed during the solar-simulation test phase, confirming that all spacecraft electrical subsystems and payload units worked satisfactorily under the solar radiation conditions to be expected during the journey to the comet.

Verification of the thermal analytical model was not fully achieved following analysis of the test results, but the decision was taken to delete the back-up solar-simulation test and to trim the spacecraft's thermal-control subsystem by analysis.

Thermal-vacuum testing

The PFM spacecraft underwent a thermal-vacuum test in order to verify correct operation of spacecraft and subsystems at the maximum and minimum expected temperatures (Fig. 6). A very comprehensive electrical test programme was performed in thermal vacuum, during which the spacecraft was subjected to hot and cold soak periods, with system performance tests performed at both extremes. A special payload test with all high voltages switched on was also performed, as a system functional test for comet-flyby conditions. Evaluation of the results from all of the tests performed in thermal vacuum showed that all spacecraft subsystems and payload units worked satisfactorily.

Acoustic and three-axis vibration testing

These tests were designed to confirm that the spacecraft would withstand the acoustic noise and vibration of the launch environment, without structural or electrical system performance degradation. These two sets of tests were performed in the Intespace facilities in Toulouse. All spacecraft subsystems, as well as the payload units, were shown to be working very satisfactorily and there was no apparent acoustic- or vibration-generated system degradation.

Static and dynamic balance

The objective of this test was to confirm the static and dynamic balance of the spacecraft about the Z-axis and adjust the balance to meet the specified requirements. In the original planning, the tests with the proto-flight model were intended to be performed under vacuum in the Dynamic Test Chamber (DTC) at ESTEC. However, as this facility was undergoing major modifications during the actual PFM-AIV programme, a portable tent was manufactured which was partially filled with helium. Evaluations were also underway to determine the degradation in balancing if performed in air or helium as opposed to the original baseline of testing in vacuum.

Extensive testing with the SM in the helium tent did not produce conclusive results and during the final checks performed in Kourou it was confirmed that balancing of a spacecraft with a build configuration such as Giotto can be performed in air and meet the specified requirements. Consequently, the back-up helium tent was not used on the PFM.

Mass-property and alignment measurements

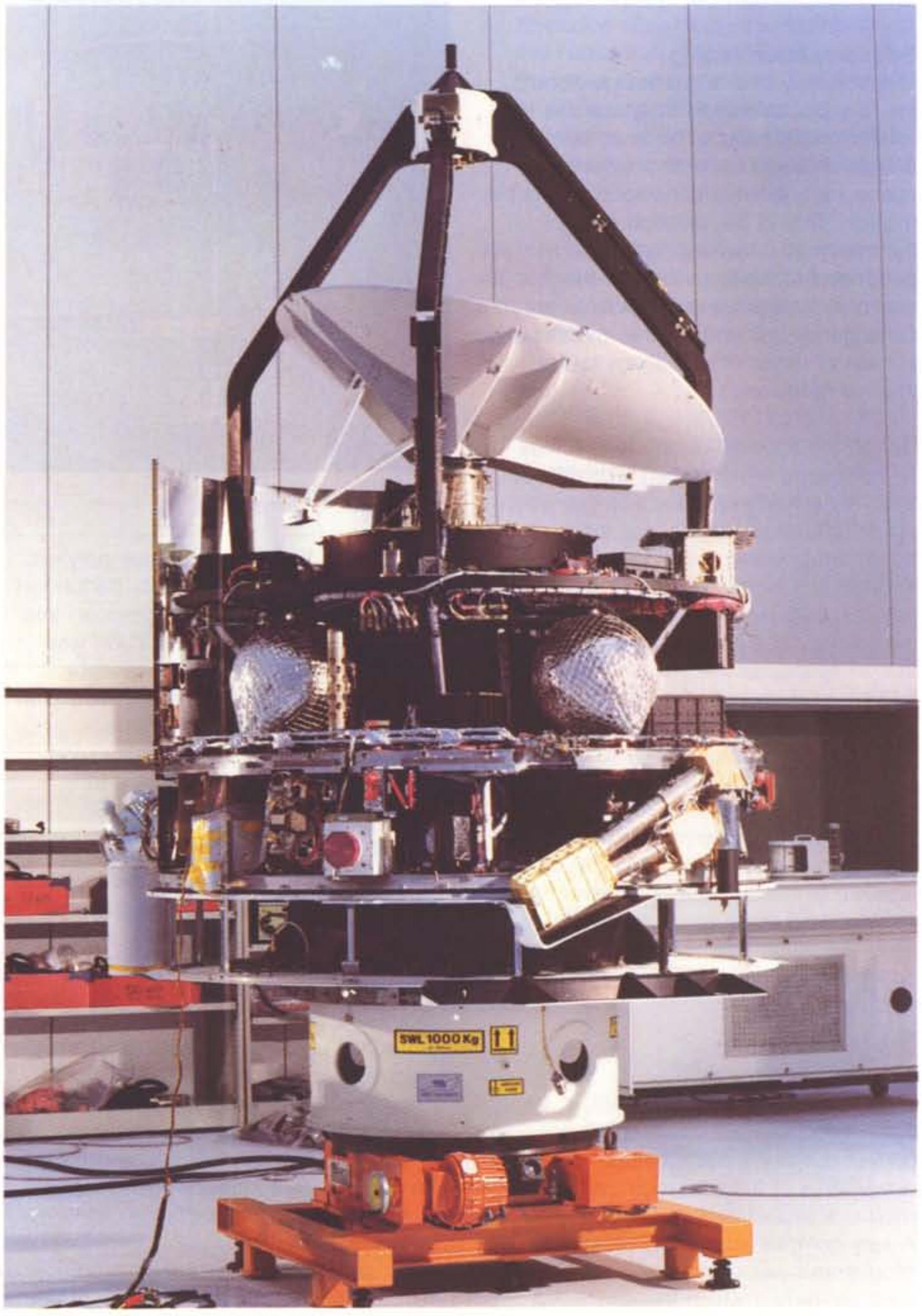
Mass-property measurements were performed to determine the mass of the spacecraft, its centre of gravity and moment of inertia. All measurements showed very close correlation with the calculated figures.

The spacecraft and unit alignment measurements were intended to determine the location and orientation of critical components in relation to previously aligned spacecraft coordinates. The measurements were performed prior to the environmental programme and were rechecked as part of the post-environmental checks and a final check at the launch site. All measurements performed showed that the spacecraft is a very stable platform, with hardly any deviations from previously aligned coordinates being found.

Magnetic testing

The objective of the magnetic testing was to reduce the spacecraft DC magnetic field to an acceptable level (deperm tests) and to measure the stray AC magnetic field in the area of the payload magnetic sensors. The tests, which took place at

Figure 7 — Proto-flight model during final alignment checking at the ESA launch base in Kourou



IABG in Munich, were very successful, the actual levels measured after the final spacecraft deperm being well within the specification agreed with the payload magnetometer team.

Comparison with the original programme

The Giotto system-level AIV schedule planning was 'success orientated' throughout the progrramme. The 'once in a lifetime' nature of this project, with its very strict launch window in July 1985, meant that if any major failures occurred during any phase of the AIV system schedule, there could be severe repercussions for the flight spacecraft. The baseline AIV schedule therefore contained some test redundancy by design, e.g. EMC testing on EM and FM before and after environmental testing. Consequently, when the actual schedule had to be compressed from the original plan, the necessary time savings could be achieved without significant technical risk by re-examining the test redundancies and optimising the overall system-level sequential test activity.

Comparison of the original system baseline planning with what was actually achieved has provided a number of interesting insights:

(a) The SM programme was successfully completed in the time scale allocated, which meant that the necessary minor modifications to subsystems and payload could be incorporated into the PFM programme without introducing any delays into the very tight schedule.

(b) Although the EM programme was troubled with many, though mostly small, hardware and software problems, and could therefore not be completed without impacting on the PFM schedule, enough confidence was gained in respect of system performance and AIV 'training' for the programme to achieve its objectives.

(c) The PFM programme was completed at the end of April 1985, and the spacecraft cleared for launch operations at the Kourou launch site, for a launch in July 1985. However, due to the many small problems encountered, it was not possible to complete all the baseline tasks planned. A second solar-simulation test, a second EMC test, and a mechanism test were therefore deleted, without significant risk.

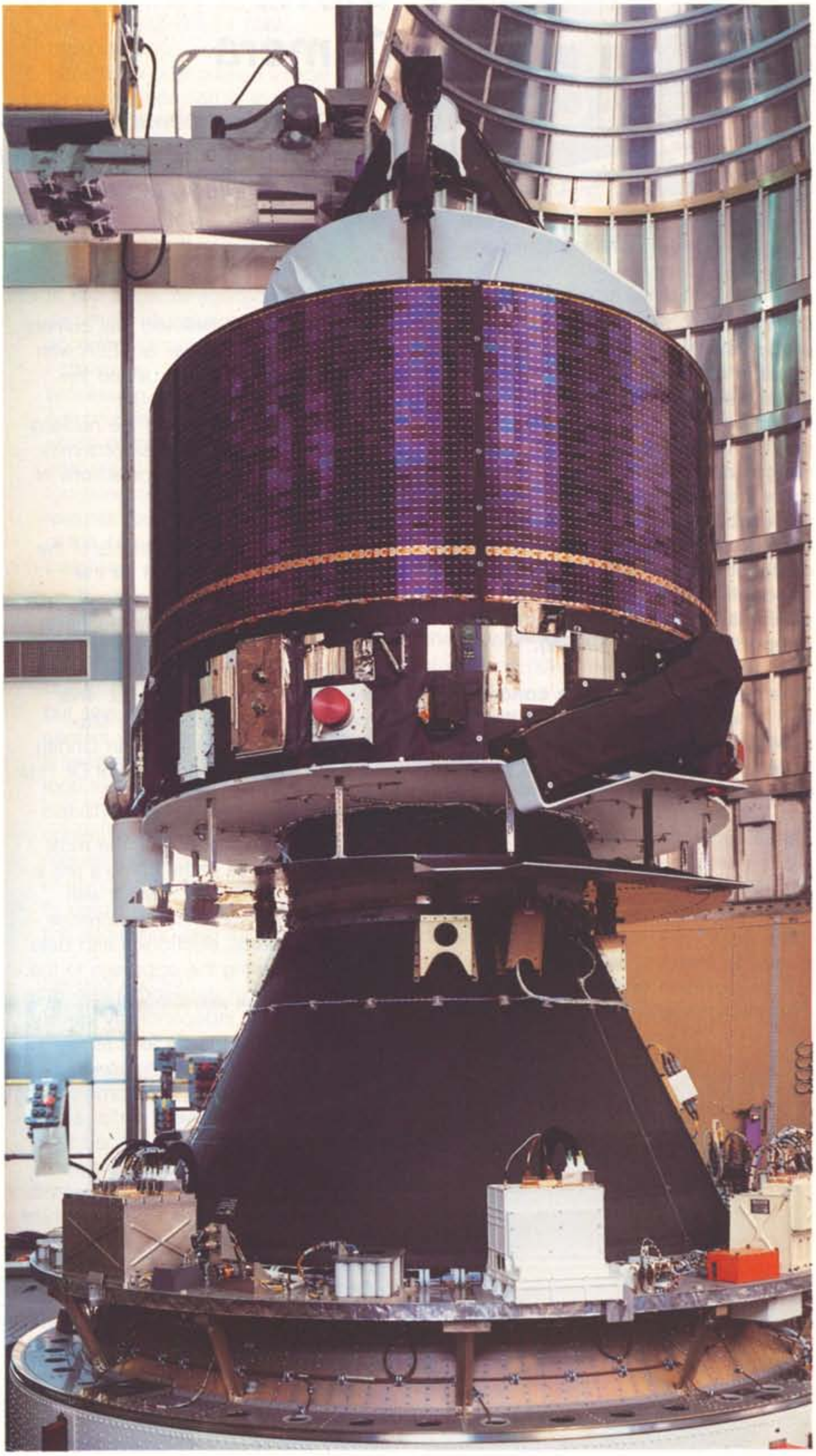
Although the temperatures recorded in some phases of the first solar-simulation test could not be fully correlated with the analytical model, it was decided to delete the second test and instead trim the thermal design by analysis. This approach has been proved to be valid by the in-orbit temperatures measured so far during the mission. Also, the second EMC test originally planned to take place after completion of the environmental programme was deleted, but the extensive EMC testing that had been performed on the EM and PFM models before the environmental programme gave sufficient confidence that this would not give rise to major problems. The decision to delete the mechanism test was based on the fact that all system tests conducted previously had shown excellent results, and gave good confidence for a successful mission. This has been borne out in practice by the excellent in-orbit performance of both the spacecraft and its payload.

Launch-site operations
The main electrical activities that had to be performed were:
- performance of post-transport abbreviated function test
- integration and testing of some experiments
- installation of transfer propulsion system
- fuelling and pressurisation of hydrazine reaction-control system
- conditioning and integration of the flight batteries
- performance of final system functional test
- software commissioning of gantry abbreviated function test
- performance of gantry abbreviated function test.

The post-transport abbreviated function test was successfully completed and no changes could be identified in any of the spacecraft or payload units. Integration and testing of the remaining experiments were successfully completed.

All other spacecraft operations, including mass-property measurements, static and dynamic balancing, thruster filling activities, etc. were also successfully completed in the allocated time scale, allowing the Giotto spacecraft to begin its historic eight-month journey to Comet Halley, exactly as scheduled, on 2 July 1985.

Figure 8 — Flight spacecraft installed on the Ariane V14 launcher prior to fairing closure



Multipurpose Electrical Ground-Support Equipment for the Giotto Halley Multicolour Camera

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On 13 March, the Giotto deep-space probe will pass within 1000 km of the nucleus of Halley's Comet. One of ten experiments on board, the Halley Multicolour Camera (HMC), will provide high-resolution, multispectral images of the comet nucleus and coma during the last four hours up to the encounter. The successful development and qualification of this complex camera required the support of sophisticated test facilities, particularly the Electrical Ground-Support Equipment (EGSE).

This article describes the concept and design of the EGSE and its application in the various development and operational phases of the camera.

Earlier generations believed that comets were omens of ill fortune, but ESA with the Giotto mission, has provided the unprecedented opportunity for observation and analysis of the nucleus of Halley's Comet from close proximity, and to dispel finally the superstitions of our ancestors.

Among the scientific instruments of the spacecraft is one that, both for the scientific fraternity and the general public, is of special interest, namely the Halley Multicolour Camera, which will provide high-resolution images from the immediate vicinity of the comet. This camera was developed by the Max-Planck-Institute for Aeronomy in Lindau, under the scientific leadership of Dr. H.U. Keller.

From a technical standpoint, the most significant features of the camera are a combination of applied physics with highly qualified and extremely precise optics, mechanics, electronics and data processing. During the approach to the comet on the spin-stabilised spacecraft, the camera must independently identify, acquire and track the nucleus as well as produce images for transmission to Earth. For this purpose, motors are provided to rotate the camera, move a mirror and select filters. The images obtained from individually controlled CCD (charge-coupled device) sensors are processed by the flight computer to select the most interesting image segments, which are then transmitted at rates of up to 20 kbit/s to Earth.

The camera control and processing are performed by an autonomous flight computer, which consists of three microprocessors, a large telemetry image memory and special hardware and software for target identification and tracking.

The problems incurred in the development of the camera were extreme. The fixed encounter date with the comet, and the resulting inflexibility of the vehicle launch period, imposed a rigid and difficult time scale on the project, which necessitated the parallel development of all components. To the classical payload restrictions of mass, energy consumption and available data rate, were added the camera-specific problems of new technology sensors and autonomous operation in the largely unknown comet dust environment. The encounter with the comet at a distance of 150 million kilometres from Earth results in a communication return link time of 17 minutes which, considering the short operational period of four hours, precludes any significant ground assistance by telecommand. Each of these problems contributed to the complexity of development and was solved only by the enthusiastic participation of all members of the camera team.

The conceptual design of the camera was followed by a logical breakdown into major components consisting of the optics, focal-plane sensors, flight computer and mechanisms, as shown in Figure 1.

As each of these components was to be developed by separate teams at geographically remote sites, the prerequisites for successful integration were well-defined performance and interface specifications, and thorough component testing with realistic simulation of the external devices.

Figure 1 — Camera conceptual design

The Electrical Ground-Support Equipment (EGSE) was designed to simulate all electrical interfaces to the flight computer, such that all operational modes of the system could be tested under almost any conceivable flight conditions. Only such comprehensive test and simulation could ensure the correct functioning of this complex camera during the short encounter after months of flight and without significant support by telecommand.

The application areas of the EGSE were defined as follows:

- Tests and development support of the flight computer and its subcomponents with full sensor and spacecraft simulation by the EGSE.
- Tests of the complete camera in the laboratory with spacecraft simulation and extensive telemetry processing.
- Integration tests of the camera in combination with the spacecraft overall checkout equipment (OCOE).
- Launch- and cruise-phase checkout and control of the camera via the OCOE.
- Quick-look data and image display from the camera during encounter.

The aforementioned areas of application can be broken down into four technical development stages, where any combination of these may be required together:

- *Sensor, telemetry and telecommand simulation*
  This fundamental facility covers the features essential for basic development. These comprise the generation of simulated image patterns, operation of the telecommand interface to the experiment and simple evaluation of the telemetry. Additional spacecraft signals may be fed in from external sources.

- *Complete spacecraft simulation*
  In this stage, all spacecraft signals and their interrelationships are accurately simulated and may be individually controlled. The data processing includes flexible and comprehensive display facilities which permit investigation and analysis of the correlation of signals, functions and performance. These features are used for bench testing of the complete experiment with integrated sensors.

- *Dynamic motion simulation*
  Adequate tests of the target identification and tracking require not only definable static image patterns, but sequences where the image content varies according to the real-time dynamic motion. Such closed-loop testing demonstrates the speed, stability and accuracy of the camera control loops. These tests also require the storage and display of as many camera parameters as possible to permit an exhaustive analysis of the acquisition and tracking modes.

- *Ground station*
  After integration into the spacecraft, the only connection with the experiment is via the OCOE with its specific data protocols. In this stage the user interfaces such as display and terminal formats, must remain unchanged, such that the impression obtained during the actual flyby of the comet is as similar as possible to that experienced in the simulated and practised encounters.

Having defined the major tasks of the EGSE, the concept of a double computer solution was chosen, where all the immediate interfaces to the spacecraft or ground data network were realised by means of special hardware in a so-called 'interface computer'. The interface computer functions can be extended by plug-in modules and the system is programmed by fixed software in PROMs. A second device, called the host computer, controls, sends commands to, and receives data from the interface computer. Both computers run in parallel and together provide considerable processing power with their multi-tasking capability.

The host computer performs the tasks of transfer control, storage, evaluation and display of data, preprocessing of images and command generation for the interface computer. The host computer is equipped with peripheral equipment including terminals, printers, hard-disk memory, digital tape recorder and a colour monitor for display of images. The storage media provide archiving of test results and enable closer investigation of interesting effects. The software is written

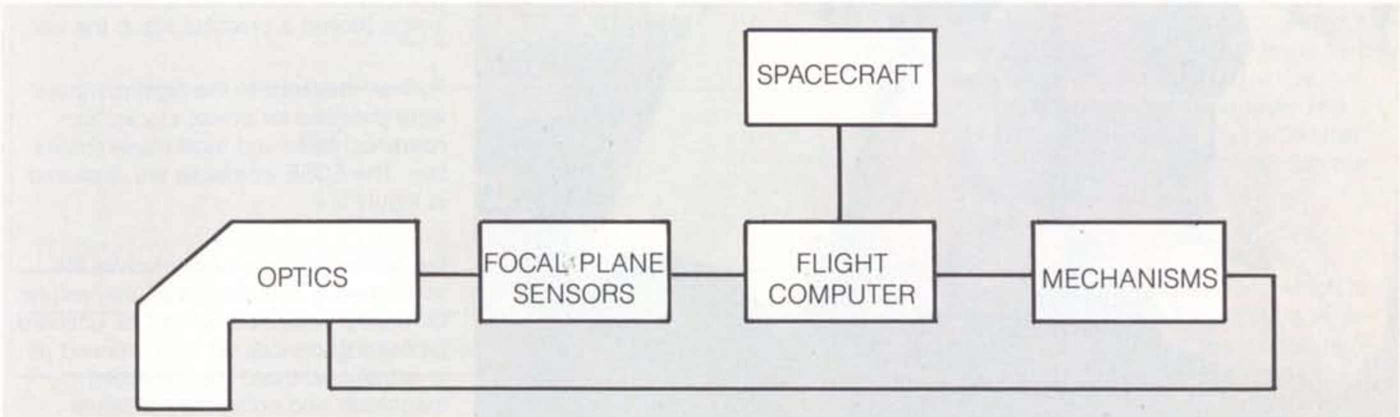
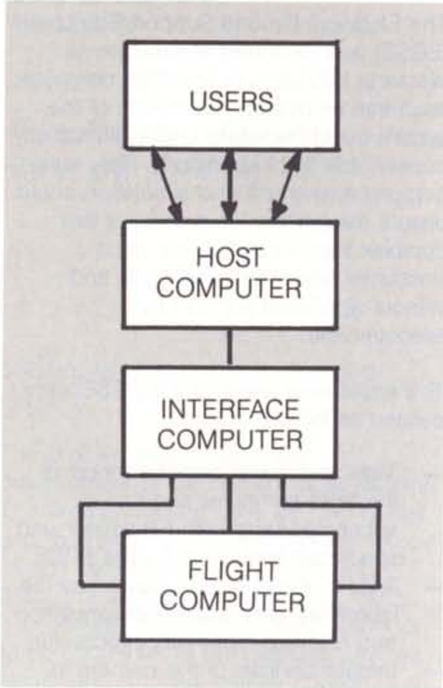


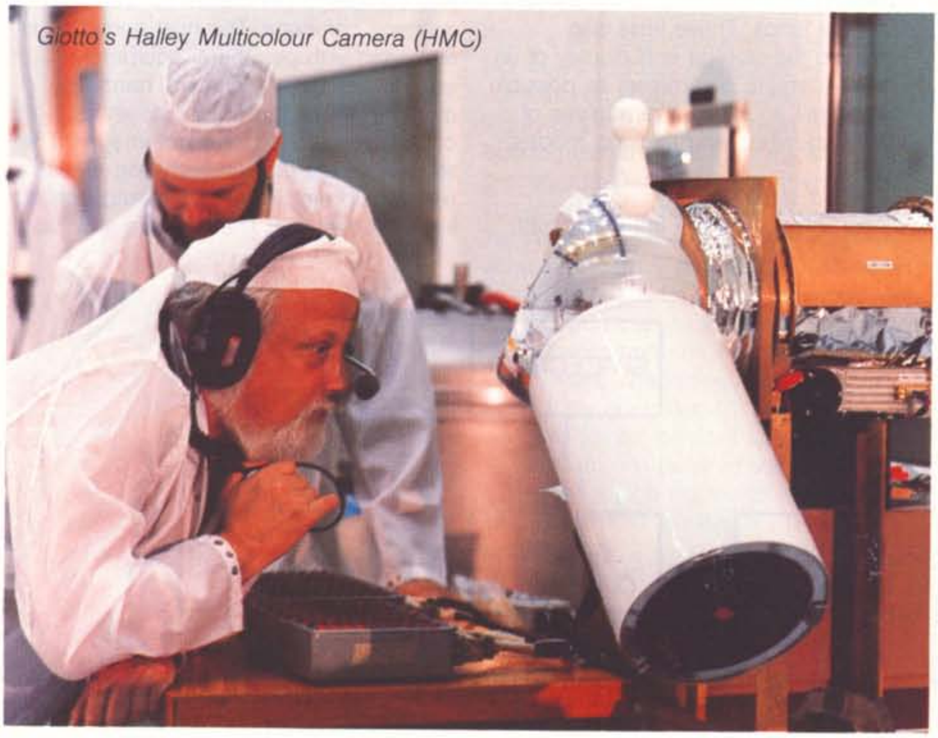
Figure 2 — The EGSE computer concept



such that it is automatically configured for the available hardware and any adaptation is transparent to the user. The user can call available test programs or enter his own routines in multiuser operation. The host computer, apart from the connection for data exchange with the interface computer, contains all of the synchronisation mechanisms for real-time operation. The host computer software permits the programming of special system test procedures in a user friendly, high-level language. Figure 2 illustrates the EGSE computer concept.

The EGSE provides an accurate simulation of the logic, timing and impedances of the four formats and two data rates of the spacecraft telemetry system. As the telemetry data is asynchronous to all other simulation activities requiring processor attention, a 'First In First Out' (FIFO) buffer is used to avoid loss of data. The acquired telemetry data is decoded, synchronised and checked for errors (e.g. synch. loss and bit rate) in the interface computer and stored in convenient blocks in a queue before transmission to the host computer, thereby reducing the load of time-consuming bit manipulation on the latter. Telecommands generated in the host computer are sent in the other direction to a second FIFO in the interface computer, where they are temporarily stored until read out at one of two data rates.

The camera contains five active CCD sensor arrays with a variety of operational modes, providing high-resolution, two-dimensional images which are processed by the flight computer for tracking information and for selection of the most interesting segments for transmission over the telemetry link. It is therefore necessary to provide comprehensive simulation of a selection of comet forms, brightness levels, contrasts and backgrounds to test adequately the accuracy and selectivity of the flight processor. As a sensor image contains a two-dimensional array of over one hundred thousand picture elements (pixels), a simulated image may be stored in a 'Random Access Memory' (RAM) which can be read out by the flight computer in the same sequence as it would normally read the actual sensors. A dual port RAM was developed such that the EGSE could store a simulated image via one port in the RAM and the interface simulator could read the information out of the other port.


Giotto's Halley Multicolour Camera (HMC)

This technique permitted thorough testing of the flight processor software for scenarios ranging from simple bright comets on dark backgrounds to complex, distorted nuclei in noisy backgrounds, such as might be expected when Giotto enters the dust cloud of the coma. The readout electronics is similar to that provided on board, but it also permits a variety of control modes whereby the EGSE may synchronise all forms of simulation, as in the case of real-time dynamic simulation described later. A video output display of the simulated image proved a practical aid to the user.

Further interfaces to the flight computer were provided for power, clocks, Sun reference pulse and focal-plane control bus. The EGSE interfaces are illustrated in Figure 3.

Full spacecraft simulation involves the simultaneous operation of all the features previously described, so that all onboard processing devices will be burdened as in actual operation. The increased magnitude and complexity of failure modes under such conditions demands a

Figure 3 — The EGSE interfaces

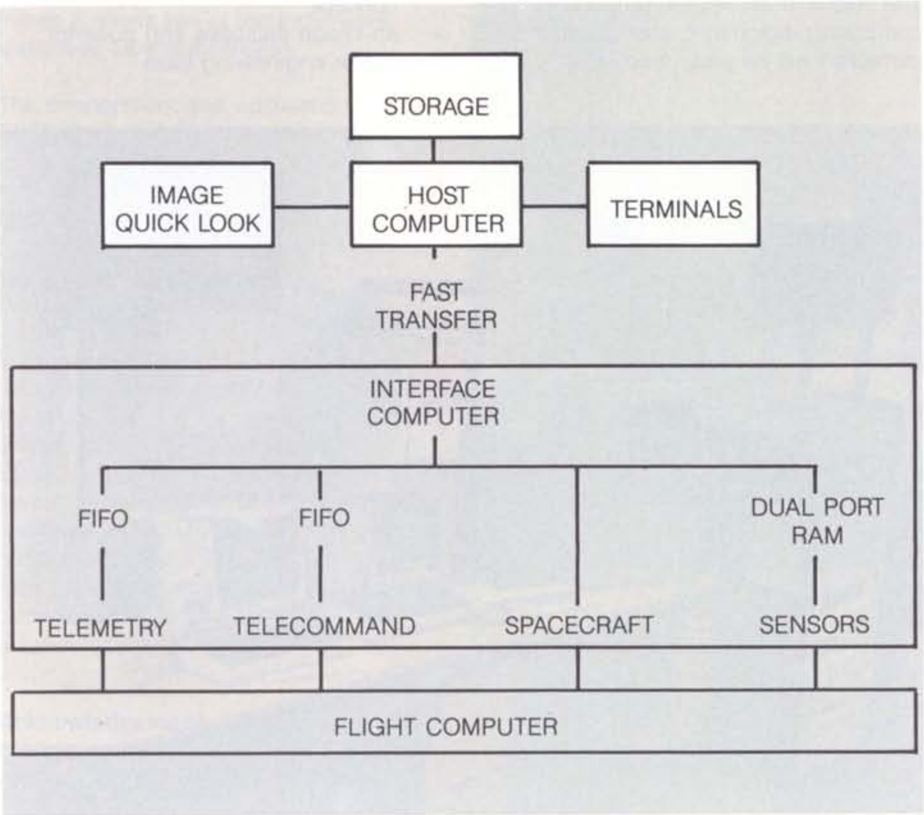


Figure 4 — The basic EGSE

maximum analytical capability in the EGSE. This is provided by terminal displays, meters and light diode arrays, and the availability of all important clock, pulse and strobe signals on coaxial connectors. All simulation parameters must be variable from the host computer. Of absolute importance is the recording of all events such as switching of functions, synchronisation loss, telecommands and responses from the camera, run time of mechanisms and any logically inconsistent events. All of these events are processed and displayed in a comprehensible form by the host computer. Figure 4 shows the basic EGSE.

The aforementioned evaluations of the camera response to a fixed image input are known as open-loop tests. The most important test for the camera autonomous functions of acquisition and tracking of the comet, is the real-time simulation of the camera dynamics, including the telescope servo mechanisms and spacecraft motion, and the effect of these on the image signals provided to the flight computer input. Such simulation is known as 'closed loop', and is illustrated in Figure 5.

As the camera is mounted on a platform in the spacecraft, the sensor signals are influenced by the combination of the camera motion relative to the platform, the spacecraft spin and nutation, and the comet trajectory.

The spacecraft motion and comet trajectory are simulated in the host computer as a function of time, while the interface computer provides a clock to the camera, which is the only time reference. The interface computer interprets the camera commands to the telescope pointing mechanisms as well as various status information and passes these data to the host computer where they are included in the simulation process for generation of the next image. The implementation of a functioning motion simulation therefore depends on the possibility of producing a mathematical model which can predict the content of the next sensor image with acceptable effort. This is not trivial as the calculation of rotational body motion is extremely computation intensive. The solution involves prediction techniques and the avoidance of computing image components consisting only of background.

Apart from the motion model, which is formulated in a high-level language, an array of control and status signals from and to the flight computer must be monitored to record adequately the performance of the camera during

Figure 5 — Closed-loop simulation

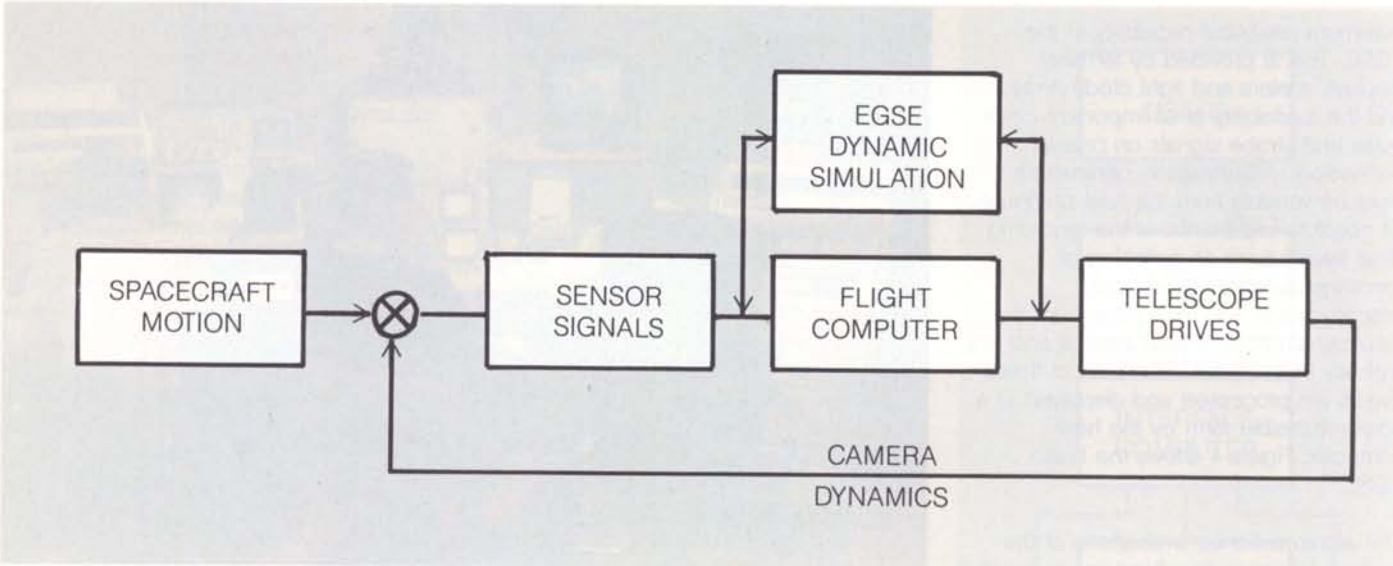


Figure 6 — Installation of the EGSE at ESOC

simulation. As the computational load precluded the operation of the various modes of simulation in real time, a start/stop technique was implemented, where the flight computer was placed into halt states during the calculation of images and recording of current status by the host computer. During the motion simulation process, all other EGSE services such as telecommands and display of telemetry images could run in parallel.

In ground-station operation, the only hardware differences were the use of a modem to feed the telemetry from the OCOE to the interface computer and a high level link to feed telecommands from the host computer to the OCOE. The interface computer software was optimised to reduce the effects of telemetry dropouts and minimise the loss of image information. Figure 6 shows the installation of the EGSE at ESOC.

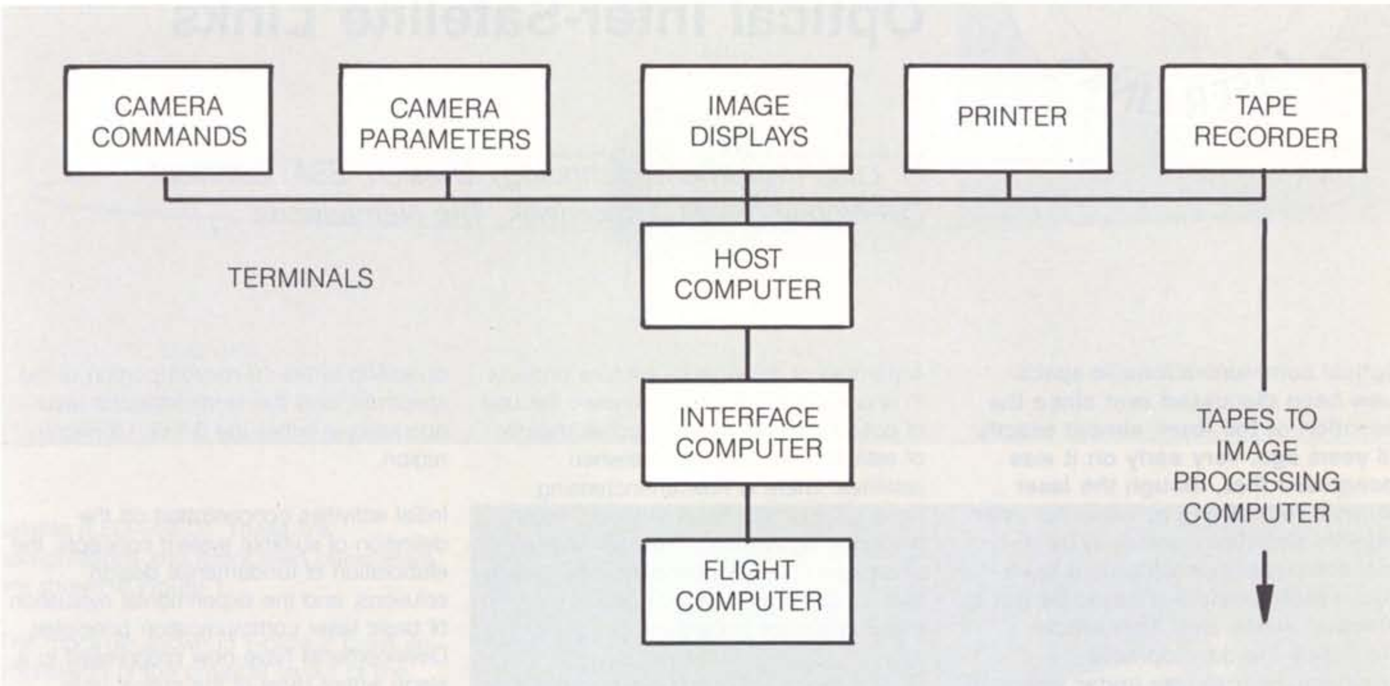
The various users developed a systematic configuration for the system which provided a logical working environment. One terminal of the host computer was used for commands and another for the display of alphanumeric camera parameters, while the telemetry images were displayed on a colour monitor. In addition, all important results were recorded on a printer and telemetry was archived on the digital tape recorder.

Image processing such as plotting of sensor lines was carried out either offline in replay mode, or on a further computer which received the data from the host computer. Figure 7 shows the system test configuration.

The final scientific image processing comprising radiometric and geometric correction will be performed on a powerful VAX computer, where the data source will be the tapes produced by the EGSE. The image processing system has been designed as a flexible configuration based on:

- an independent multi-work-station concept
- an image database and powerful image engineering tools

Figure 7 — System test configuration



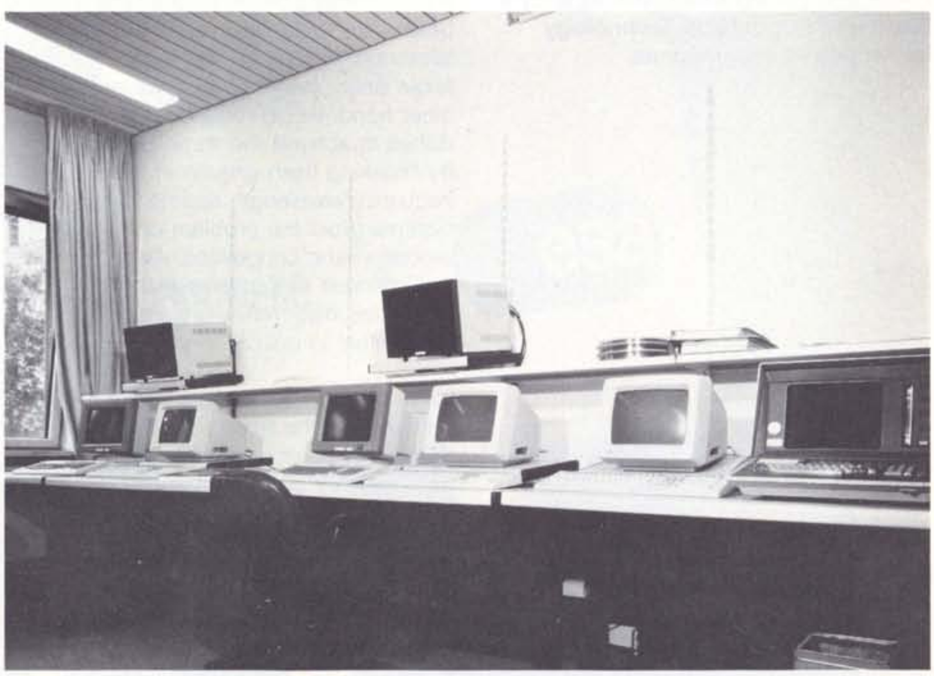
— a high-level image interpreter language.

Figure 8 shows two of the three work stations at Oberpfaffenhofen.

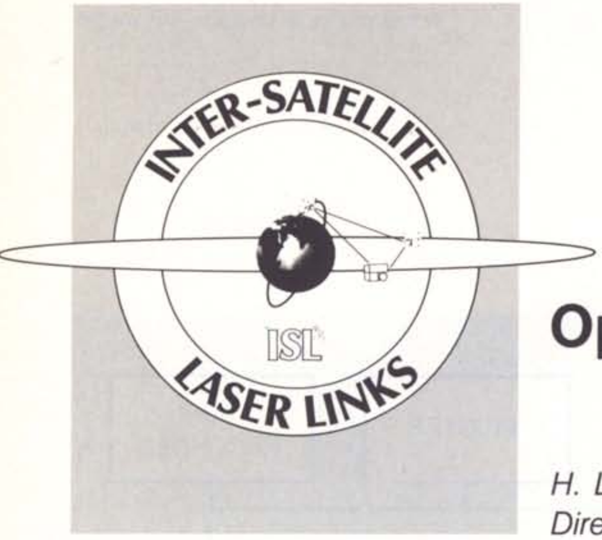
The development and application of the EGSE illustrated that the most important requirements for such equipment are real- time data management, reliability in operation, transportability, ease of operation by multiple users and flexibility of simulation for a continuously developing project.

The choice of a double computer concept is of little importance to the user; however, control of the maximum number of interfaces, reconfigurability of the EGSE for individual problems and the possibility for program changes and the introduction of one's software, are of major significance. The distribution of EGSE tasks on two separate computers contributed significantly to the achievement of these goals.

Figure 8 — Image-processing work stations



Acknowledgement
The authors would like to thank the Max-Planck-Institute for Aeronomy for their support in the implementation of the user software and mathematical models and ESTEC for their assistance with the problems of the high-speed data link.



Optical Inter-Satellite Links

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Optical communications in space have been discussed ever since the invention of the laser, almost exactly 25 years ago. Very early on it was recognised that, though the laser showed very strong promise for inter-satellite data links, much systems- and component-development work was required before it could be put to practical space use. This article discusses the development programmes currently under way, with particular reference to the activities being carried out under the Agency's Basic and Supporting Technology Development Programmes.

A number of the Agency's future projects in space communications foresee the use of optical carriers as an effective means of establishing data links between satellites. There is now an increasing need for inter-satellite links to enhance the capacity, coverage and connectivity of satellite communication systems, which traditionally have relied on direct microwave links to Earth.

Optical techniques have the potential to provide the required high-rate data links with precisely pointable transmitter beams, involving only very low, moving telescope masses for fast, wide-angle beam steering. Microwaves, on the other hand, would require large antenna dishes to achieve the same performance. By breaking fresh ground in the frequency/wavelength regime, optical systems avoid the problem of frequency allocation and congestion. Also, disturbances due to terrestrial radio-frequency interference are virtually nonexistant in optical links.

ESA's plans to use optical inter-satellite links include the linking of two telecommunications satellites in geostationary orbit and the high-speed transmission of data from a low-Earth-orbiting platform to the envisaged European Data-Relay Satellite (DRS). In both cases, experimental laser communication packages are foreseen for inclusion in pre-operational missions, so that the basic elements of optical inter-satellite-link technology can be tested in orbit.

Technological preparations for missions involving optical inter-satellite links have been going on for some time. Prime consideration has been given to two promising laser candidates: the CO_2 laser operating in the 10 micron portion of the spectrum, and the semiconductor laser operating in either the 0.8 or 1.3 micron region.

Initial activities concentrated on the definition of suitable system concepts, the elaboration of fundamental design solutions, and the experimental evaluation of basic laser communication principles. Developments have now progressed to a stage where most of the critical units needed for the manufacture of an optical inter-satellite-link payload are at a laboratory breadboard stage.

CO_2 laser communication

Systematic efforts to deal with the problems of optical space communications were started by ESA in 1977 with a technology project based on the CO_2 (carbon dioxide) laser. The latter was selected from among other potential sources — notably the Nd-YAG laser — because of its technical maturity, good efficiency and high output power capability. The programme, called ISL^2 (Inter-Satellite Laser Links), was initiated as a complementary ESA/German national endeavour aimed at developing experimental CO_2 laser-communication hardware suitable for in-orbit demonstration and verification in the early 1990s. In order to have a suitable reference frame for this development, a baseline CO_2 laser transceiver package was defined, capable of establishing a two-way satellite-to-satellite data link with a channel capacity of 1 Gbit/s.

The baseline system was configured such that it would be suitable for: (a) two-way communication between two geostationary satellites (GEO—GEO), and (b) data linking from a low-Earth-orbiting satellite to a geostationary data-relay

Figure 1 — Baseline link models for CO_2 laser transceiver development

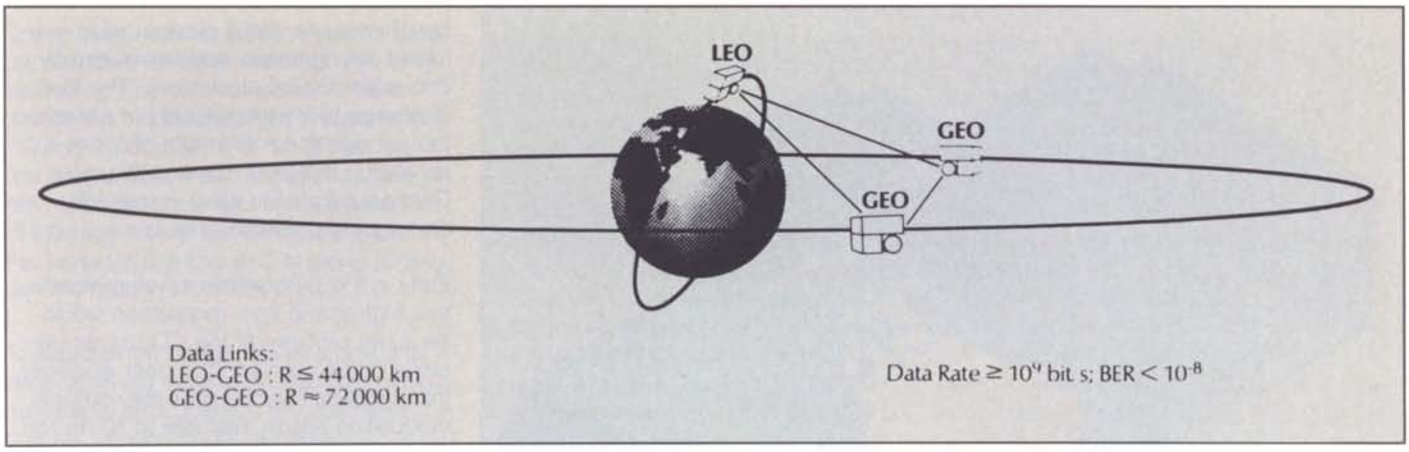


Figure 2 — Model of CO_2 laser transceiver package (overall dimensions 80x30x75 cm^3, including coarse-pointing assembly)

satellite (LEO—GEO). These link configurations and associated parameters are shown in Figure 1.

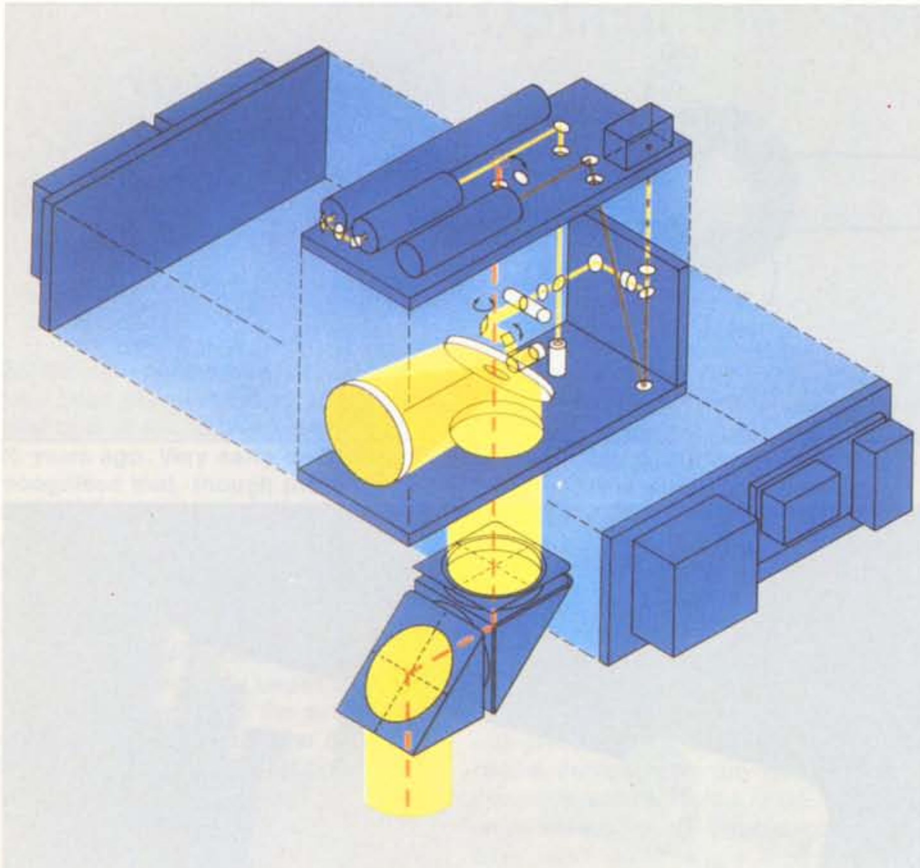
The mock-up shown in Figure 2 gives an impression of the physical layout of the baseline CO_2 laser transceiver package. The mechanical configuration is a self-contained, box-like structure in which most of the opto-mechanical subassemblies and components are housed. The prominent feature on the outside of the lower baseplate is the coarse-pointing assembly needed to provide hemispherical steering of the laser beam. This assembly can be omitted without influencing the other transceiver functions if a special mission, such as a GEO—GEO link, does not require a coarse pointing capability. The active, heat-generating opto-electronic components, such as the laser, modulator and receiver, are assembled on the upper baseplate of the overall transceiver box.

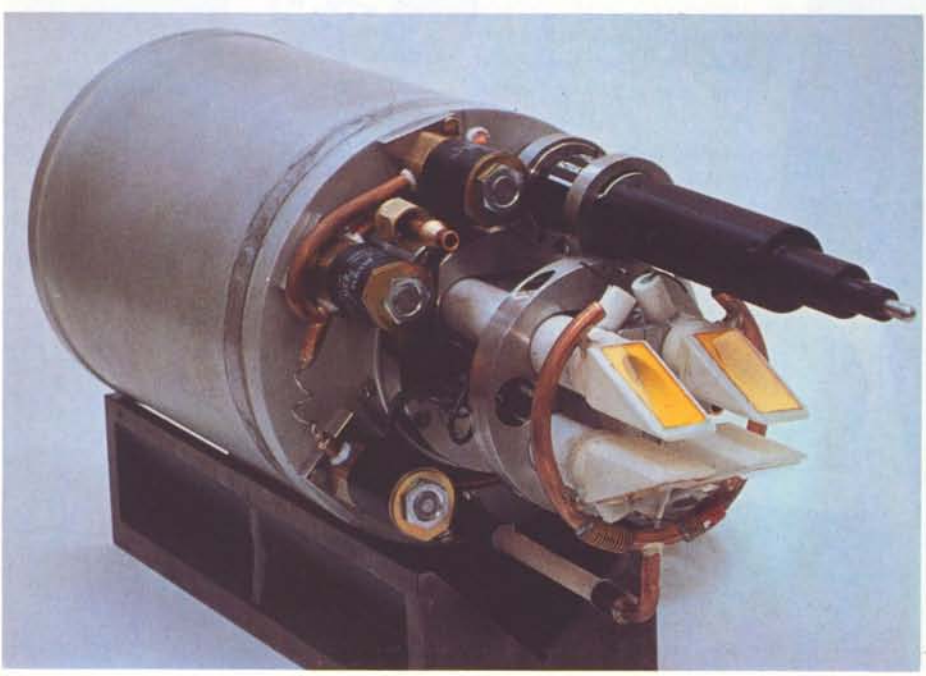
Figure 3 is an exploded view of the transceiver package, showing the optical transmit and receive channels. The transmitted and received laser beams pass through the same telescope and opto-mechanical beam-steering arrangements; polarisation diplexing is used for channel separation.

The transmitter laser is a 10 W continuous-wave CO_2 laser designed for excellent passive frequency stability. Figure 4 shows the interior of the laser, with its four sealed, 35 cm-long,

Figure 3 — Schematic of CO_2 laser communication system, indicating common optical transmit and receive channels

Figure 4 — Heart of CO_2 transmitter laser





beryllium-oxide (BeO) plasma tubes in a folded arrangement, and terminated by zinc-selenide (ZnSe) windows. The four discharge tubes are optically in series, so that an overall cavity length of 1.3 m is achieved. This laser, developed under German national funding, is currently undergoing qualification tests.

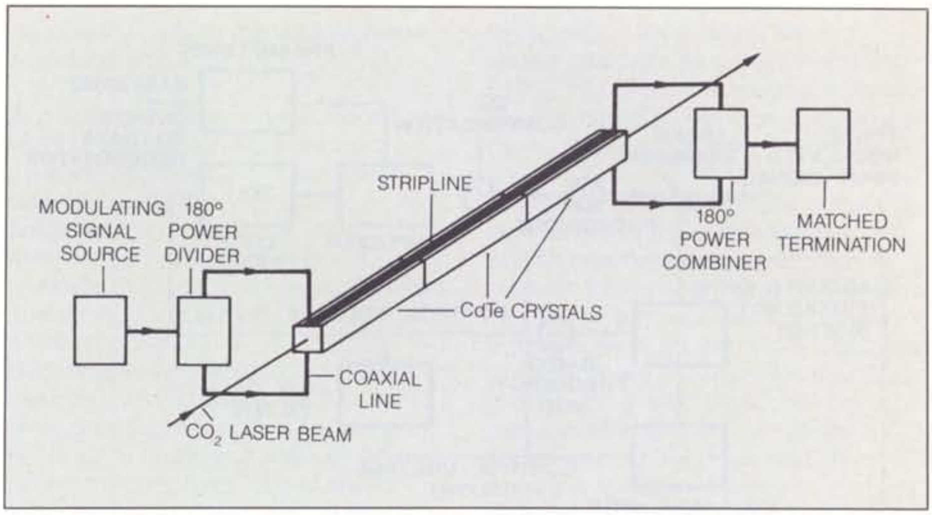
Early in the programme it was realised that high-speed light modulation would be a key problem of the CO_2 transceiver design, due mainly to the poor efficiency that characterises the physically suitable modulation effects available at 10 micron. This problem was approached by developing a travelling-wave light-pipe modulator that uses electro-optic interaction in cadmium telluride (CdTe) to achieve modulation bandwidths in excess of 1 GHz. The device (Fig. 5) consists of several long, thin CdTe crystals arranged in cascade to form an oversized optical waveguide. The modulating electrical signal travels co-linearly with the optical wave along the stripline electrodes. By proper choice of the dielectrics surrounding the crystals, the modulating electrical signal travels in synchronism with the optical wave, resulting in the desired large-bandwidth operation.

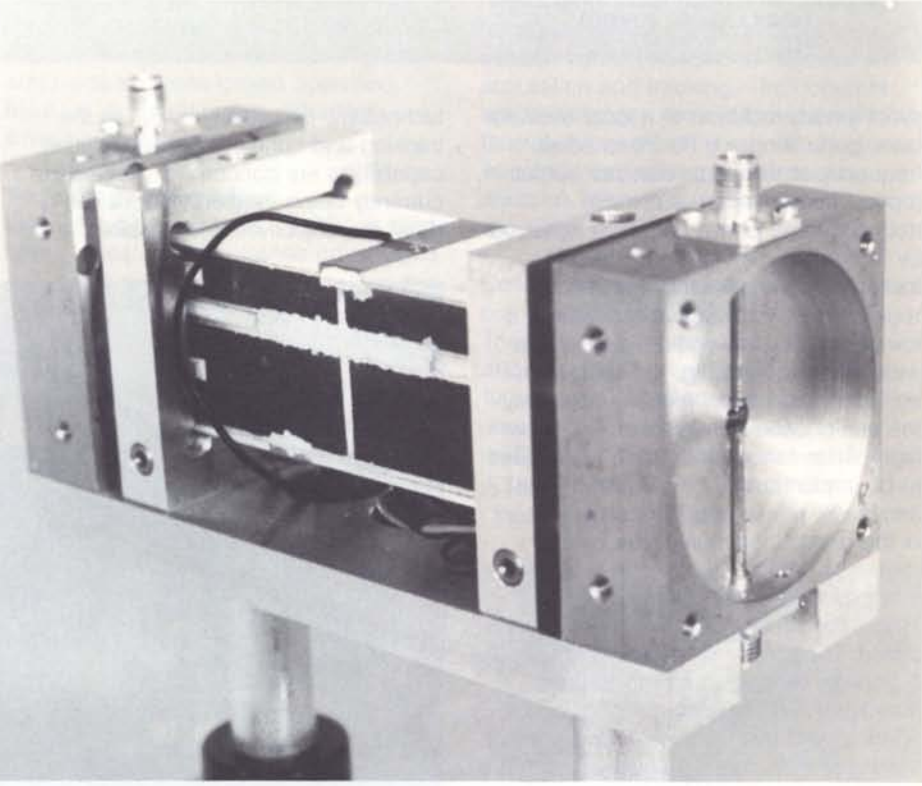
A scale model of this modulator (Fig. 6) has been built and successfully tested. Work on a full-size prototype employing space-qualifiable technology has recently been initiated. It will generate at least 1W of modulated optical sideband power when 10 W of continuous incident laser power is provided, using a radio-frequency (RF) drive power of the order of 20 W.

It may come as a surprise to the microwave engineer that modulation is performed at such high power levels. In microwave systems, the modulated signals are usually generated at low power and subsequently amplified. At optical wavelengths, this is not practical, mainly because there are no suitable light amplifiers available. Significant reduction of RF drive power could be achieved with internal cavity laser modulation. This principle only works at frequencies below 200 MHz. At higher modulation frequencies, laser oscillation would be disrupted.

Figure 5 — Principle of travelling-wave light-pipe modulator

Figure 6 — Laboratory model of 1 Gbit/s laser modulator





Space laser communication systems have the attractive ability of allowing exceedingly narrow transmission beam widths (e.g. 10 microrad for the present CO_2 laser package) with small-aperture telescopes. This, however, leads to one of the most intricate engineering problems of inter-satellite optical communication: the accurate pointing and tracking of the communicating terminals.

To establish an optical link in space, the laser terminals have to be pointed, using ephemeris data, towards the estimated angular location of the opposite spacecraft. The receiving system acquires the incoming laser beam from the partner satellite by scanning the window of angular uncertainty. During this phase, the transmitting terminal illuminates the sector in which the acquiring satellite is positioned by deliberately widening its transmission beam width. Upon acquisition of the beacon signal, the receiving system directs a narrow (intense) beam at the other terminal which, in turn, searches for the narrow-beam signal over the uncertainty angle, using its narrow communication beam width. Angular fine tracking starts as soon as mutual acquisition occurs. It is accomplished either by a monopulse system with quadrant photodetectors or a conical-scan system with a single-element detector.

In the case of the CO_2 laser baseline system developed by ESA, accurate pointing of the very narrow laser beam is performed by a two-stage arrangement of movable optical components which are common to the transmit and receive channels. There is no need to move the total mass of the telescope. A coarse-pointing assembly with two large mirrors rotatable around two orthogonal axes is located in the object space of the telescope. It provides more than hemispherical coverage at comparatively low speed. High-bandwidth, fine-pointing control is accomplished by a two-axis fine-pointing assembly located near the exit pupil of the telescope. Because of the finite velocity of light, a variable angular offset about ten times larger than the beam divergence is needed between the transmit and receive optical beams in order to compensate for the aberration of light caused by the relative motion of the communicating terminals perpendicular to the line of sight. This variable lead angle is introduced with the help of a separate point-ahead assembly consisting of two slowly movable mirrors.

The stringent requirements of optical inter-satellite links have led ESA to pioneer the field of optical coherent detection. Coherent detection is very well known in radio-frequency systems as a means of obtaining high receiver sensitivity. For the purposes of the present CO_2 laser communication system, a coherent detection receiver has been developed in which the incoming signal is mixed with the phase- and frequency-

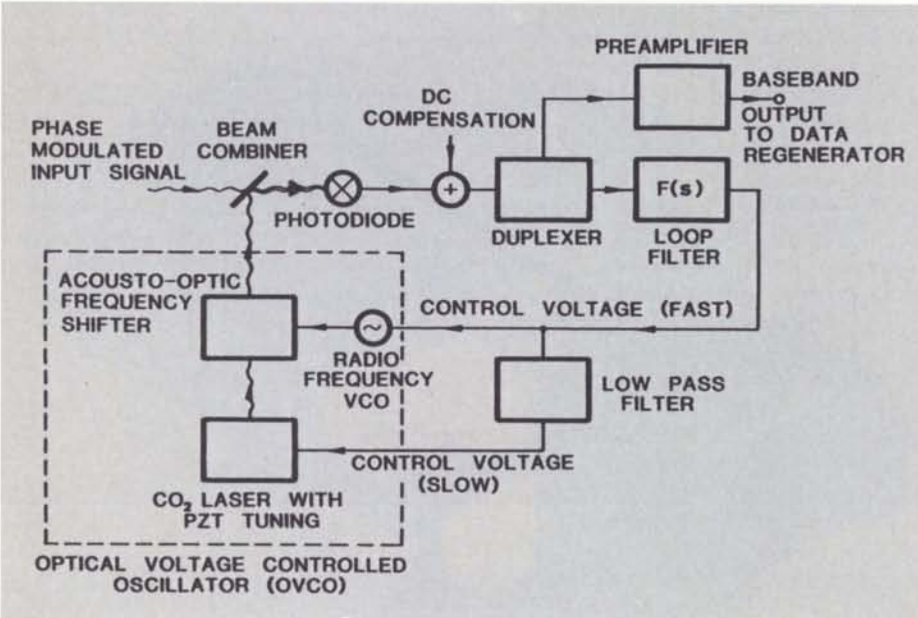


Figure 7 — Optical phase-locked-loop receiver with acousto-optically controlled local oscillator

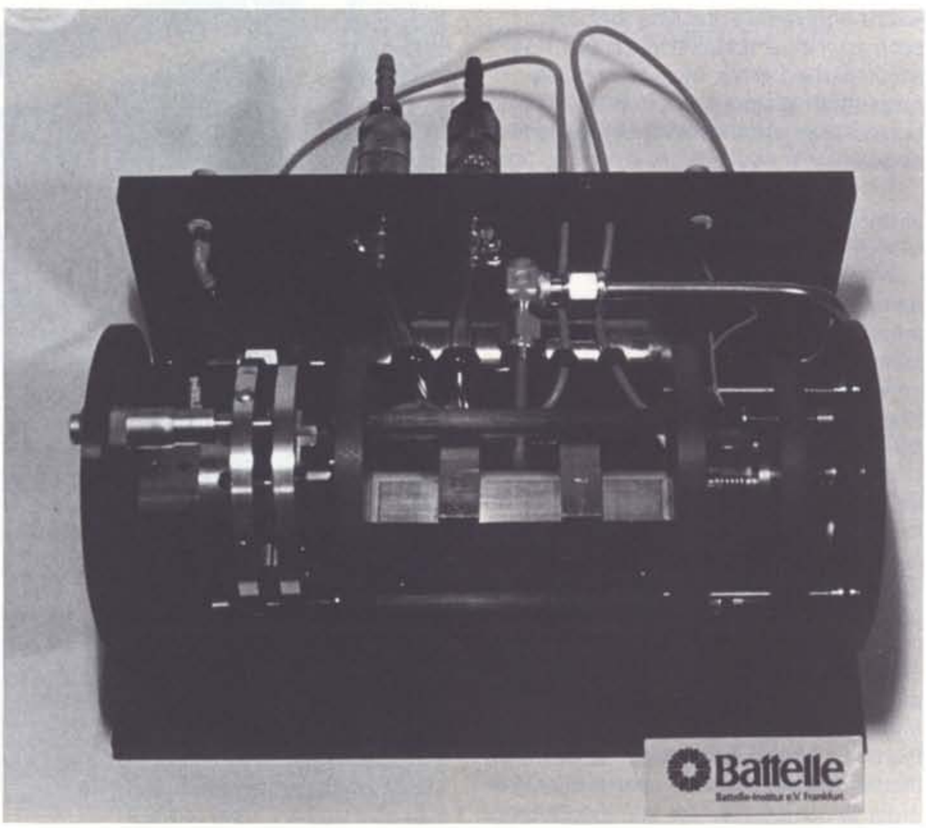


Figure 8 — Breadboard of CO_2 waveguide local oscillator with 1.4 GHz tuning range

synchronous radiation of a local oscillator laser, generating a 0 Hz intermediate frequency at the photo-detector output (optical homodyning). Automatic frequency and phase control is achieved by translating the well-known phase-locked-loop principle into the optical regime (Fig. 7). The local oscillator is a low-power CO_2 waveguide laser with a wide tuning range (Fig. 8). Apart from achieving the utmost receiver sensitivity, the use of coherent detection will allow high-performance modulation techniques to be implemented, fully exploiting the amplitude, phase and frequency content of the optical communication beam.

The development of the key building blocks for the CO_2 laser communication system is currently progressing at various European centres, including Battelle (Frankfurt), Teldix (Heidelberg), Schrack (Vienna) and the Technical Universities of Vienna and Stuttgart. It is expected that a full CO_2 laser transceiver package will be available for laboratory testing in the 1988—89 time frame.

Future hardware efforts will be increasingly oriented towards obtaining the requisite levels of reliability, lifetime and space qualification. An important element for the successful implementation of optical inter-satellite links will also be an early in-orbit demonstration of the technology, particularly as far as the tracking and coherent communication capabilities are concerned. Studies are currently being initiated to work out in detail the objectives and possible experiment configurations for space tests in the framework of ESA's Technology Demonstration Programme (TDP), or other mission opportunities.

The prospects for semiconductor-diode lasers

A number of years ago it was hardly conceivable that semiconductor-diode lasers could be used for data links in space. Early devices were notoriously unreliable, and the achievable beam quality and power levels were extremely poor. Recently, however, the prospects of terrestrial optical-fibre communications have advanced device development to a stage where diode laser systems become a serious contender for inter-satellite links. In fact, the diode laser has a number of features that make it particularly attractive for use in space: it is a very power-efficient device of extremely small size, weight and power consumption (Fig. 9).

For free-space communication, the diode laser transmitter must be powerful and provide a single-lobed far-field radiation pattern. Preferably the output should be from a single spatial mode so that diffraction-limited collimation can be achieved. The desired single-mode operation can be obtained in a predictable way by implementing advanced geometries on the laser chip for high optical confinement. Reduced guiding cross-sections, however, lead to increased optical power and carrier densities, and hence danger of degradation, limiting the ultimate power output capability.

At present, typical continuous-wave power levels attainable with laser diodes are in the order of 50 mW. For many space links that we have in mind, however, this power level is not sufficient. ESA is therefore sponsoring development work at Alcatel-Thomson (France) and Standard Telecommunication Laboratories (UK) with a view to achieving reliable, long-life diode lasers with single-mode output levels in the hundreds of milliwatt realm. Work is addressing both optimisation of single stripe lasers and methods of coherent power combining of several laser beams. The latter method consists of coupling together several laser stripes, closely spaced on the same substrate (Fig. 10). Light leaking from each stripe couples the individual emission regions and leads to phase-locked operation, resulting in a high-power, diffraction-limited output beam.

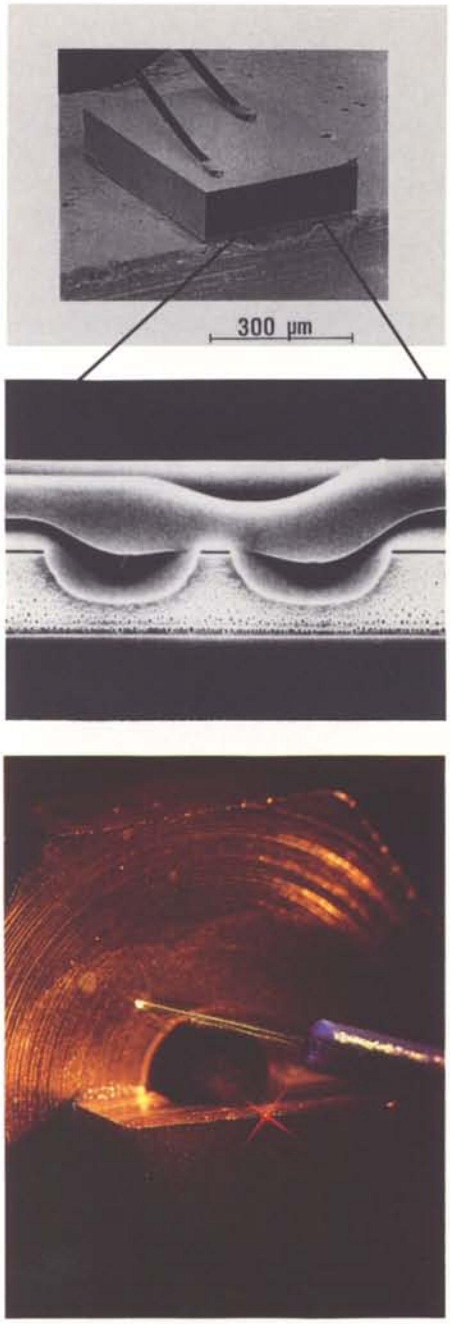


Figure 9 — Microscopic views of semiconductor laser diode (courtesy of Standard Telecommunication Laboratories, UK)
Top — Laser diode chip
Middle — Enlargement of active area
Bottom — Laser diode (red spot) on heat dissipating support

Technology comparison

Each of the technologies — CO_2 or diode laser — has its characteristic advantages and disadvantages, depending upon the particular mission and link requirements. The diode laser may be optimal for short-to-medium range applications such as inter-cluster or short-arc links between geostationary telecommunications satellites. The CO_2 laser, on the other hand, may be the preferred choice for long-distance applications, although system proposals have been made (by CNES) for using semiconductor lasers for the high-capacity, inter-orbit links required by the Data-Relay Satellite System (DRS).

One of the major advantages of the CO_2 laser is that it has no theoretical upper limit as regards output power. This provides the corresponding system with inherent growth capabilities up to very high data rates, e.g. beyond 1 Gbit/s, and generally allows CO_2 laser systems to operate with smaller telescopes than corresponding laser diode systems. Because of the higher wavelength of operation, the beam-pointing requirements are significantly relaxed compared to laser diode systems. The high energy output of the CO_2 laser transmitter also provides a powerful beacon source, needed for efficient link acquisition and tracking. The coherent optical detection principles used with CO_2 laser systems offer high sensitivity, good selectivity and efficient background rejection, even in solar-conjunction situations.

Coherent optical detection, however, adds complexity to the CO_2 laser system. There is need for frequency acquisition and Doppler tracking, calling for wide tunability (±700 MHz) of the local oscillator CO_2 waveguide laser. In addition, the detector requires cooling to approximately 100 K. This can be

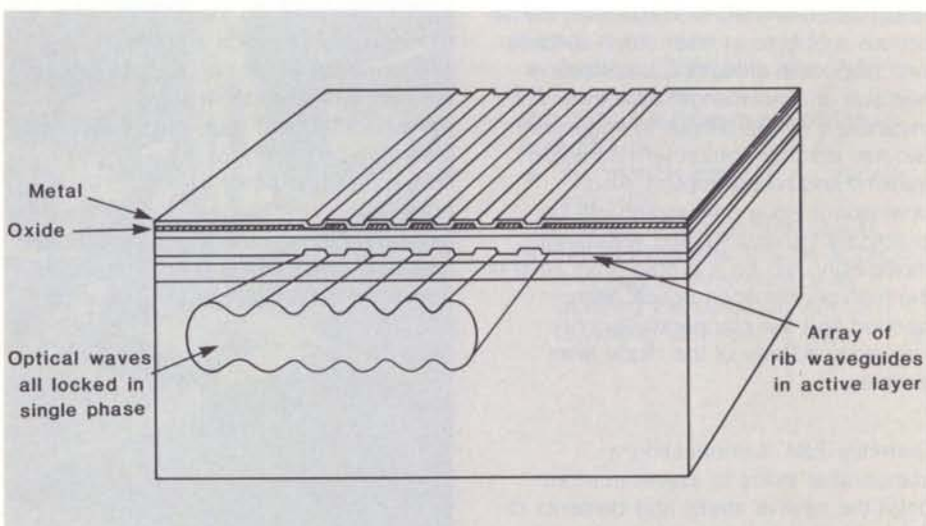


Figure 10 — Phase-locked laser diode array

achieved with the help of a closed-cycle minicooler, but at the expense of added problems with respect to reliability and lifetime. Also, a comparatively high modulator drive power (typically 20 W RF power for 1 Gbit/s) is needed for the post-modulation of the CO_2 laser. Significantly reduced power requirements can only be obtained with internal cavity modulation, which is feasible only for data rates lower than 200 Mbit/s. Gas refilling of the CO_2 laser will be needed to achieve the requisite lifetime in orbit.

Laser diode systems have the advantage of being comparatively straightforward as they use direct (on/off) modulation of the laser diode and direct detection receivers which do not have special cooling requirements. Because of their small size and reliability, the qualification of laser diodes is relatively easy and redundancy is readily achieved. System advantages are, however, somewhat offset by the severe output-power limitations of laser diodes, generally making larger optics necessary to achieve link performances comparable to those of CO_2 laser systems. The power limitation of laser diodes is particularly critical in the acquisition phase, where special laser diode beacon arrays are needed to obtain acceptable acquisition times. Laser diode systems, because of their shorter wavelength of operation, will also have to cope with an order-of-magnitude higher beam pointing accuracy than corresponding CO_2 laser systems.

Direct detection, albeit simple, may cause serious problems in laser diode systems with respect to cross-talk, background rejection and wavelength selectivity. For instance, it will be difficult to implement two-way communication with common transmit and receive optics. Also, operation in solar conjunction will be practically impossible, and wavelength multiplexing will be a problem because of the high-performance optical filters needed and the comparatively poor frequency stability of the diode laser sources.

Currently, ESA is conducting a comparative study to assess in more detail the relative merits and demerits of the two technologies in terms of suitability for inter-satellite communications, in particular for the Data-Relay Satellite System (DRS). Many assertions of this comparative analysis, however, will have to rely for the time being on mere projections of technological capabilities, rather than proven fact. Intensified technological research is still needed in a number of crucial areas in order to gain confidence in the technical approaches envisaged. This requirement has been taken into consideration in ESA's technology-research planning.

Future technology efforts in space laser communications will also be strongly influenced by developments in other fields. The CO_2 laser technology has widespread industrial and military applications, and developments in these areas will greatly benefit endeavours to use this laser for communications in space. Similarly, diode laser technology will profit from the dramatic advances now being achieved in optical-fibre communications.

These developments will be carefully watched in order to optimise use of ESA resources. For instance, the general trend in optical-fibre systems is to use the 1.2—1.6 micron region, where optical-fibre attenuation and mode dispersion are lowest. ESA will therefore put emphasis on this wavelength region in its development efforts on laser diode communications in order to take advantage later of the highly reliable and efficient components that will become available in this field. Also, ESA's technological research in laser communications will be oriented beyond the needs of mere technology demonstration and start to address topics likely to be required for the implementation of high-capacity, operational laser inter-satellite links, such as heterodyne detection of laser diode radiation, wavelength multiplexing or advanced methods of beam acquisition and tracking.

In Brief

Remote-Sensing Agreement Reached by ESA and NASA

Dr. William Graham, NASA's Acting Administrator, and Prof. Reimar Lüst, ESA's Director General, on 14 January 1986, signed a Memorandum of Understanding on NASA/ESA cooperation in connection with ESA's first Remote-Sensing Satellite (ERS-1), to be launched in 1989.

Under the Memorandum, ESA has agreed to permit direct readout of ERS-1 Synthetic Aperture Radar (SAR) data for US Government research purposes at the Fairbanks (Alaska) station which NASA is developing in connection with its Navy Remote Ocean Sensing Satellite System Scatterometer (NROSS) programme. Under the agreement, NASA will also exchange NASA scatterometer and radar imagery for other ERS-1 data of interest. The data received from ERS-1 should enhance NASA- and ESA-supported polar-ice research and complement NASA experimental activities related to NROSS, the Ocean Topography Experiment (TOPEX) and Shuttle Imaging Radar-C, all of which are projected to operate in the same time frame as ERS-1.

This Memorandum of Understanding maintains a tradition of remote-sensing collaboration between NASA and ESA for the benefit of the international research/application user community. In permitting NASA direct data readout from ERS-1, ESA is reciprocating similar provisions made in the past by NASA for European data readout from its Seasat and Nimbus-7 spacecraft.

Ariane Launch Calendar

The Ariane V16 launch, using the last Ariane-1 launcher, will place into heliosynchronous orbit the French Earth observation satellite SPOT and the Swedish scientific satellite Viking.

The V16 launch, previously postponed until 16 January 1986 due to the failure of V15, has now been rescheduled for 21 February following the discovery of a crack in the 2nd-stage water tank. While experts investigate the cause of this, the defective tank will be replaced by a new one. This operation will take place on 23 January.

The updated timetable for V16 and subsequent launches is currently as follows:

- V16: SPOT & Viking (Ariane-1 from pad ELA-1)
  - 21 February
- V17: G-Star 2 & Brasilsat (Ariane-3 from pad ELA-2)
  - 12 March
- V18: Intelsat-V F14 (Ariane-2 from pad ELA-1)
  - Approx. 2.5 months after V16, i.e. end April
- V19: ECS-4 & Spacenet 4 (Ariane-3 from ELA-1)
  - Two months after V18, i.e. approx. end June
- V20: TV-Sat (Ariane-2 from ELA-1)
  - Two months after V19, i.e. approx. end August (Arianespace is studying the possibility of launching V20 from ELA-2).

IUE Observes Comet Halley

The first observations from space of Comet Halley were made in 1985 by the International Ultraviolet Explorer Spacecraft (IUE), in the context of the worldwide cooperation of astronomers in the International Halley Watch (IHW). These observations with the IUE satellite observatory were the responsibility of Dr Festou of Besançon Observatory, France and Dr Feldman of The Johns Hopkins University in Baltimore, USA, who are coordinating the ultraviolet observations of Comet Halley.

The first space-based observations were made with IUE in early April 1985, when the comet was still 700 million kilometres from Earth. In December a more intensive cycle of observations was started, which will last until the comet returns to the outer regions of the solar system, after its closest approach to the Sun (perihelion) on 9 February 1986. More than 150 hours of observing time on IUE will be dedicated to the observation of Comet Halley. Observations will be particularly intense at the time of the Halley encounters by the various cometary spacecraft between 6 and 14 March 1986.

Spectra taken with IUE on 15 December, when the comet was some 115 million kilometres from Earth, show clear evidence of a considerable increase in activity in the comet caused by the increased solar radiation. The comet's gas composition appears to be similar to that found in older comets observed earlier with IUE. The characteristic emissions of the elements hydrogen, carbon, oxygen and sulphur have been identified, as well as the emissions of carbon-sulphide and a possible water decomposition product (hydroxyl).

In the IUE images the comet appears to have a quite dense and rather compact dust coma, extending for some 20 000 kilometres, i.e. roughly one tenth of the extent of the gas coma. In addition to the faint gas tail which has developed, a small dust tail is also apparent on images taken with IUE's star tracker. Giotto will encounter these dust clouds as it makes its planned flyby within 500 kilometres of the nucleus on 13/14 March.

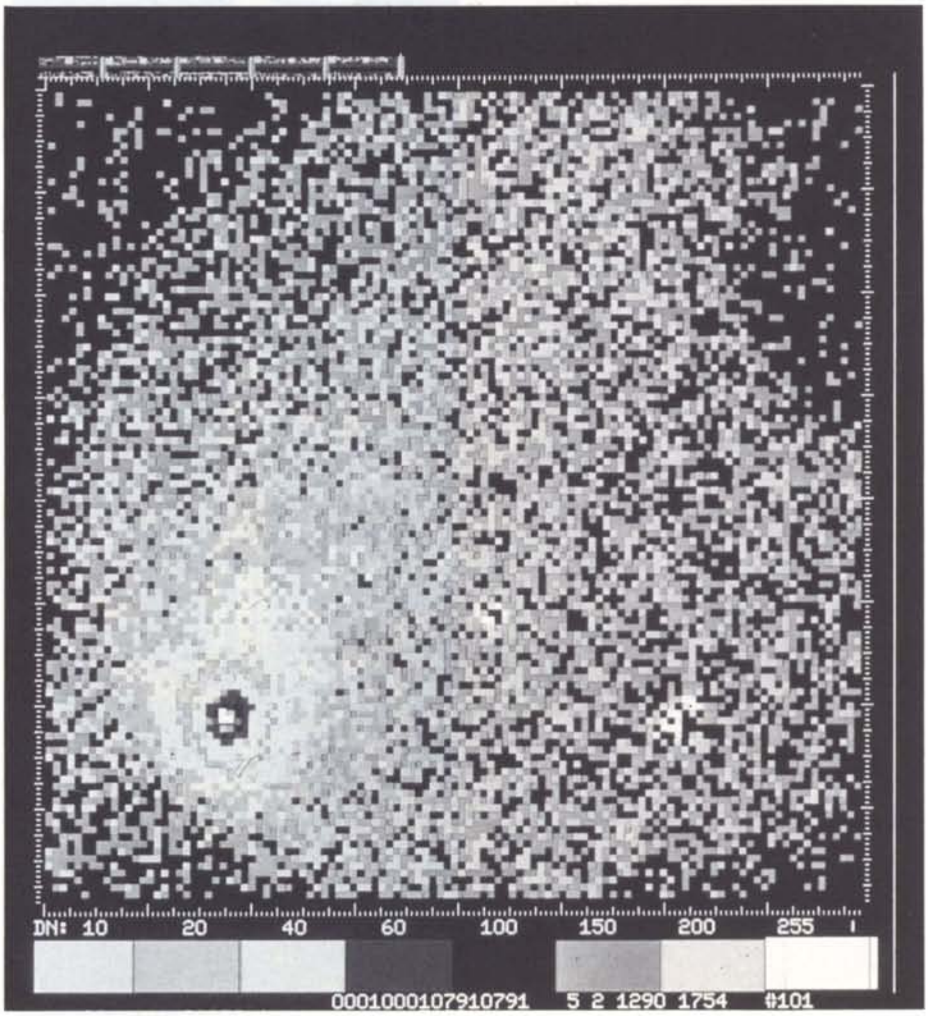


Image of Comet Halley taken by the IUE spacecraft on 31 December 1985. A full-colour-enhanced version appears on the front cover of this Bulletin

ESA Signs Three New Contracts with Arianespace

On 10 December 1985, ESA signed three new contracts with Arianespace, two for future launches and one for technical assistance with the launch of passenger satellites on the first flight of Ariane-4. The two launch contracts are for the launch of ESA's ECS-4 communications satellite, scheduled for the second quarter of 1986, and of the Agency's Hipparcos scientific satellite, scheduled for June 1988.

ECS-4 will replace ECS-3, lost due to the September 1985 launch failure. The ECS-4 spacecraft was already in production at that time and scheduled for a launch in early 1987. Its completion has been accelerated and Arianespace is providing the earliest possible launch slot, in accordance with the re-launch conditions contained in the ECS-3 launch contract.

The third contract provides for technical assistance by Arianespace for payload operations for the first launch of Ariane-4, an integral part of the Agency's Ariane-4 development programme, which will be carried out under ESA's responsibility. This launch, scheduled to take place during the third quarter of 1986, is intended to demonstrate the operational capability of Europe's most powerful launcher. ESA is providing part of the payload for this launch with Meteosat-P2, a refurbished spacecraft from the pre-operational series designed to bridge a potential gap between Meteosat-2 and the first of the operational meteorological spacecraft, MOP-1, scheduled for launch in the second half of 1987. The other payload elements will be Amsat Phase III-C, the second unit of the third generation of 'Oscar' radio-amateur satellites, and a telecommunications satellite still to be selected.

The contracts were signed for ESA by Mr G. Salvatori, Director of Telecommunications (for the launch of ECS-4), by Dr R.M. Bonnet, Director of Scientific Programmes (for the launch of Hipparcos), by Mr M. Bignier, Director of Space Transportation Systems (for Ariane-4 technical assistance), and for Arianespace by Mr C. Bigot, their Director General.

International Halley Watch to Meet at ESA Headquarters

The last full meeting of the International Halley Watch (IHW) before the spacecraft encounters Halley's Comet in March will take place at the Agency's Paris Headquarters from 7—9 February 1986.

Set up in 1980, the IHW is responsible for stimulating, coordinating and archiving all ground-based observations of Halley's Comet throughout the present apparition. Eight discipline specialist teams or, 'nets', have been coordinating work in their respective areas on a worldwide scale for the last six years. The eight disciplines covered by the 'nets' are: Astrometry, IR spectroscopy and radiometry, large-scale phenomena, near-nucleus studies, photometry and polarimetry, radio studies, spectroscopy and spectrophotometry, and meteor studies.

A Press Conference will be held on the afternoon of Friday 7 February, at which the two IHW leaders and representatives of each of the eight nets will give a brief overview of the status of observations in their respective areas. In addition, the Giotto Project Scientist, Dr R. Reinhard, will give a status report on the Giotto mission to Halley's Comet, and Dr H.U. Keller, Principal Investigator for the spacecraft's Halley Multicolour Camera, will comment on the pictures of the Earth taken with the Camera (see cover and pages 96—97 of ESA Bulletin 44).

IHW

INTERNATIONAL HALLEY WATCH

Children's Painting Competition to Celebrate Giotto's Encounter with Comet Halley

During the night of 13/14 March 1986, ESA's Giotto spacecraft will fly within 500 km of the nucleus of Comet Halley. The next opportunity for an encounter will not occur until the year 2061.

In mid-January, ESA invited all children under 10 years of age to commit to paper their concept of this year's historic encounter with the comet, so that their impressions of this event could be documented for the comet's return in 76 year's time.

All entries received by the closing date of 15 February are being carefully archived with a view to staging an exhibition in 2061. The originators of the best drawings and paintings are to be invited to the Agency's Paris Headquarters in the course of 1986 to receive their prizes.

Further information can be obtained from ESA Press and Publications Section at ESA Headquarters, 8—10 rue Mario Nikis, 75738 Paris 15, France.

ESA Philatelic Competition for the Giotto Encounter

At the invitation of ESA's Director of Operations, Mr K. Heftman, all ESA staff were invited last November to participate in a competition to design a 'Sonderstempel', or special postage frank. A total of 18 proposals were received and a jury, consisting of members of the Giotto Public Relations Working Group, evaluated these inputs and awarded the following prizes:

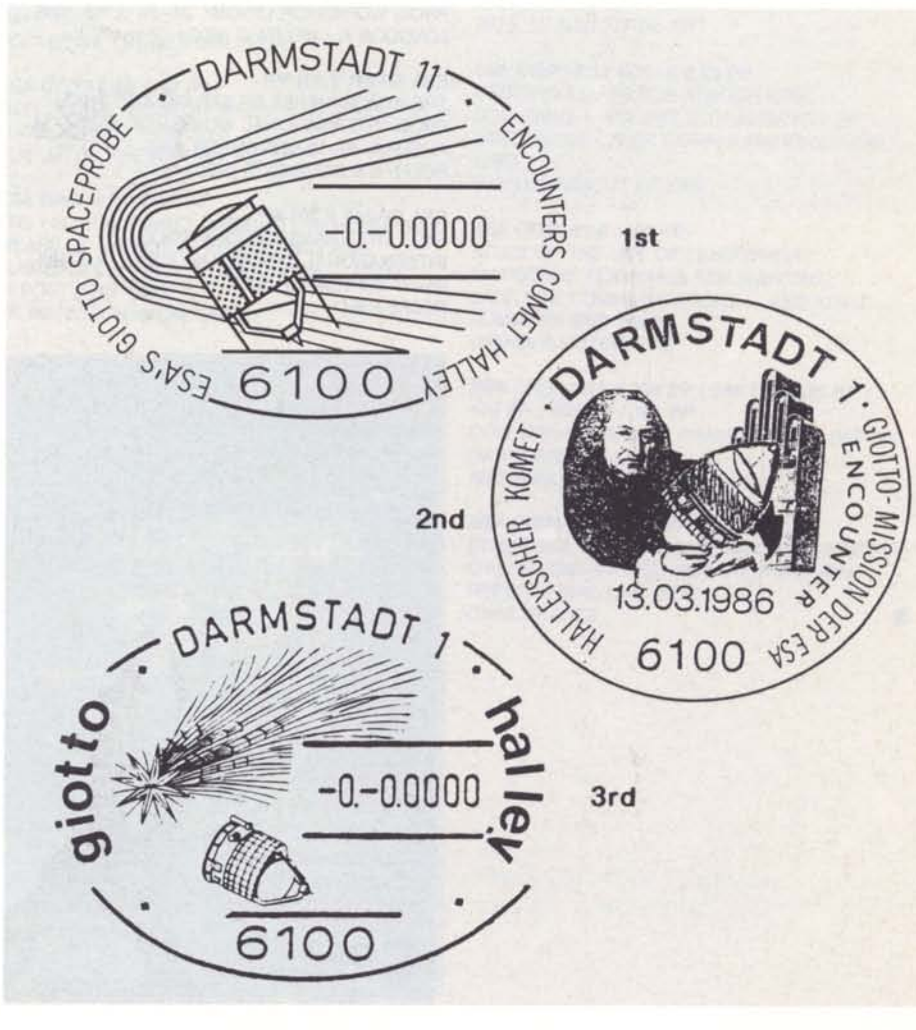
First prize:	Mr E. Balaguer, ESTEC
Second prize:	Mrs B. Dorner, ESOC
Third prize:	Mr D. Dixon, SSD/ESTEC

The winning proposals are shown in the accompanying illustrations.

The winners have each been awarded a one-twentieth scale model of Giotto and have been invited to participate in the Giotto encounter activities at ESOC.

The winning design by Mr E. Balaguer will be used by the German PTT to produce a special franking mark. On the 13 and 14 March, a special Post Office will be opened at ESOC and all mail posted from there will carry the special frank. The mark will then be available for philatelists for another month in the main Post Office in Darmstadt

Mr Heftman would like to take this opportunity to thank, once more, all those who participated in this competition.



Publications

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

ESA Journal

The following papers have been published in ESA Journal Vol. 9, No. 4:

STRATEGIES FOR THE CALIBRATION AND OPERATIONAL USE OF ERS-1 SAR WAVE MODE
J P GUIGNARD

FOREST SIGNATURES IN IMAGING AND NON-IMAGING MICROWAVE SCATTEROMETER DATA
A J SIEBER

LASERS IN SPACE – APPLICATIONS TO ATMOSPHERIC SCIENCES
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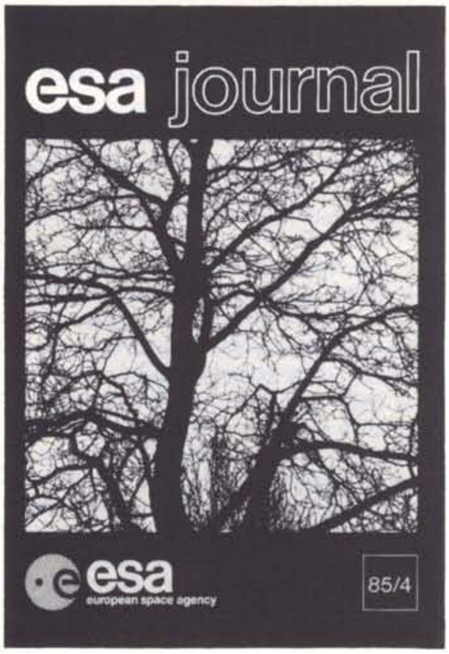

Special Publications

ESA SP-233 // 261 PP
PROCEEDINGS OF THE EARSEL/ESA SYMPOSIUM ON EUROPEAN REMOTE-SENSING OPPORTUNITIES, SYSTEMS, SENSORS AND APPLICATIONS (JUNE 1985)
LONGDON N / MELITA O (EDS.)

ESA SP-239 // 308 PP
A COSMIC X-RAY SPECTROSCOPY MISSION, PROC. WORKSHOP, LYNGBY, 24–26 JUNE 1985
LONGDON N / MELITA O (EDS.)

ESA SP-241 // 311 PP
THE ATMOSPHERES OF SATURN AND TITAN, PROC. INTERNATIONAL WORKSHOP, ALPBACH, AUSTRIA, 16–19 SEPTEMBER 1985
ROLFE E & BATTRICK B (EDS.)

ESA SP-245 // 201 PP
SATELLITE TRANSMISSIONS, PROC. INTERNATIONAL SYMPOSIUM, GRAZ, AUSTRIA, 25–27 SEPTEMBER 1985
ROLFE E (ED.)

Contractor Reports

ESA CR(P)-2098 // 90 PP
GROUND-SEGMENT CONCEPT FOR A DATA-RELAY SATELLITE — PHASE-1 FINAL REPORT (JAN 1985)
MATRA ESPACE, FRANCE

ESA CR(P)-2099 // 187 PP
DEVELOPMENT OF SOFTWARE FOR COMPUTING THE COUPLING COEFFICIENTS OF THE ERS-1 ANTENNAS – FINAL REPORT (JAN 1985)
ERA TECHNOLOGY, UK

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TESTING OF SPACECRAFT ATTITUDE AND ORBIT CONTROL SYSTEMS (MAY 1985)
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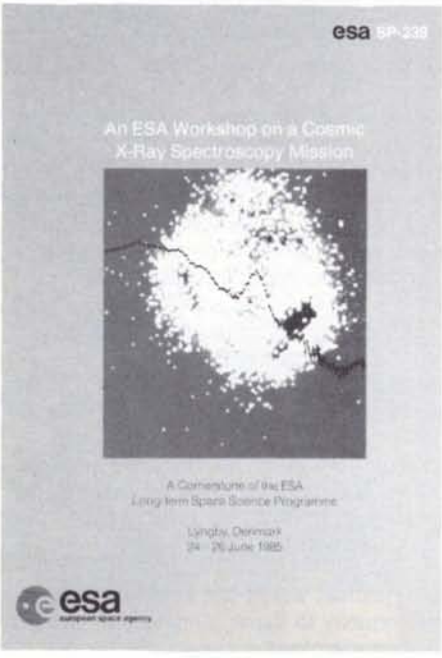

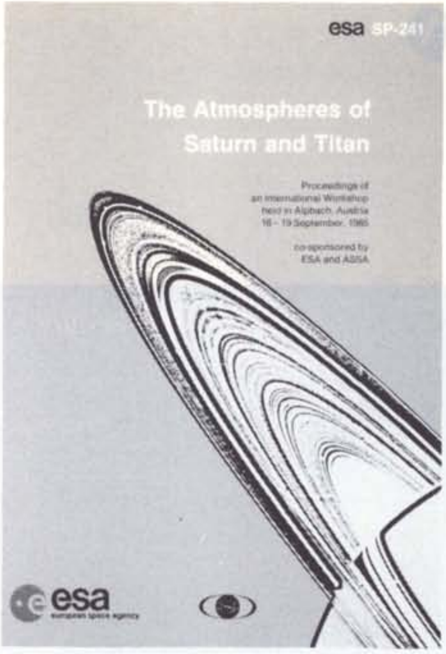

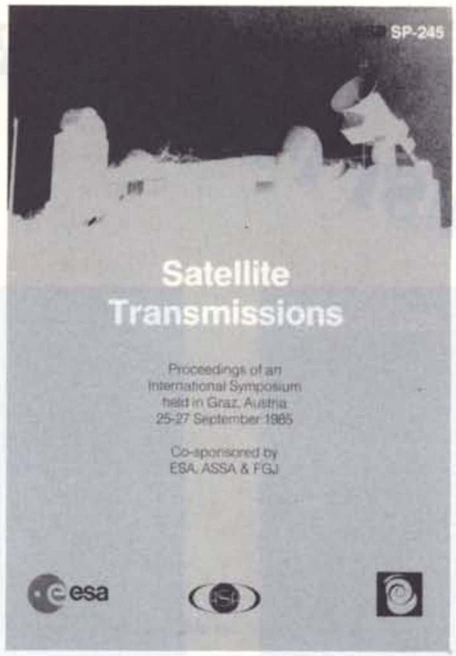

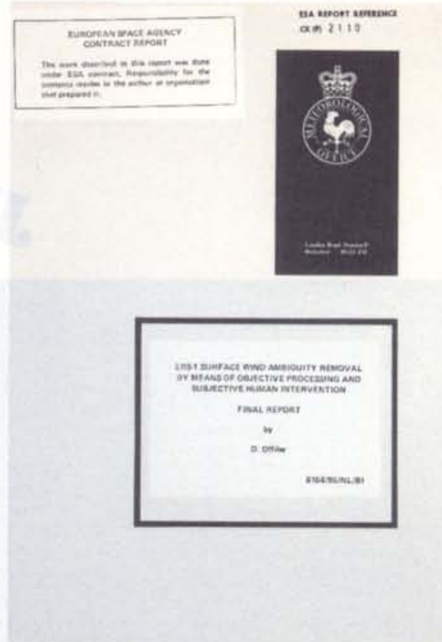

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GEC ENGINEERING RESEARCH CENTRE, UK

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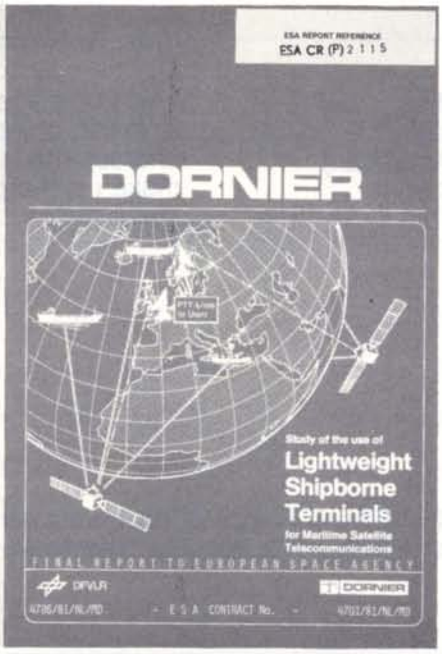
UK METEOROLOGICAL OFFICE



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ESA CR(P)-2112 VOL. 1 // 278 PP
ORBITING LIDARS FOR ATMOSPHERIC SOUNDING – FINAL REPORT, VOLUME 1 (DEC 1984)
BATELLE-INSTITUT EV, FRG

ESA CR(P)-2112 VOL. 2 // 79 PP
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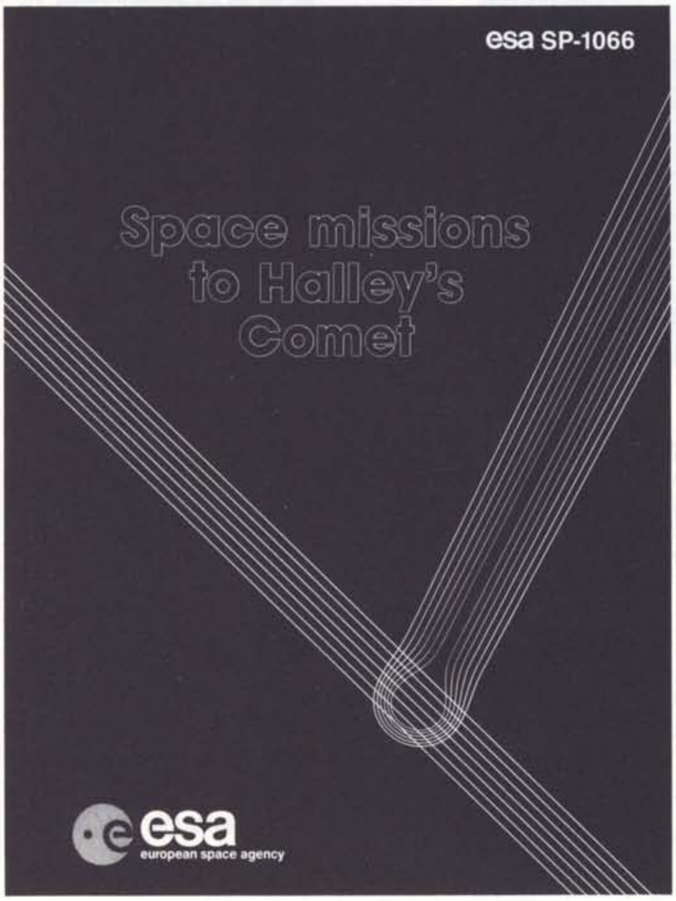

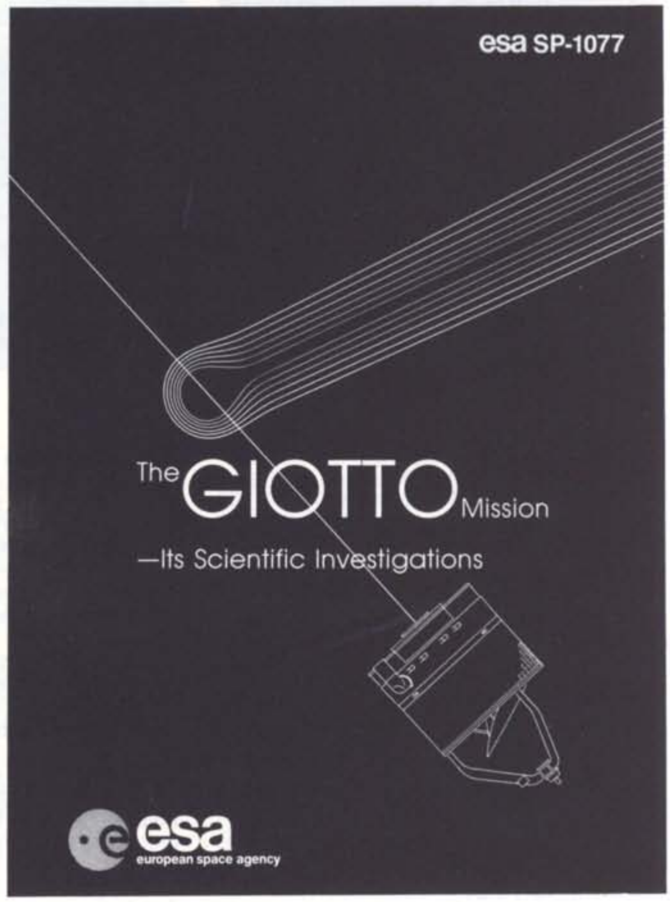

ESA SP-1066 Space Missions to Halley's Comet

(Eds. R. Reinhard & B. Battrick)

This volume contains detailed scientific descriptions of the major space missions (European, Russian, Japanese and American) being undertaken to study Halley's Comet during its March 1986 apparition.

ESA SP-1077 The Giotto Mission — Its Scientific Investigations

(Eds. R. Reinhard & B. Battrick)

This 200-page volume describes in detail the scientific objectives and technical characteristics of the eleven experiments that make up the payload of ESA's Giotto spacecraft.

Copies of both documents (200 French Francs or equivalent per volume) are available from:
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