ASTRONAUTICS FOR PEACE AND HUMAN PROGRESS

PROCEEDINGS OF THE XXIXth INTERNATIONAL ASTRONAUTICAL CONGRESS,
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PREFACE

The 29th Congress of the International Astronautical Federation was held in Dubrovnik upon the invitation of the Yugoslav Astronautical and Rocket Society.

The theme of the Congress was "Astronautics for Peace and Human Progress". As usual, the theme was the subject of the Invited Lecture, which this year was delivered by Academician L.I. Sedov, one of the leading space scientists and a long standing member of the Bureau of the Federation.

The co-Chairmen of the International Programme Committee, G.G. Chernyi of the U.S.S.R. and R. Monti of Italy, achieved praiseworthy results in structuring a scientific programme which balanced the development of the Congress theme with the scientific and technical sessions and harmonized all these with the symposia organized by the International Academy of Astronautics and the Colloquium of the International Institute of Space Law.

This book of proceedings contains invited papers and a selection of survey and state-of-the-art contributed papers. Other papers offering original contributions in the many specific subjects dealt with in the sessions organized by the Federation will be found in the companion publication constituted by a special issue of Acta Astronautica.

This year proceedings will interest an even wider and more diversified audience than previously. The first section, indeed, is an updated cross section of the on-going space activities, including overviews of the programmes of the U.S.A., E.S.A., U.S.S.R., Federal Republic of Germany, and Japan. The last two are explicitly singled out in this preface because the corresponding member societies will be our hosts for the next two congresses.

The second section of the proceedings deals with the systems for space exploration. As may be expected, a great share of this section is devoted to the SPACELAB, but other relevant scientific ventures such as those associated with the Voyager programme and the International Solar Polar Out-of-Ecliptic Mission also have their place, and an interesting report on the evolution of Space Power Systems is presented.

The third section concentrates on what I like to refer to as the second generation space technology utilization, namely Earth Exploration from Space. The survey touches upon all the main aspects of this application, going, as it does, from the space-borne sensors to the latest developments of automatic data analysis, to the presentation of the results obtained in indicative fields.

The fourth section records current events in the first generation of space technology utilisation, namely communication satellites. At last year's congress, a special symposium was devoted to this topic. This year, the selection presented is meant to keep interested people up to date on the latest developments and/or projects.

The fifth and last section deals briefly with the technology needed to do the things discussed in the foregoing sections.

It is my pleasant duty to acknowledge the contributions of the many people who made these proceedings possible: the members of the Programme Committee, the Session Chairmen, the I.A.F. Secretariat, the Publisher, and of course, the authors. I am confident that the work of all of them will contribute to the further development of "astronautics for peace and human progress" as was the aim of this year's Congress.

Luigi G. NAPOLITANO
Editor in Chief
Proceedings XXIXth
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THE ROLE OF ASTRONAUTICS IN THE STRUGGLE FOR PEACE AND THE PROGRESS OF MANKIND*

L. B. Sedov

It is already more than twenty years since the first satellite was launched round the Earth by the Soviet Union, on 4th October 1957, and since then we have witnessed a steady development of space studies thanks to man-made devices travelling in circumterrestrial and interplanetary space.

Everyone knows the fantastic feats accomplished in the space field within the few years that followed the dawn of this new era. After the billions of years that Earth has existed, humanity now has the possibility of looking at the hidden side of the Moon, and even its own planet, through photographs taken from outer space, while photographs of other planets, taken at close range, have already been transmitted to Earth.

Man has already produced terrestrial satellites that are actually space laboratories, served by crews periodically replaced. Now, we see the construction and development of reusable spacecraft capable of ensuring the transportation of cosmonauts, of various materials, and of instruments connecting ground bases and space stations, and remaining in orbit for long periods.

During these twenty years, specialists have obtained fundamental results in the field of pure and applied sciences, and important technical progress has been made in the construction of space rockets, satellites and space laboratories. These spectacular results have already had repercussions on the development of various branches of technology and in important areas of the everyday life of people throughout the whole world.

It is thus that modern science, and particularly the theory and practice of space flight, modify the way of life, the psychology, and the economic situation of various peoples.

Nowadays, international relations depend more and more on the development and progress of science and technology.

Conversations and exchanges of views between nations and intergovernmental agreements

*Paper translated from the Russian original.

are concerned with various essential points, such as the development of science and technology and, in other cases, the limitations of their possibilities regarding military applications. Let it suffice to recall, at this point, the diplomatic efforts deployed in favour of disarmament or the interdiction to use chemical or biological means for the destruction of mankind.

The impact of science in general, and particularly that of space studies, is already outstanding on the accelerated rate of contemporary history.

The possibilities of the fight against hunger in some parts of the world, the increase of the average living standard of populations, and the lengthening of the mean life-span can now be improved thanks to scientific and technical progress.

It is also obvious that it is only through a scientific organization of production and the introduction of a series of drastic measures that we can slow down, and even stop the progression of pollution in our environment, and thus save mankind and the whole living world from a catastrophic self-destruction; and not only save, but even preserve, the existence of a rapidly increasing world population: according to statisticians, this population is at present 3.5 billions, and this figure should reach 5 billions by the year 2000.

The elimination of tensions existing between some countries and success in the struggle for peace now depend to a great extent on the essential contribution of scientists in the resolution of general problems raised by the struggle for peace.

It is now over thirty years since a major war on our planet, similar to the first or second world war, but we frequently witness bloody events or local wars, which fortunately remain circumscribed to such or such country or region, and in which the frightful means available for global destruction have not yet been used.

All the specialists, scientists and engineers have a duty to convince the population masses of all countries, and the people governing them, of the absolute necessity to renounce war and to look for peaceful means to settle all impending conflicts which in many cases are caused by small influential groups, and which could easily be settled if only the profound interests of the populations of the countries concerned were taken into consideration.

The progress realized in most modern disciplines of fundamental and applied sciences and in advanced techniques play an important role in the development of modern intellectual and material culture. This was proved during recent years and will undoubtedly be still more true in the near future.

Science can and must be the source of a still higher material living standard for all peoples and of a fundamental transformation of their states of mind, a transformation that conditions the mutual relations and the collaboration between the various governments as well as between the different classes of the population within the same country.

Many are the inhabitants of all countries who think and hope that the most elementary common sense and the most sincere and apparent aspiration of large numbers of the population of all countries towards peace will eventually triumph: common sense and the simple concept of the possible consequences of a major war, in our time of atomic bombs and intercontinental rockets, should be a guarantee of their rejection of it.

With the present-day scientific and technical development, a new major war would cause an incalculable number of victims and a global catastrophe; but fortunately, thanks to that same progress, the heads of state are more and more convinced that a major war should be averted; so we can hope that there will not be any more, and that the ever greater accumulation of costly and terrifying weapons is of no use, as there will be no occasion to use them.

Those who will understand this, and act accordingly, will harvest its benefits. But the details of these questions are very complex and outside the scope of this paper.

In the favourable perspective of a pacific coexistence that we see dawning, a solution of the problem of disarmament must be sought, or at least a partial suspension of armament efforts. It is necessary to arrive at a limitation of the development and accumulation of armaments and various means of destruction, of which enough already exist to annihilate all life on this planet within a few days. There are many today who solemnly declare that the continuing production of these monstrous means of destruction is not necessary, as these means should not and will not be used.

History and everyday experience show us that not everything in our world is reasonable. It is not uncommon that the force of events and collective psychoses essentially created to serve the interests of small groups of people lead whole countries into powerful upheavals, in which the conduct and actions of otherwise reasonable and normal members of a population are dictated by the momentary situation and do not correspond in any way to their opinions or deep convictions.

We have many times witnessed paradoxical situations which not only arose, but lasted, and in the end were of no advantage to the people concerned, but from which there was practically no way out.

We know that, thanks to progress in science and technology, air flight has become a very safe activity. In particular, engineers and pilots have learnt how to avoid catastrophes resulting from navigational errors or from the application of a bad technical solution, leading to a spinning stall, a downward helicoidal motion of the aircraft that cannot be stopped.

The development of modern culture can and must prevent the global catastrophe that would result from joining in the mêlée of a new world war, by finding the ways to get out safe and sound from local wars without enduring the fearful consequences of a hopeless situation.

There is no doubt that the great advances of modern science, particularly space science, mark important steps in the progress of mankind. Nowadays, it is mandatory to consider it when we examine the international situation. Many people firmly hope that this progress will incite our leaders to reason, and thus have an action favourable to peace.

The ever broader use of a large variety of machines, engines, radio, television, electric home appliances, computers and a multitude of other technical achievements has irresistibly transformed the way of life of twentieth-century man, and continues to transform it.

The present scientific and technical development, which is related to existing and future discoveries and inventions, will give rise to important modifications in industry and in the living standard, the relations and the mentality of people.

We have every reason to suppose that the important increase, in many countries, of the number of specialists possessing a medium or higher education, and the broadening of the fields of research, will lead to new qualitative modifications of our way of life and of the distribution of work in our society.

Nowadays, in many countries the government funding of scientific research increases noticeably; nonetheless, it remains much lower than that of some other necessary but unproductive expenses, such as military expenses, which can and should be reduced. It is possible that this reduction will be one of the most important results of scientific work.

It is often necessary to discuss the usefulness and interest of such or such public expense, or the allocation of human resources to the solution of such or such scientific or technical problem. In these discussions one should take into account the present situation, our thirst for peace, and long-term prospects.

At the same time as critical remarks on the short-term usefulness of the intense efforts made to solve fundamental problems of physics and astronomy, particularly the structure of matter and the study of the universe, we rather often hear an opinion, expressed even by eminent scientists, according to which the space research programmes carried out or planned in the USSR would be of little use.

Let us stay for a moment on the subject of the interest of space research. First of all, let us remark that all the great scientific or technical discoveries always met with a strong resistance. Among the famous sceptics, we can cite the great Goethe, who wrote "to the wings of mind we shall never add material wings". Hardly twenty-five years ago, among the great scientists whose contribution to the techniques of space flight is now essential, some did not believe in the imminent realization of artificial satellites, let alone that of interplanetary flight. We also know that some scientists, who today are authorities in the field of nuclear physics, did not believe before the war in the possibility of the practical use of atomic energy.

Indeed, during the twenty-odd years of what we may call the heroic period of the space era, outstanding successes in space flights were recorded. Man has put a large number of artificial satellites in orbit around the Earth; has sent interplanetary stations to the Moon, to Venus, to Mars and close to the Sun, has accomplished soft landings on the Moon, Venus and Mars. Man has also walked in space outside spacecraft, and has actually set foot on the Moon surface. Direct studies of the atmosphere and surface of Venus have also been performed. Scientists have initiated the direct study of the physical properties of Jupiter and its atmosphere, and it is planned to investigate, in the near future, the planet Saturn.

Space research has made possible discoveries of prime importance. The scientific devices mounted on spacecraft have become one of the main means of carrying out fundamental physical studies. Just as with the microscope in biology and the telescope in astronomy, the spacecraft equipped with complex measuring instrumentation is now the principal means for studying the nature and properties of the universe as well as the properties of matter and magnetic fields in conditions not existing on Earth.

People from all countries have followed with enthusiasm and emotion the most important space flights. So the joys of discovery and the satisfaction for the success achieved have been shared not only by the many participants to these feats, but also by all levels of population the world over.

Thus, science creates new concepts of what is great and what is meaningful, concepts that relegate into the background conflicts resulting from sordid and egoistic interests which, till now, have been the cause of much evil to man. Besides the monuments erected to czars, kings, conquerors, generals, personalities of art and literature, more and more often monuments are built to the memory of pioneers of science and technique, and to the authors of the great discoveries who transformed into reality the dreams of mankind.

Science and technology and in particular astronautics, have become one of the sources to satisfy the urge to create and the spiritual needs of man.

In addition to its theoretical value, which forms the basis of the general progress of culture and of various industrial applications, astronautics has already acquired practical importance, and entered our everyday life because of the many things it has made possible such as radio-communication and intercontinental telecommunication, meteorological forecasting, harvest prediction, improvement in the accuracy of the maps on Earth, the solution of many other practical problems interesting all the people on Earth.

There is no doubt that the space technology and the research it brings forth has a particularly stimulating effect on the development of present-day techniques, contributing noticeably to their progress, in particular in the development of servo-systems, on radio-electricity, on television and remote control, on informatics, on new materials, on new devices and instruments, on miniaturization and weight reduction of machines and instruments, on the precision and reliability of various automatic systems, etc.

In other words, everyone clearly sees that, just as aviation and naval engineering, space technology has become one of the pillars of modern technology in the broadest meaning of the term.

In the resolution of the essential problem of our time, which is the establishment and maintenance of peace, a problem of prime importance for all the inhabitants of Earth, the beneficial role of space research takes on more and more relevance and becomes more and more obvious. We now attribute international importance to the collaboration of scientists of different countries, as well as to the implementation of cooperative space research programmes and to the joint solution of new technical problems. One should also point out the importance of the fruitful scientific cooperation between scientists of socialist countries in the space field, organized by Inter-Cosmos (Council for the international cooperation in the exploration and use of extra-atmospheric space). Within the framework of this cooperation, flights have already been carried out by cosmonauts of Czechoslovakia, Poland and East Germany together with Soviet pilots. We shall also note the particular importance of the cooperation between scientists and engineers of the Soviet Union and of the United States during the implementation of the "Apollo-Soyuz" programme.

Science and technology have become now a field of international cooperation that constantly widens. The development of such a cooperation on a basis of equality of rights and of mutual advantages between countries with different social structures appears as an important contribution for the elimination of international tensions, offering a new basis for the maintenance and strengthening of the détente through the international spirit that pervades it.

The positive contribution of space research to peace shows that the efforts deployed and the financial resources invested in this field have already brought results whose importance should not be underestimated.

The International Astronautical Federation, founded in 1950 as an international scientific and technological association formed by several organizations bringing together space researchers and enthusiasts, facilitates contacts among scientists and engineers working in the various fields of human knowledge connected with the realization of systems ensuring the travel in space of man and/or scientific instruments, and which have already permitted landings on the Moon, Mars and Venus.

Besides the study and resolution of problems of scientific and technological character, and the formulation of various short-and long-term predictions in this field, the International Astronautical Federation exerts a favourable influence on the attitude taken in the whole world with regard to space flight, and contributes to international cooperation in this field.

This cooperation runs smoothly, and we have already many examples of international projects, some of which are already realized or planned for the near future.

These joint activities have undoubtedly a favourable influence on the international situation, as they contribute to bring people closer to each other and to set their minds towards a mutual understanding with a view to fulfilling a noble purpose. All this serves the cause of peace as it contributes to the exchange of scientific experience and stimulates the development of modern science and technology throughout the world.

The founders of the International Astronautical Federation and all those who have succeeded them have always been animated by a profound humanism and, conscious of the necessity of looking for mutually acceptable means of reaching a fruitful cooperation and of establishing concerted rules and actions, have a favourable influence on the onset and development of space technologies, of which one of the first goals was sending man into space and keeping him and his instruments in direct contact with the ground and other celestial bodies.

There is no doubt that the development of space research stimulates international cooperation in this field, which, in turn, has a very favourable influence on the development of international relations.

At first, the backing of scientists and funding of research establishments relied on gifts from interested sympathizers and on the realism of heads of states who perceived the necessity of the development of intellectual culture, of scientific formation, and who also were driven by motives of national prestige.

Nowadays, the financial support of scientists and research work in scientific establishments has become an essential governmental necessity. Indeed, the expectations and projects, as well as the external and internal policies of governments, are more and more tightly related to the development and progress of science and technology.

Apart from the ideas, methods and solutions adopted by isolated scientists on important problems, we more and more often meet the case of entire groups of scientists and engineers working together at the solution of complex problems requiring a large amount of research.

The development of modern science requires the use of very complex instruments and impressive, even sometimes gigantic facilities for experimentation.

Large-scale modern scientific research often presents the character of industrial production. Because of that, and the very nature of these works, the need for cooperation and planning is brought to light. Experience shows that the choice of an appropriate plan plays a major role in the resolution of large technical problems. So the definition of the proper solution of complex problems, as well as the establishment and implementation of the best means of achieving it, are a necessary condition for the successful conclusion of the works undertaken.

Just because the correct decisions taken in the course of history appear, with the passage of time, to be simple and obvious does not mean that they actually were easy to take. At the present time, any decision concerning planning and the prediction of results of scientific endeavours constitutes an important problem. If only for the taxpayer, the choice of such or such research theme is a major question, as well as the correct evaluation of the practical benefits to be expected from it. It is thus of prime importance to clearly judge whether real or illusory results are sought.

A widespread opinion is that it is impossible to make predictions in scientific matters, and that observations made by luck are important. In everyday articles and in many historical stories we often see the description of unexpected situations that led to a discovery. There are many anecdotes on this subject. Let me recall, for example, the one according to which Newton, after having seen an apple falling, formulated the law of universal gravitation. Actually, before Newton saw his falling apple, millions of people, some of them of genius, had been in a similar position for thousands of years. It goes without saying that the main cause of that remarkable discovery had been, not the fall of the apple in Newton's garden, but the laws of Galileo on the fall of bodies on Earth, the laws of the Moon motion, the laws of Kepler, which were already well known at that time and which are the result of scores of observations distributed over many years, and also the knowledge of the Jupiter satellite motions and many others.

It is true that some important scientific discoveries have been made by chance. It should, however, be remembered that these discoveries have been made by scientists in fully active pursuit of their labours and, what should be most emphasized, not haphazardly.

Can we plan and predict scientific discoveries? Many answer no. Actually, the profound meaning of a discovery often resides in its unexpected and paradoxical character. Some consider that this is the very essence of scientific discoveries.

However, one should not forget that, for the researcher, observation and thought become a source of discovery only if he has prepared himself for that event by the formulation of hypotheses which will later have to be verified and confirmed.

History teaches us that it is difficult, and not always possible, to correctly predict, plan and evaluate the value of scientific returns. It should be noted that these difficulties apply even to the most creative and best-informed specialists. These can, however, in some cases, predict very precisely the main technical advances that will be realized in the near future, say, five to ten years at most. This is due to the fact that the development and entry into service of modern complex machines and instrumentation usually require a rather long time. Indeed, the facility that will be operational in five to seven years, for instance, is already conceived, studied in detail and even in the course of production. Knowing the characteristics of the new operational rockets, we can enumerate the space flight projects that might be realized within the next ten years from the scientific and technical viewpoints. Once more, what will be realized within ten years is already designed and its fabrication has been started. The difficulty in making predictions is often related not only to the technical difficulties of the study, construction and development of hardware, but also to financial difficulties, these being furthermore liable to have economic or social causes, or both.

In view of their extremely high cost, many projects that are today fully realizable will only see completion if particularly favourable conditions are fulfilled. The prediction of the approximate dates at which new scientific discoveries will be made, or new scientific progress achieved, is today complicated by economic considerations due to the considerable costs implied and to the large number of specialists they require.

The predictions announced in 1955 in Copenhagen at the International/Astronautical Federation Conference on future space projects and the discoveries that would result from them happened to be broadly correct.

Without mentioning the well-known projects in the course of implementation and which will be carried out within the next ten years, we can now already, in a further perspective, speak of fantastic projects of creation of large electric power plants transmitting solar energy from space to Earth, a system that should solve the problem of the next century, because of the exhaustion of terrestrial energy resources and of the so-called "energy crisis" which is already so much talked of.

In view of the rapid increase of the world population, it is perfectly justified to establish projects of space colonization and the creation of space cities inhabited by colonies of about 10,000 people.

In a completely different field, there is no doubt that the development of methods for the fabrication of materials in space or celestial bodies other than Earth, and the utilization of matter picked up on other planets, will have a strong influence on the evolution of fabrication process techniques, both in laboratories and on an industrial scale.

The conditions of weightlessness or very reduced gravity, and also the conditions of high vacuum existing in space and unable to be reproduced on Earth, open new technical vistas, such as the realization of crystallization processes, the organization of physico-chemical processes in the absence of convection, or the development of fabrication methods for ultra-pure materials.

Scientific bases have been laid down for the study of astrophysics, general physics and space biology, and also for the study of celestial bodies and of the states of matter passing through various evolution stages, and for many other fundamental problems. It seems that the basic questions of the origin of planetary systems and of the appearance of life on Earth, as well as many other biological questions, might find an answer thanks to studies performed on board spacecraft.

As regards present-day problems, related to space flight, and whose resolution presents a direct practical importance, we may recall the following points.

Everybody is well aware of the tremendous progress achieved in the field of space radio-communications and of telecommunications in general, and particularly the retransmission of sport or political events, teletransmission or telescopy, and photographs worldwide. We also obtained impressive results in the field of radio and television communications with spacecraft flying in interplanetary space. Research and application works in these fields are actively pursued, and in the near future new progress will be achieved whose results will be widely introduced in the everyday life of all the peoples of the world.

The utilization of artificial satellites for maritime and aeronautical navigation purposes also assumes an ever-increasing importance.

The research carried out by satellites on meteorology and for the in-depth study of our environment and the pollution of the atmosphere, land surface and oceans develops daily. There is no doubt that the observations from artificial satellites will play an ever greater role in the resolution of such very important problems as weather and storm prediction, climatic variations of the various regions of earth, the dynamics of the terrestrial crust, the characteristics of water motions in rivers and oceans, etc.

A greater and greater importance is attached to research on geodesy, geology, and to the improvement in the precision of geographic, geodetic and gravimetric mapping, this precision being obtained thanks to instruments carried by artificial satellites. It has become possible, with these satellites, to remotely detect terrestrial resources in useful fossils such as minerals and oil. We can in particular already place great hopes in the results of studies of the gravitational field within the framework of Newton's mechanics and of the general relativity theory, carried out with the help of inertial space navigation systems and of instruments measuring gradients in gravitation fields. We already utilize the monitoring of certain harvests by remote sensing satellites, as well as the evaluation of the growing and state of forests, the survey of the movement and distribution of water resources, and we detect important events such as forest fires, cricket swarms, etc.

Today, the increase rate of scientists and engineers in scientific establishments and expenditures for studies and research in the Soviet national budget is higher than the increase rate of this same budget and of the gross national product.

It seems that in the near future it will be necessary to limit the increase in number of scientific research studies. This orientation will emphasize the importance of the question of efficiency in the various research centres. We should expect to see science and technology developing in harmony with society, remaining always and for everybody a source of wellbeing and a sure instrument for the resolution of the many complex problems that mankind is already facing.

The internal joy and satisfaction provided by a creative task leading to the acquisition of new knowledge for the good of all should spread over the whole world and become the privilege of all members of society.

UNITED STATES SPACE PROGRAMS, PRESENT AND PLANNED

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In this autumn of 1978, the Space Age is just entering its third decade. In relative terms space technology is about where aviation was in 1924. That was the year of the first round-the-world flight which began with four Douglas Cruiser biplanes and ended 175 days later with only two. Lindbergh's famous flight was still three years in the future. There were no airlines or airliners. The great aviation industry, with global exports in 1976 of $9.5 billion in aircraft and parts alone, was miniscule and inconsequential to the world economy.

I am convinced that the future for space is as promising and wide open in 1978 as was the future for flight in 1924. We are effectively space age pre-adolescents still groping in an unfamiliar metier for the right things to do and the best ways to do them.

In the civil space program of the United States, our "educated groping" is shaped and guided by two overriding and governing critera--usefulness to human life and intellectual importance. Although separate, those criteria are, of course, closely related and overlapping since intellectual accomplishment, the acquisition of knowledge, has most often ultimately led to usefulness to a degree unimaginable at the time of acquisition. Simply stated, intellectual importance eventually translates to maximum long-term usefulness.

In applying those criteria we are further guided by the dynamic interests of the American people who, through their taxes, have made a significant investment in space. They have a right to expect--and their government has a responsibility to provide--a return on that investment in both material and intellectual terms. To provide that return we do our best to think, plan and operate imaginatively, innovatively and creatively within the limits of sound science and technology.

Within that philosophical framework, our efforts in space fall into three general categories:

- the use of near-Earth space for remote sensing, communications and other purposes directly beneficial to human welfare;

- the scientific exploration of the solar system to improve our understanding of our planet and its phenomena, coupled with exploration by observation of the universe in the continuing effort to understand the place of Earth and man in the cosmos; and

- investigation of the Sun-Earth relationships so basic to the whole bio-system in which we evolved and in which we live.

Here is where we stand in each of those three categories.

In the area of Earth sensing, Landsat 1, launched in mid-1972 with a life expectancy of one year, has now been shut down after five-and-a-half-years of operation and the production of nearly a third of a million remarkably useful images of the Earth and its resources, open and available to anyone. Landsat 2, launched in early 1975, Landsat 3, launched in early 1978 and Seasat A orbited last June, are continuing and expanding the Earth sensing programs. They are augmented importantly by a Heat Capacity Mapping Satellite placed in orbit in April of this year, by three U.S. Geostationary Operational Environmental Satellites, Nimbus, Tiros, the European Space Agency's Meteosat and by a Japanese weather satellite.

Landsat 3 improved importantly on the technology of its predecessors by adding a Return Beam Vidicon camera to the previously flown sensors. Although the performance of the fifth thermal channel has degraded about fifty percent in flight, the Return Beam Vidicon is presently returning images with a resolution of forty meters.

International interest in Landsat is widespread and expanding as advantages of remote sensing become more apparent. More than 100 countries have purchased Landsat data from our Earth Resources Observation Satellite Data Center, the largest US Landsat data dissemination facility. Eleven countries are establishing ground stations to receive directly, process and distribute Landsat data of their regions. Ground stations in Canada, Brazil, Italy and Sweden are currently receiving Landsat data of areas roughly 3,000 kilometers in all directions from the site of their stations' antennas. A Landsat station in Iran is under construction. Australia, India, Japan, Argentina, Chile, and Zaire are planning to build similar facilities under agreements with NASA. A number of other countries including Romania, Mexico and Indonesia are also considering the establishment of Landsat stations. The underlying science for this kind of effort is only now developing, but already the images and the data derived are providing a growing ability to understand and to apply sensible management techniques to many of our problems relating to resources, land-use, environmental decisions and related areas.

Seasat has been designed to prove the concept of monitoring ocean dynamics and phenomena from space. It carries research five instruments: a narrow-beam radar altimeter, an L-band synthetic aperture radar, a scanning multichannel radiometer, and a scatterometer, backed up by a visual and infrared radiometer. With these devices it is providing all-weather research data on wave heights, ice fields, icebergs, sea surface temperatures, wind speed and direction, atmospheric water content and ocean currents. It covers 95% of the world's oceans every thirty-six hours, supplying data equivalent to about 20,000 ship reports a day.

Communications and weather satellites have been with us for so long that we take them for granted. Many of our children can't even remember when they couldn't watch sports and news events as they happened on another continent, or see a nightly picture of the weather pattern across their particular portion of the globe.

We forget that we are able to telephone between continents today for about half of what it cost before 1965 when the "Early Bird" satellite entered service.

But even more significant for the future are the much more powerful and complex "broadcast" satellites which permit the use of correspondingly simple, cheap and reliable ground stations, ideal for use in isolated and undeveloped areas.

As an illustration of the capabilities of such spacecraft, one of two currently in orbit, the Applications Technology Satellite or ATS-6, in recent years provided two particularly important services.

In India, villagers in 5,000 isolated communities gathered before specially simplified and "ruggedized", 19-inch black-and-white television receivers for four hours a day for a year to watch programs developed by the Indian government and brought to them through ATS-6. In the mornings the children received curriculum supplements from what Indian journalists came to call the "blackboard in the sky", and in the evenings adults viewed programs on such subjects as farming, family planning, dental hygiene, how to cook for people with peptic ulcers, and how best to cope with floods and droughts.

Later in the same year, by means of an ATS-6 project called Aidsat, millions of people in southeast and south Asia, the Middle East, Africa, South and Central America and the Caribbean viewed filmed and live programs in which eight presidents, three prime ministers, a king, a sultan and many senior ministers and leading businessmen participated. In live panel segments, leaders in each country discussed with experts in Washington the applications of space-related technologies to local communications, education, health, forestry, agriculture, hydrology and and geology.

In an entirely different application in the summer of '76, the American Red Cross was able to maintain contact with the outside world from flooded Johnstown, Pennsylvania by means of the Communications Technology Satellite positioned over the Pacific and a mobile unit at the scene. With all other communications out, the Red Cross was able to order additional nurses and workers, medical supplies, food and potable water. The United States and Canada make joint use of this spacecraft and time was generously made available by Canada for the Johnstown emergency operation.

Obviously the potential for devices of this kind is immense.

Our exploration of the solar system is showing us new aspects of the Earth in comparison with other planets. Indeed, the solar system contains experiments on various ways in which planets and planetary environments may be constructed. These natural experiments,--the different kinds of planets,--shed light on the ways in which the solar system may develop further, and, indeed, the ways in which our own man-made changes to our planet may affect its further development. Comparative planetology not only helps us understand the universe and its formation, but also many of our particular problems here on Earth.

Six planetary probes are presently in flight.

- After making the first close-up observations of Jupiter, Pioneer 10 is enroute out of our solar system, the first product of mankind to leave our home corner of the galaxy. It is inscribed with its place and time of origin and a rendering of the life-form which created and dispatched it, for the benefit of whatever intelligence might possibly encounter it in its timeless voyage through the universe. Its sister craft, Pioneer 11, is approaching Saturn to give us our first close look at that interesting planet in September 1979.

- Two Voyager spacecraft, launched a year ago, are well on their way to make follow-up measurements of Jupiter and Saturn and their satellites. On October first Voyager 1 is about 705 million kilometers from Earth, traveling with a heliocentric velocity of fifteen kilometers-per-second. One-way communication time is 39 minutes 12 seconds. Voyager 2 is about 620 million kilometers away with a speed of 14 kilometers-per-second. The first Voyager is scheduled to begin Jupiter imaging in December, make its closest approach in early March 1979 and complete its Jupiter work in April. It will observe the Saturn system from August 1980 through January of 1981. Voyager 2 will arrive at Jupiter four months after Voyager 1 and reach Saturn a year behind its sister craft. Voyager 2 is having radio problems, with only one receiver operational and no recourse should that one fail. However, a command sequence has been stored in the back-up computer command subsystem which will permit operation of all eleven experiments including imaging at Saturn but not at Jupiter even if the remaining receiver fails. If there is no further deterioration of Voyager 2 it will be targeted for Uranus after Saturn with an expected arrival date of January 1986.

A two-part Pioneer mission to Venus, consisting of an orbiter and a multiprobe spacecraft is also on its way, launched in May and August of this year. The first element will swing into Venusian orbit in December with the probes scheduled to enter the planet's hot and heavy atmosphere five days after the orbiter's arrival.

The orbiter is designed to map the entire Venusian atmosphere by remote sensing and radio occultation, directly measure the upper atmosphere, ionosphere, and the solar wind/ionosphere interaction; and examine the planet's surface by radar mapping. It will be placed in a highly inclined elliptical orbit with the lowest point in the mid-latitudes at an altitude of about 200 km and is scheduled to continue its investigations for at least one Venusian year or 225 Earth days.

The spin-stablized multiprobe spacecraft consists of a bus, a large probe, and three identical small probes, each carrying a complement of scientific instruments. The probes will be separated from the bus 20 days prior to arrival at Venus. The large probe will conduct a detailed sounding of the lower atmosphere, obtaining measurements of the structure, composition, and clouds from 70 km to the surface. Entering at points widely separated from each other, the three small probes will provide information on the general circulation pattern of the lower atmosphere. The probe bus will provide data on the Venusian upper atmosphere and the lower atmosphere down to an altitude of about 120 km, where it will burn up.

In addition to these six spacefarers, although one orbiter was shut down last summer, the remaining orbiter and both Viking landers are continuing to send valuable scientific data back from Mars where they landed in the summer of 1976.

Our understanding of the deeper universe beyond the solar system has expanded greatly since we began to look at it from space, above the interfering veil of the atmosphere. This examination has discovered or confirmed strange objects which we do not understand such as quasars, pulsars and "black holes." But the history of new observations not understood has always been a history of later understanding, of new physics and, eventually, of useful technology arising along with the new physics and stemming from it. We are continuing to explore and to learn.

Our primary tool for this kind of exploration is the first in a planned series of three High Energy Astronomy Observatories (HEAO), launched in August of last year. HEAO-1 is the heaviest Earth-orbiting unmanned satellite ever launched, containing four large X-ray and gamma ray astronomy experiments designed to scan and map the entire celestial sphere for gamma ray and X-ray sources down to extremely weak intensities.

In its first hundred days of operation HEAO-1 had already discovered fifteen previously unknown X-ray sources, including two halfway to the edge of the known universe, and provided data which may eventually allow astronomers to make a positive identification of at least two "black holes." It has now completed its survey of the universe and is investigating specific X-ray and gamma ray sources and looking for "black holes." The faintest sources detected by HEAO-1 are a million times weaker than the first X-ray star discovered fifteen years ago and the data it is providing are of major importance to an understanding of the early evolution of the universe.

One of the most interesting results provided by HEAO-1 concerns the general glow of X-rays that covers the entire sky. This glow was discovered years ago using sounding rockets, but with the much more sophisticated analysers carried on HEAO-1, we have now been able to determine precisely the <u>nature</u> of the radiation. It appears to be exactly the kind of radiation that one would expect from an extremly hot gas--about 500 million degrees. One interpretation is that we are seeing the glow from a thin hot gas pervading the universe. If this interpretation is correct, then we have discovered the bulk of the matter of the universe--more than all the stars, planets, and galaxies combined--for although the gas is low in density, the universe is immense in volume. HEAO-1 may thus change our concept of the universe in which we live.

Other orbiting astronomical observatories launched much earlier are making important contributions. One such device, OAO-3 called Copernicus, after six years in orbit, last summer found a third very active and convincing "black hole" in the constellation Scorpio.

In addition, an International Ultraviolet Explorer, a cooperative venture with the United Kingdom and the European Space Agency, was launched last January and is giving us valuable new data on the nature of the different kinds of stars in our galaxy, on the inter-stellar material from which stars are formed, and on many of the objects which are emitting radio waves and X-rays.

The exploration of the relationship of the Earth to the Sun, and of the electrical properties of the high atmosphere of the Earth, can give us clues to the understanding of the world's climate and weather. While we may not be able, or may not be able soon to influence weather and climate, perhaps we will be able at least to understand climate change, to anticipate its effects, and to prepare for them.

For this special kind of investigation two primary systems are currently in use, the two-element Helios and the three-element International Sun-Earth Explorer (ISEE).

Helios is a joint venture of the United States and the Federal Republic of Germany and consists of two spacecraft built by Germany and launched by the United States with the U.S. also supplying tracking and data acquisition and technical support.

The two vehicles were launched about a year apart, in December of 1974 and January of 1976, into highly elliptical solar orbits with Helios 2 approaching to within about 43 million km of the Sun, closer than any previous man made object, every 93 days. Instruments in both spacecraft are providing data on the solar wind, the Sun's magnetic field, solar and galactic cosmic rays, electromagnetic waves, micrometeoroids and the zodiacal light.

Similar instruments are also carried on Pioneers 10 and 11, another Pioneer orbiting the Sun at about one AU and on two Interplanetary Explorers in Earth orbit. Data received by these spacecraft, which measure solar phenomena from various points in the solar system over a long period of time and under varying conditions, is being correlated with that received by the two Helios probes.

The International Sun-Earth Explorer (ISEE) program is a joint venture of the United States and the European Space Agency with the objective of learning more about the Earth's magnetosphere, its boundaries, the dynamics of the radiation trapped inside it and how it is affected by the solar wind. Two spacecraft, ISEE 1 and 2, were launched a year ago into the same highly elliptical Earth orbit of 14,000 to 280 km where they maintain a separation of 100 to 5,000 km. ISEE-3 was launched in mid-August of this year for a position about 1.5 million km out on a line between the Earth and the Sun. From that position it will be able to transmit data to Earth on solar particles traveling in our direction a full hour before they arrive. These data will provide important correlative information with that obtained from ISEE 1 and 2 as they swing first close to Earth and then out through the bow shock where the solar wind impinges on the Earth's magnetosphere.

A large portion of the resources available for space programs in recent years has been devoted to the development of the Space Transportation System, the heart of which is the re-usable Space Shuttle. With its ability to lift about 30,000 kilograms into Earth orbit in an unobstructed cargo bay 4.6 meters in diameter and 18.3 meters long, the Space Shuttle is a major next step forward in space. It cuts across every field of space activity, accelerates our progress in every area, brings us closer to almost every goal. When it becomes operational in 1980 it will free us from the weight and volume restrictions of expendable launch vehicles, from the necessity to design for automatic deployment and for extreme and very-long-term reliability, opening the door to the assembly of large structures in space; to more definitive experiments in space processing and manufacturing, and to other opportunities which we have not yet imagined. It will provide rapid, versatile and economical access to and from space. It will offer us wholly new capabilities such as payload retrieval and reuse, on-orbit maintenance and piloted maneuverability. These capabilities in turn will improve our ability to communicate with deep space probes, to develop larger space solar power systems permitting more elaborate experiments and observations leading to new knowledge which will bring a further generation of benefits to mankind.

The advent of the Shuttle means that, for the first time, man will have regular, frequent, routine, economical access to space. Space, like the sea, the land and the air will become an environment in which man can live and work for the welfare of his species.

Like so many important space programs, the Space Transportation System has significant international aspects. In this case those aspects consist of Spacelab, a manned scientific laboratory designed to fit in the orbiter's cargo bay, and a Remote Manipulator for retrieving vehicles from space and inserting them into orbit.

Unlike the U.S. Skylab and the Soviet Salyut which are designed for relatively short life-time, Spacelab like Space Shuttle is reusable, launching and landing with the orbiter as many as fifty times over a ten-year period. It can be configured either as a pressurized module where as many as four scientists and engineers, male or female, can work in shirt-sleeve comfort; or as an instrument-carrying pallet, or as both together. Instruments on the pallet are controlled from the Mission Specialist's station on the orbiter's flight deck and are accessible by pressure suit. Crew movement between the Orbiter and the Spacelab is via a tunnel, which is variable in length to ensure that the Orbiter's center of gravity remains in the right place.

A portion of the pressurized laboratory carries equipment common to all missions and necessary for the functioning of Spacelab (computers, tape-recorders, checkout consoles). The other portion of the laboratory and the segments of the pallet carry the experiments themselves (furnaces, microscopes, centrifuges, incubators and photographic apparatus in the laboratory; telescopes, antennas, radars and sensors on the pallet).

Whereas the crew of the Orbiter is composed of astronauts, the crew of the spacelab are scientists and engineers who operate the experiments. They have on board the necessary computing facilities for a first interpretation of the results obtained and, being "on the spot", can modify most experiments while they are in progress and take corrective action in the event of malfunctions.

Spacelab represents approximately a half-billion dollar contribution to space exploration and use by ten member nations of the European Space Agency and is designed, equipped and supplied by ESA. We expect that Spacelab will fly on about 40% of all Shuttle missions during the first decade of operations.

The Remote Manipulator System is an extendable arm with gripping and holding devices at its end, equipped with remotely controlled television and lights to provide side viewing and depth perception. It is being designed, developed, and manufactured by a Canadian industrial team with funding and overall direction from the National Research Council of Canada.

Development of the Space Transportation system is proceeding substantially as planned. Approach and landing tests were completed in October of last year and successfully demonstrated the orbiter's ability to perform the final low altitude, sub-sonic portion of its mission and land with safety and precision.

Full scale ground vibration tests are in progress and should be completed before the end of the year.

Structural tests on the orbiter, the external tank and the solid rocket boosters are underway and approximately on schedule.

Because of the very advanced technology of the main engine we have encountered a series of problems in the propulsion test program as one would expect in a research and development effort of this complexity but, after some modifications and redesign of components, progress is being made.

The six-flight orbital test program will be completed in early 1980 and shortly thereafter the Space Transportation System will commence operational missions.

Another major space project, made practical for the first time by the Space Shuttle, is the Space Telescope. This device, which astronomers have been planning since the early sixties, will become a reality thanks to the ability of the Shuttle to revisit for orbital maintenance.

The 2.4-meter diameter Space Telescope will be capable of accommodating up to five different instruments at its focal plane. It will weigh about 9,070 kilograms and will orbit the Earth at an altitude of approximately 500 kilometers, above the obscuring effect of the atmosphere.

It will be operated remotely from the ground but will be designed to permit maintenance and change of instruments by a space-suited astronaut and to be retrievable by the Space Shuttle for return to Earth for extensive overhaul and subsequent re-launch.

The European Space Agency has agreed to provide a major scientific instrument and a spacecraft subsystem, participate in the in-orbit operation and maintenance of the telescope, and arrange for participation of ESA-sponsored European astronomers in the observation programs.

The Space Telescope is expected to see celestial objects with at least 10 times better resolution than from the ground. It will be able to see objects which are 50 times fainter and seven times farther into space and hence will explore a 350-times greater volume of space than the largest ground-based telescopes. It will be the centerpiece of space astronomy for the decade beginning in the mid-eighties and there is reason to hope that its contributions to our understanding of the physics of the universe may dwarf all but the most fundamental discoveries of the past and lead to a quantum growth in our knowledge of the basic nature of time, matter and energy.

Our plans for the fiscal year which just started include significant advances in all three major categories of space operations.

In the development of the down-to-Earth benefits of space, we plan to continue the improvement and optimum use of existing systems including a fourth Landsat Earth resource satellite, a NIMBUS-G environmental quality monitoring satellite and a TIROS-N next generation weather satellite. We also plan to begin development of a Halogen Occultation Experiment to improve our ability to monitor pollution of the upper atmosphere; and an Earth Radiation Budget Satellite System to contribute to climate research by acquiring data on the energy exchange between the Earth's atmosphere and space, on global and regional fluctuations in this energy exchange, and on other atmospheric phenomena.

In the field of space science or the scientific exploration of the solar system and the universe, which incorporates most of the activities we classify as intellectually important, the second High Energy Astronomy Laboratory will be orbited to make more detailed investigations of the X-ray and gamma ray sources and the hot intergalactic gas discovered by the first such satellite; and new data will be received, interpreted and assessed from Pioneer 11, the two Voyagers and the Pioneer mission to Venus.

We will also be moving ahead with the Galileo mission to Jupiter scheduled for launch by the Space Shuttle in late 1981 or early 1982. Galileo will conduct the most detailed scientific investigation yet of Jupiter, its environment and moons, including the first direct measurements of the planet's atmosphere.

The mission consists of an orbiter which will circle the planet for at least 20 months and a probe which will plunge deeply into Jupiter's atmosphere. The orbiter will carry 10 instruments, and the probe will carry six.

The Federal Republic of Germany is participating in the program with the assignment of selected scientific investigators and the contribution of a Retro Propulsion Module designed to inject the Galileo spacecraft into orbit around Jupiter. The German scientists will be involved in the preparation and operation of the spacecraft and in the analysis of the resulting data. Scientists from the European Space Agency and from Canada and France are also contributing to the Galileo payload.

In the field of Earth-Sun investigations we will be working toward the launch in November 1979 of a solar research spacecraft on what we call the Solar Maximum Mission.

The major objective of this project will be to investigate solar flares and related phenomena and their effects on the solar-terrestrial system through a coordinated set of unique instrumentation for observing transient high energy, ultraviolet, and visible radiations from the Sun. The information to be developed will have the potential for forecasting flares and their effects on Earth.

A significant new initiative in this field will be the Solar Polar Mission, a joint project with the European Space Agency to send two spacecraft, launched from the Space Shuttle in 1983, past Jupiter, using the gravity of that planet to achieve an out-of-ecliptic trajectory that will permit study of the polar regions of the Sun for the first time. The data obtained by this mission, together with that acquired by the Solar Maximum Mission, Helios and the Explorer spacecraft, will contribute significantly to our understanding of the Sun and the influence it exerts on the Earth, its atmosphere, environment, and climate.

Beyond fiscal year 1979 we will be in effect looking at the beginning of the next stage in space. Some projects we are quite certain we want to do. Others look productive and are being considered. Still others we are just beginning to think about.

In the area of near-Earth operations we are considering development of

- a 25-kilowatt orbiting power module which would extend the stay-time of the shuttle in orbit; support attached payloads in a free-flying mode, and support the on-orbit, shuttle-tended construction of large structures and advanced space processing activities;

- a Tethered Satellite which would be suspended from the payload bay of the shuttle and trolled through the Earth's upper atmosphere as far below the shuttle as 100 km; and

- an orbital demonstration of a space fabrication capability, including proof test of the space fabrication machine, handling fixtures and structural assembly concept.

Farther downstream in our thinking, we might consider

- a large (200-500kw) orbital Power Module to support such space operations as materials processing, space construction, advanced communications systems and other future applications and scientific projects; and

- an Orbital Transfer Vehicle which could support manned operations in geosychronous orbit in the late 1980's.

In the area of remote sensing we are working toward the integration of all the various systems in use or projected into a continuous, accurate world information network for the wiser management of planetary resources and human affairs.

In space exploration we have begun the necessary studies to launch a Venus orbiter with imaging radar to map that planet's global terrain through its totally obscuring atmosphere, and we are considering a flight, powered by the ion drive propulsion, to rendezvous with the comet Encke in 1985. We are also thinking about a mission to Saturn similar to the Galileo Jupiter project.

To continue our investigation of the far universe we are giving highest priority to

- a Gamma Ray Observatory to study the high energy nuclear and gravitational processes occurring in the vicinity of neutron stars and black holes, as well as the formation of elements in supernovae, the cause of gamma-ray bursts, and the nature of the newly-discovered gamma-ray sources; and

- an advanced X-ray Astrophysics Facility to provide high-resolution data on the position and structure of pulsars, binary-star systems, quasars, Seyfert galaxies, clusters of galaxies and the intergalactic medium.

As a follow-up to our studies of the Sun and Sun-Earth relationships, we have already started preliminary work on an Explorer program, which would involve two spacecraft investigating the coupling between different components of the Earth-space system, specifically the neutral atmosphere of the Earth and space plasma. The upper spacecraft would study the magnetospheric energy inputs into the upper atmosphere at high altitudes, while the lower spacecraft (100 km apogee) would look at the resulting currents, winds and heating.

We are also considering a Solar Probe Mission that would travel to within 1 to 3 radii of the Sun; with another option to go right into the Sun, and a Solar Mesospheric Explorer to study the phenomenon of ozone creation in the upper stratosphere and natural and man-made perturbations in the ozone layer.

Although no single paper of manageable length can adequately cover a subject of this scope which includes such a range and variety of programs and projects, that is the space environment as we see it today and as it appears it might be in the future.

As a final note, speaking as a scientist as well as an administrator, I would like to assure my colleagues in the international community that it will be a prime policy of the civil space program of the United States in future years as in the past, in every area of space endeavor, simply to do good science, science in the sense of a sustained accretion of human knowledge, as perhaps the highest adventure of the human spirit, as the response of Man's inquisitively creative mind to the challenge of the mysteries of creation, matter, energy and life.

OVERVIEW OF CURRENT AND PROSPECTIVE EUROPEAN SPACE PROGRAMMES

R. Gibson

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INTRODUCTION

In this presentation I should like to report briefly on what has been happening in the European space field since the last IAF Congress, and to indicate what new activities are planned. The Convention of the European Space Agency, signed in 1975, gives the Agency the tasks of strengthening European cooperation in space research and technology for purely peaceful purposes, and of establishing a long-term European space policy. We are a long way from having achieved these goals, but the Agency is sufficiently well informed for me to be able to include in this paper something of the major national activities of our Member States.

I propose to deal with space activities under the following headings:-

- scientific programme
- communications programme
- earth observation programme
- Spacelab and its utilisation
- Ariane launcher programme.

SCIENTIFIC PROGRAMME

At the time of the XXVIII IAF Congress, ESA participants were perhaps noticeably gloomy, for our first geostationary scientific satellite, GEOS, had failed to achieve its proper orbit because of malfunctioning of the Thor Delta launcher. Happily, another launcher from the same stable functioned perfectly on 14 July 1978, and GEOS 2 is now in orbit and providing data. (Incidentally, the first GEOS was not a complete loss, for we were able to manoeuvre it into an orbit which gave limited satisfaction to some of the experimenters. This rescue operation was, incidentally, ESA's first experience of recovering an erring satellite, and the operations centre at Darmstadt responded extraordinarily well.) GEOS was a contribution to the International Magnetospheric Study programme, and there will be ample opportunity elsewhere to discuss its scientific results. I should like here simply to refer to some of its interesting technological features apart from the unusually stringent requirements on electric and magnetic cleanliness:

- it was the first flight of a completely European developed hydrazine system for altitude and orbit control;

- it incorporated a specially developed European apogee boost motor;
- the bit-rate of more than 100 Kbit/second (equivalent to four closely printed A4 pages every second) - two orders of magnitude higher than any previous scientific satellite - at least in Europe;
- the array of 8 booms up to 20 m long made the satellite's dynamic behaviour more complex than for any other previous European satellite.

Since our Prague meeting ESA has had another successful scientific satellite launching (23 October, 1977) - ISEE B (now re-baptised ISEE 2), which was ESA's contribution to a cooperative programme with NASA. Here again I will not attempt to describe the nature of the experiment, but rather to point to a particularly interesting feature: the high degree of commonality between experiments on the ESA and NASA satellites and the correlation between their measurements.

Another interesting example of international space science cooperation which was consummated by the launch on 26 January, 1978, was the IUE - International Ultraviolet Explorer, in which the Agency played a relatively minor role, together with NASA and the British Science Research Council. As part of its contribution, ESA provided a ground station at Villafranca, near Madrid, where European astronomers can profit from the eight hours of observing time which is theirs under the terms of the observation agreement.

I cannot leave our scientific satellites in orbit without mentioning the continuing success of our COS B satellite - designed for a two-year lifetime, it has been operating nearly three years and is still active.

ESA has three scientific projects under development: EXOSAT and contributions to NASA's Space Telescope and Solar Polar (Out of Ecliptic) programmes.

EXOSAT, due for launch by Ariane early in 1981, contains one of the largest telescopes of its kind ever built for space research. It will fly a European on-board computer and has a unique orbit correction capability: in order to maintain the satellite in an optimal position with respect to an X-Ray source and the moon occulting it, the satellite's velocity can be changed. Total velocity increments or reduction are 200 m/s distributed over approximately 180 observations.

In October, 1977, NASA and ESA signed an agreement to cooperate in the development of the Space Telescope. ESA is to contribute the faint object camera, the solar array and provide a certain support to the activities of the scientific centre which will exploit the instrument, in return for a share of the viewing time. Both the European hardware contributions are technologically challenging:

- the faint object camera allows measurement of objects down to 29th magnitude in the wavelength range 1200 to 1800 Å. There are extremely stringent requirements on the structural stability of the optical bench, and the sensitivity of the detector is approaching limits;
- the solar array will be of the flexible, roll-out type, and must be retractable to allow the Space Telescope to be brought back to earth for refurbishing after five years' operation. It will be the largest and most powerful solar generator ever produced in Europe: 33 m^2 and capable of producing 4 kW after two years in orbit.

Although the second NASA/ESA cooperative programme - Solar Polar - has not yet been formally approved in the U.S., preparatory work has already started on the ESA satellite due for launch with its NASA partner in February, 1983.

Under this heading of scientific satellites, I should like also to mention IRAS, the joint Netherlands, U.K., U.S.A. infra-red astronomical satellite project scheduled for launch in February, 1981. It will have a high-pointing accuracy of 20 arc seconds and a high data rate - 1 Mbits/s - during the play-back of its tape recorder.

Of course, the Agency is conducting a number of studies in order to allow our Science Programme Committee to choose the next scientific programme. As usual, money is much scarcer than good ideas.

COMMUNICATIONS PROGRAMME

Another reason for ESA unhappiness at the time of the Prague Congress was the failure of the Thor Delta launcher to put our telecommunications satellite OTS into orbit. Happily, as with GEOS, the second try was successful and our OTS 2 is in orbit since 11 May and functioning well. This Orbiting Test Satellite, as its name implies, is designed to demonstrate the in-orbit performance of the equipment and to carry out propagations measurements at 11/14 GHz, as well as tests and experiments. One such experiment worthy of special mention is the CERN experiment connecting the computers of a number of atomic energy centres in different parts of Europe.

No doubt much more will be said in other sessions about OTS and its successors, and I should like now only to dwell briefly on some of the significant advances in European space technology which have resulted from the OTS and the supporting technology programme. For example:-

- travelling wave tube amplifiers at 11/14 GHz, output power 20 W (a variant of this technology has been successfully flown on the Canadian CTS satellite);
- dual-polarised reflector antennas;
- lead-lubricated solar array drives and other mechanisms, the tribology aspects of which are now systematically evaluated in the European Space Tribology Laboratory at Risley (U.K.) set up by ESA for this purpose;
- two-axis infra-red sensors based on the principles of thermopiles and bolometers;
- double-gimballed and fixed momentum wheels, one type of which is competitive on the worldwide market;
- lightweight rigid solar panels based on carbon-fibre technology;
- flexible fold-out solar array technology (again, used on the Canadian CTS).

The operational European telecommunications satellite system will be established by the launch by Ariane of the first ECS spacecraft in 1981, followed by a second satellite a year later. If traffic requirements remain constant, needs up to the end of the decade can be satisfied with two more spacecraft.

The system, owned and managed by EUTELSAT, will be used by the PTT Administrations represented in CEPT to complement the existing terrestrial public network, primarily for telephone traffic and for the exchange of programmes between member organisations of EBU. Nine repeater chains are foreseen to operate simultaneously accommodating two television channels and 12,000 telephone circuits.

To a large extent, ECS uses technology developed for, and proven by, OTS. Some deviations were necessary to optimise the overall system; for instance, the number of repeater chains is increased from 9 to 12; whilst on OTS 6 can be operated simultaneously during the sunlit phase and 2 in eclipse, these numbers are 9 and 5 respectively for ECS. Consequently, there are changes to the switching system and other components of the telecommunications package.

The European maritime communications satellite, originally called MAROTS because it was based on the OTS platform, was intended as an experimental system, but having all requirements of a later operational system in conformity with the requirements developed by IMCO on behalf of the still unborn INMARSAT. A second flight model was subsequently decided by the ESA Participating States to make a European contribution to a worldwide maritime communications satellite system.

The story is a long one - and not yet finished - and we have no time to go into the details. Suffice it to say that negotiations started with the aim of founding a "Joint Venture" which would fund and operate the worldwide - post MARISAT - system. The initiative came from Interim EUTELSAT and COMSAT General, but in recent months this latter has been obliged to withdraw pending a clarification of the U.S. position. The discussions have, nevertheless, been attended by other countries, notably the U.S.S.R., Canada and Japan.

As it became probable that 4/6 GHz would become the INMARSAT standard for that link, ESA decided to reconfigure the MAROTS payload accordingly. This entailed a slippage in the launch date to 1980, which permitted the upgrading of the satellite platform to that of ECS with the main advantage of allowing full operation during eclipse. Hence the present acronym MARECS.

INTELSAT has recently joined in the action, with a proposal to add a maritime package to certain of its INTELSAT V satellites, and the members of the Joint Venture - at this moment meeting in Bergen - are trying to decide between a number of options, including a mixed INTELSAT V/MARECS option, which has recently gained a great deal of support.

The political and industrial in-fighting, that characterises all but the scientific area, is nowhere more evident than in the Agency's work on TV broadcast satellite. After a year's hesitation after approval in principle in February, 1977, the Agency was authorised to start the first phase of what is known as H (for Heavy)- satellite. The mission objectives are as follows:-

- Development and in-orbit performance demonstration of a multi-purpose satellite platform making full use of the Ariane payload capabilities.
- In-orbit performance demonstration of the technologies capable of meeting requirements of future operational broadcast satellites in the 12 GHz band.
- Provision of facilities to permit experimental sound and TV broadcast over Europe.
- Propagation measurements at 20/30 GHz (follow-on to ATS-6 and SIRIO experiments).
- Flight qualification of other new technologies (mainly electric propulsion).

Launch could take place in 1982, followed by operational satellites 3 to 4 years later.

The programme requires technological advances mainly in the following areas:-

- 150 W and 450 W TWT amplifiers and their power supplies;
- RF sensors for satellite fine-pointing (0.5° required);
- antennas;
- advanced magnetic bearing momentum wheels;

- 20/30 GHz components and equipment for propagation measurements;
- thick film technology in the power distribution sub-system;
- heat pipe radiators;
- solar arrays (in the longer run hybrid arrays will be required).

It is too early to say whether, and in what form, this project will be continued, and this depends largely on the results of national studies and by members of the European Broadcasting Union. In this connection, we must note the German and French studies and, of course, those being carried out in the Scandinavian countries, the well known NORDSAT. My own conclusion is that this evident interest on the part of the end-users can, in the end, only be positive, but it must not be allowed to stampede individual nations into action which will prove harmful to the European cooperation so painfully built up over the past ten years.

EARTH OBSERVATION PROGRAMME

METEOSAT, Europe's contribution to the Global Atmospheric Research Programme (GARP) of the World Weather Watch, was successfully launched on 23 November, 1977, and is operating well. The characteristics of this satellite are fairly widely known and I intend here merely to draw attention to some special features:-

- the water vapour channel - a feature not included in the U.S. geostationary satellites;
- a technologically interesting radiometer which provides the first known application of cadmium/mercury telluride detectors in this region of the IR spectrum, and which enables in-flight IR calibration;
- a unique optical design needing no large scanning primary mirror;
- a new type of contaminant-free cable cutter;
- the first European electronically de-spun antenna.

METEOSAT 2 is now in preparation and is due for launch on the third Ariane test flight (L03) in May 1980.

The METEOSAT programme is the first Agency satellite programme in the field of earth observation, but the Agency has plans and ambitions in this area which may be of interest to you.

As a practical first step, ESA had created its EARTHNET programme which is a network of five national facilities (FUCINO, KIRUNA, LANNION, OAKHANGER and CANARIA) for the acquisition, pre-processing, distributing and archiving of remote sensing data - in the first instance from U.S. satellites, and subsequently from European satellites. The extremely high bit-rates (up to 120 Mbits/s for SAR data) require significant advances in the state of the art.

In ESA discussions Member States have expressed a preference for:-

1. Land applications payloads (i.e. agriculture, forestry, water resources, development aid).

2. Coastal ocean monitoring payloads (i.e. fisheries, environmental monitoring, surveillance, continental shelf operations).

- A European remote sensing satellite will have to provide optical *and* microwave imaging capabilities.

- The two payloads mentioned above (a third one for global ocean monitoring has received lower priority) should be flown on a *common* European platform.

Consequently, several studies are under way, or will shortly begin, on:-

- preliminary definition of payloads and identification of requirements on sensors;
- evaluation of the requirements on a common platform;
- assessment of critical areas for payloads and platform already known;
- evaluation of the role of Spacelab as a test bed before commissioning of a payload in an operational satellite (note that FSLP will carry a metric camera and microwave experiments, all provided under a national programme);
- definition of a supporting technology programme.

A proposal is to be put to Member States towards the end of this year, and we hope to have approval to proceed early in 1979.

Meanwhile, there has been a lot of interest and activity in Member States and, in particular, I should like to refer to the French programme, SPOT.

SPOT (Système Probatoire de l'Observation de la Terre) will be the first Earth observation satellite for remote sensing of the Earth applications other than meteorology. Proposed by France for "Europeanisation", SPOT did not win the support of a sufficient number of ESA Member States and will now be conducted as a French national project, though perhaps with participation from one or more other Member States. The project is a significant contribution to the planned European remote sensing programme by virtue of the technologies developed and the know-how acquired.

The SPOT system is conceived as a multi-mission spacecraft consisting of a reusable platform and a mission-specific payload section. ESA will be investigating the suitability of the SPOT platform for a later European remote sensing satellite.

As we understand it, SPOT 1 will carry 2 high-resolution multispectral cameras, operating in the visible part of the spectrum giving stereoscopic views of 10 and 20 m resolution. The cameras are of novel technology, using charge-coupled devices as so-called "push-broom detectors", thereby eliminating the need for mechanically moving devices to perform scanning of the earth.

Launch of SPOT is envisaged for early 1984 by Ariane.

Given the considerable and growing interest in Europe in the whole field of earth observation, this is clearly one of ESA's growth areas.

I should like here to stress that the European space effort has placed great importance on the up-grading of our technological competence. We unfortunately cannot claim that each step has been in accordance with a master plan, but the modest fact remains that the competence of the European aerospace industry has increased enormously over recent years. The taxpayers' money being devoted to ESA (in 1978 over 650 million U.S. dollars) is, we believe, also having an effect outside the specific area of ESA's interest. The Agency recently commissioned a study by the University of Strasbourg (the results are to be published shortly) which, after prolonged interviews with 70 or more of ESA contractors, concludes that each monetary unit ESA spends in European industry generates more than two monetary units of "usefulness". There is, regretfully, no time to go further into this interesting aspect.

You will be delighted to hear that I can deal more rapidly with the two remaining chapters: Spacelab and Ariane. Not that this means that they are less important - far from it - but rather that it is difficult in such a review to do justice to programmes of this size. In any case, I expect that both of them will be discussed in detail elsewhere during this Congress. For this reason, I propose now just to confirm that both programmes are running well, and to give you the chance to see slides of recent hardware development.

SPACELAB AND ITS UTILISATION

ESA, on behalf of the ten participating European countries, is responsible for the design, development, manufacture and delivery to NASA of one flight unit, an engineering model, two sets of ground support equipment and initial spares. ESA will also provide engineering support through the first two Spacelab flights and will ensure a follow-on production capability in Europe.

Spacelab will provide greatly increased opportunities in many fields of science, applications and technology. Its extremely stable and gravity-free environment will, for example, open up entirely new possibilities for separating biological materials in order to obtain pure preparations of cells for transplantation, for preparing concentrated antibodies for the treatment of certain diseases and for purifying vaccines. In conditions of weightlessness, ultra-pure metals, semi-conductors and glass can be processed, free of contact with containers, for research and applications in electronics, laser technology and optical products. New types of composite materials with improved strength at high temperatures may be processed in Spacelab, as well as perfect crystals for computers, communications and other electronic uses.

Spacelab offers environmental control for payloads and mission specialists and has extensive data handling facilities. A particular feature is the Instrument Pointing System (IPS) which is designed to carry payloads (e.g. astronomical telescopes) of up to 2000 kg mass, 4 m length and 2 m diameter and to point the line of sight of such payloads with an accuracy of better than 1 arc second. The IPS is a technologically very challenging project in itself and will almost exclusively make use of European-developed technology.

ARIANE LAUNCHER PROGRAMME

The first of the four test flights is scheduled for mid-1979, and I am happy to be able to say that we see no reason for not meeting this date. The second, third and fourth test flights will all carry satellite payloads, one of which is APPLE, the Indian telecommunications satellite.

The funding for the first batch of five operational launchers is now assured, and attention is now being given to a device (known as SYLDA) to permit double launches and to up-rating Ariane's payload capability.

A great deal of progress has also been made in the last twelve months in preparing the Ariane launch site in KOUROU, French Guiana. Here, too, work is on schedule.

Perhaps the most convincing testimonial for the Ariane programme is the fact that Ariane is being considered - together with the U.S. Shuttle (with Atlas-Centaur as back-up) for launch of one or more of the last three satellites in the INTELSAT V series - and this after a very professional examination of the launcher programme and the launch facilities by the INTELSAT Executive and its consultants.

* * *

You will perhaps have noticed that during this talk I have made several references to cooperative ventures. As an international organisation, virtually everything that we do is made possible through the cooperation between our Member States, but increasingly there is a tendency for this cooperation to extend beyond the bounds of these Member States, and this not only in the scientific field. It is a trend which will continue but which, in my opinion, should not be left to chance. Cooperation in global satellite systems, whether they be for some form of telecommunications or in the area of earth observation, is of as much interest to those countries which do not have a space capacity as it is to relatively few countries which are able to build and launch satellites. It is, in my view, not appropriate for this development to be seen as an industrial free-for-all.

I noticed recently a report of some wise words from my friend Dolf Thiel of TRW who, when giving evidence before the U.S. Congress, pointed to the need for an international body to sponsor an earth resources satellite programme of international cooperation. In the same vein, he is quoted as saying: "We feel it timely to reconsider the need for including certain space technology, particularly on the commercial communication satellite and scientific satellite area, on the munitions list. Such technology is already in hand in Western European countries and Japan." He said that the U.S. aerospace industry urges the removal of artificial barriers to the exchange of space technology - within the limits of national security - and I can only applaud this sentiment. But who is going to pick up the challenge?

Dubrovnik, curiously enough, provides us with a maxim which is well in line with the theme of this year's IAF Congress: "Astronautics for Peace and Human Progress", and which might well be brought to the attention of the world's space "powers". It is to be found in the upper gallery of the Rector's Palace, over the door of the chamber in which the Great Council used to be held, in the 13th and 14th centuries, I suppose. It reads: "Obliti privatorum - publica curate", which I would crudely translate as "Forget about what is good for you - think about general well being". Perhaps we should all take time out to see the inscription and to ponder on its relevance to our present situation.

SOME TRENDS OF SPACE RESEARCH IN THE U.S.S.R.

B. N. Petrov

The first Soviet artificial Earth satellite launched in 1957 marked the beginning of a new era in the history of mankind, an era of direct research and exploration of outer space. Space science and technology have gone a long way over the past 20 years. Many scientific and technological problems have been outlined and solved, radically new engineering approaches determined, various classes of launch-vehicles and spacecraft developed: satellites, automatic interplanetary stations, manned spaceships and orbital complexes. Many unique experiments and outstanding flights have been carried out. New trends in science have appeared, new discoveries have been made, horizons of the contemporary science have been expanded.

The XXVIIIth International Astronautical Congress was held in Prague in September 1977 with the motto "Two Golden Decades". It demonstrated great achievements in space technology and space research in various countries.

We have entered the third decade of the space era. Major trends in space research are obvious now. Space science and technology have passed from first occasional experiments, from first manned reconnaissance flights to regular, wider and more profound investigations of processes and phenomena in space and on various space objects of great scientific and applied importance. Of ever greater role are national economy oriented studies and the practical application of space technology.

The Soviet Union has contributed tremendously to the progress of world space technology. Priority in solving many fundamental problems in this sphere of man's activity belongs to our country.

The Soviet space programme covers major current directions of space exploration and use of space technology for the benefit of science and national economy. The emphasis is placed both on studies with automatic means and on manned missions on spaceships and orbital stations.

The Soviet Union recognizes the importance of co-operation with other countries in space exploration. Multilateral co-operation with socialist countries is developing within the Intercosmos programme; we have also bilateral co-operation with India, France, Sweden, and the United States.

Studies of the upper atmosphere, near-Earth space, solar-terrestrial links and research in space astronomy are carried out with the aid of Cosmos, Intercosmos, Prognoz, Meteor satellites and research sounding rockets as well as during the manned flights on spaceships and orbital stations.

The studies of the Intercosmos programme today make use of a new generation of satellites, the so-called automatic unified orbital stations (AUOS), and geophysical rockets "Vertikal", which carry the on-board equipment up to 1500 km, that descends on a parachute and allows a vertical cross-section of the atmosphere to be made. High-apogee (about 200,000 km) Prognoz satellites make it possible to study processes in the Earth's ionosphere and magnetosphere and to place scientific instruments beyond their borders, beyond the shock boundary so that the interplanetary medium and solar wind can be studied and the effect of solar activity processes on the interplanetary medium and magnetosphere determined. They have provided vast amounts of interesting information, in particular about the dynamics of the magnetosphere.

Out of many Cosmos satellites it would be worthwhile to mention the biological satellites Cosmos-690, 782 and 936. Interesting biomedical experiments were conducted on them which permit thorough studies of how space flight conditions effect living organisms. Thus, the Cosmos-936 biosatellite performed a whole range of physiological, biological, radiation physics experiments, and comparative studies of zero-G and artificial gravity effects on living organisms were carried out. These were international studies with instruments developed in Czechoslovakia, France and the United States on board the satellite, along with Soviet scientific equipment. Animals of a highly clean line from the CSSR were also carried in the flight.

In accordance with the programme of co-operation with France, a wide range of experiments was conducted in the fields of near-Earth and interplanetary medium space physics, of processes on the Sun as well as space astronomy studies. In particular, the French satellite Signe-3 was launched to conduct γ-astronomy investigations. The Soviet-Swedish experiment was carried out on board Intercosmos-16 using a spectroheliograph developed by Swedish scientists. The first Indian satellite Ariabhata was launched with a Soviet launch-vehicle, and preparations are going on for the second Indian satellite launching. The joint Soviet-American ASTP flight was of world-wide importance.

Another notable achievement of Soviet space science and technology is the development of a new generation of lunar vehicles that twice landed on the Moon with lunar rovers and three times delivered lunar soil samples to the Earth. The automatic stations have unified landers on which either lunar rovers or a drilling device, a manipulator and Earth-Moon rocket for sample delivery to Earth are mounted.

Among many planetary research experiments I shall discuss some aspects of Venus's studies. Soviet automatic Venera stations performed a wide range of unique investigations and solved many mysteries of the planet which had been fascinating scientists since the time Lomonosov discovered its atmosphere. Venera stations made first direct measurements of the physical parameters and chemical composition of the atmosphere, while the descending modules landed on the day and night sides of the planet and transmitted surface *in-situ* data to the Earth. In particular, Venera-8 data permitted us to estimate illumination conditions on the surface of the planet. The data obtained allowed comprehensive investigations to be prepared for modified stations Venera-9 and Venera-10. These stations became artificial satellites of Venus while their descending modules transmitted unique panoramas of Venus's surface at their landing sites.

At present the Venera-11 and 12 automatic stations launched on September 9 and 14 of the current year are flying to Venus. Their goal is to continue scientific investigations of the planet which they will reach in December, as well as studies of the properties of the solar wind, cosmic rays, UV- and X-ray radiations during their interplanetary flight. These stations are equipped with scientific instruments designed by Soviet and French specialists in accordance with the Soviet-French co-operation programme on exploration and use of outer space for peaceful purposes. Interesting data on γ bursts has already been recorded with these instruments.

The studies in the interest of national economy and the application of space techniques to the solution of many practical problems in the field of space communication, meteorology, navigation and remote sensing of Earth resources are becoming more and more significant and their part in the Soviet space exploration is growing with every year.

The manned flights to which the Soviet programme of space exploration gives much attention are very important for space studies. Thirty-six manned spacecrafts and six Salyut orbital stations were launched in the Soviet Union after Yuri Gagarin's legendary flight on the Vostok spacecraft. Forty-four more Soviet cosmonauts and three cosmonauts from the socialist countries have worked in space, harnessing the new habitat.

A comprehensive programme of co-operation between the socialist countries in the field of manned missions is now under way. Following the USSR and the USA, Czechoslovakia, Poland and the GDR were the countries whose citizens went into outer space.

The design of scientific complexes including manned spacecraft, automatic space freighters and long-term orbital stations with crew-shift is one of the important trends in Soviet space technology. We believe that this trend of space technology to be the thoroughfare of Man into space.

In September 1977 the Salyut-6 scientific orbital station was launched. Salyut-6 is a second generation of orbital stations as compared with the previous orbital stations. It has two docking units and allows two spacecraft to be docked. The Salyut-6-Soyuz scientific orbital complex consisting of the orbital station itself and two spacecraft enables us to carry out long and various space investigations, sending us to Earth the experimental materials: films, magnetic tapes, samples of biological and technological studies and other things.

The net mass of the Salyut-6 station together with two docked spacecraft is more than 32 tons, the length is about 30 meters, the span of solar arrays is 17 meters. The station designers provided the possibility for two cosmonauts to go out into space at one time; in this case the transfer module is used as an air lock chamber. Special EVA spacesuits of the semi-rigid type with an independent life-support system were developed. Such a spacesuit was successfully tested during two EVAs.

The station designers provided the best possible comfort conditions as possible for the work of cosmonauts during prolonged flights, e.g. they installed a shower-bath device, video recorder, developed a complex of prophylactic means against the weightlessness effect on human organisms: running track, ergometric bicycle, pneumovacuum suit, devices for stimulation of muscular activity, a special load-suit.

The essentially new problem of how to supply the station with fuel, various materials and additional scientific instrumentation was solved using Progress-type freighters. The delivery to the Salyut-6 station of fuel, life support facilities, films and instruments and devices permits us to increase the orbital flight time and the long-term stabilization of the complex necessary for many experiments and astrophysical observations. The Progress-type space vehicles operate as space tankers, dry cargo ships, automatic containers to remove the wastes from the station and used unnecessary units. They serve as space tugs transferring the station into a new orbit. The net mass of the Progress space vehicle is 7020 kg and its load capacity is 2300 kg.

For a year of the Salyut-6 functioning, ten docking operations were carried out including the redocking of the Soyuz-31 spacecraft in September. Three Soviet and three international crews were delivered on board the station. Soviet cosmonauts Romanenko and Grechko worked in space for 96 days, up to September this year. This flight was the longest manned space flight in the history of space exploration. Soviet cosmonauts Kovalenok and Ivanchenkov have been working now for more than 100 days on board the Salyut-6 orbital station and their flight is continuing successfully.

Together with the "veterans" of the orbital complex, the other four crews worked on board the station: the Soviet crew of cosmonauts Dzahanibekov and Makarov and the international crews of cosmonauts Gubarev and Remek (CSSR), Klimuk and Germashevsky (PPR) and Bykovsky and Yen (GDR).

The Salyut-6 station is equipped with various scientific instruments that can be added and replaced with the aid of the Progress freighters. Among various pieces of scientific equipment unique large instruments were installed: the BST submillimetre telescope with the sensor cooling system to liquid helium temperature (about 4° K) and the six-band MKF-6M system; their net mass is more than 820 kg. To carry out the technological experiments the Splav installation was mounted on board the station, which is a general-purpose electrical heating furnace which is capable of varying heating, soaking and cooling regimes in temperatures and time ranges, as well as the Kristall installation.

The Splav installation provides the heating of materials up to 900 to 1000° C and has three zones of temperature: "high" (900 to 1000° C), "low" (600 to 700° C) and gradient, where the temperature is linearly decreasing from "high" to "low" values.

The Progress-2 freighter delivered to the station a new modified electrical heating installation, the Kristall, which includes an electrical furnace, a control system and cassettes with holders for capsules with the tested materials. This installation is intended for growing semiconductors as ingots, bulk crystals or epitaxial structures from melts, vapour or gas phases. It is self-contained and provides for a high degree of automation of the technological processes that can be performed for temperatures within the range from 400 to 1200° C.

The Salyut-6 station is a multi-purpose scientific laboratory that allows many experiments and studies to be carried out on major problems of space research under conditions of the orbital flight. These are studies in the field of space physics, space astronomy and evolutionary biology necessary for solving the basic problems of modern science; studies of the atmosphere, the surface and natural resources of the Earth in the interest of the national economy; experiments in the field on space technology under zero-G conditions that are of scientific and practical value; the complex of medical and biological investigations of space flight factors on living organisms and the possibilities of long-term space flights of man without damage to his health are studied; and, finally, technical experiments necessary for further progress in space technology.

Twelve cosmonauts on board the Salyut-6 orbital complex carried out scientific investigations immense in their scope and significance. Two EVA experiments were also performed. Cosmonauts Romanenko and Grechko during 1 hour and 28 minutes inspected and tested the external elements of both the station structure and one of the docking units. In so doing, the new spacesuit of the semi-rigid type with an independent life-support system was tested and proved itself comfortable during EVA operations.

The activities of cosmonauts Kovalenok and Ivanchenkov in outer space included disassembly and partial replacement of the scientific equipment installed on the external surface of the station. During 10 months from launch experiments on studying the micrometeor situation and the influence of space medium on the properties of various materials were carried out with the help of this equipment. The equipment for recording of space radiation was also installed on the external surface of the station. The second EVA period was 2 hours 5 minutes.

At present the materials of scientific investigations and experiments carried out on-board the orbital complex are processed and thoroughly studied. The results of this mission will be delivered to the appropriate international conferences, in particular to the IAF Congress. Just two examples can be presented to demonstrate the enormous practical benefit of cosmonaut activities on board Salyut-6 to science and national economy.

During the technological experiments carried out with the Splav and Kristall installations cosmonauts Kovalenok and Ivanchenkov have obtained more than thirty various materials whose manufacture under earth conditions meets with considerable difficulties and in some cases is absolutely impossible. These materials are essential for electronics, optic and laser techniques. Some of the space materials have been already used for manufacture of experimental equipment.

The importance of the experiments on studying the Earth and its natural resources can hardly be exaggerated. Already these investigations are of high economical benefit. The scope of their use in national economy is unusually broad: detection of regions promising mineral deposits, studies necessary for agriculture and forestry, hydrology, oceanography, land use and so on. These studies will also allow us to improve the environmental pollution control. Cosmonauts Kovalenok and Ivanchenkov have taken about 18,000 photographs of the Earth's surface and the Oceans. There is no doubt that considerable time would be required to take such a number of photographs with the use of other technical means.

The missions of the international crews with the participation of the citizens of the CSSR, the PPR and the GDR are a great advance in Soviet Space technology. These missions are a new stage of the Intercosmos programme which has been carried out for more than 10 years by Bulgaria, Hungary, the GDR, Cuba, Mongolia, Poland, Romania, the Soviet Union and Czechoslovakia. In the past year scientists and specialists of these countries have obtained results in five basic fields of joint co-operation (space physics, communication, meteorology, biology, medicine), which have made valuable contributions to space sciences and the usage of space achievements for national benefit. These results were reported to the representative international forums, COSPAR sessions, IAF Congresses, and were widely accepted.

The international crews have performed on board the scientific Salyut-6-Soyuz complex more than thirty technological, medicobiological, geophysical investigations and experiments jointly prepared by the scientists and specialists of the USSR, the CSSR, the PPR and the GDR.

Participation of cosmonauts from socialist countries in the studies performed on board the Soviet spacecraft and orbital stations and involvement of scientists and specialists of these countries in the preparation of a wide range of experiments in space reflect a high degree of co-operation between the socialist countries. While preparing the programme for international crews, comprehensive and continuous studies were envisaged, in particular, repetition of some experiments to obtain more valid results.

The prospects of space research development are broad and diverse. The Soviet space programme envisages further investigation with satellites of the Cosmos and Intercosmos series, the high apogee Prognoz satellites, the sounding vertical rockets and the automatic stations. There will be further launches of biological satellites in order to develop the fundamental problems of space biology and to help in solving the problems of preparation for long-term missions of man in space. Further attention will be paid to space research concerning Earth's natural resources for many branches of the national economy and for the control of environmental and atmospheric pollution. Application satellites will obtain greater importance: communication satellites, meteorological and navigation systems. The technological experiments will be further developed. Orbital stations will perform long-term missions recrewing the transport spacecraft with crews and freighters for delivering fuel and life support facilities and other loads. The USSR will further expand international co-operation in space with other countries. In particular, international manned missions with the participation of citizens from socialist countries participants of the Intercosmos programme will be continued. The candidates – cosmonauts from Bulgaria, Hungary, Cuba, Mongolia and Romania – are now undergoing training in Zvezdnyi gorodok near Moscow.

The programme of space research is one of further investigation and exploration of outer space in the interests of peace, science development and the social progress of mankind.

AN OVERVIEW OF SPACE ACTIVITIES IN JAPAN

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ABSTRACT

Space activities in Japan are being carried out exclusively for peaceful purposes in two areas: scientific research and practical application. An overview of these activities is presented in this paper, focusing the view points on the research and development of satellites and launch vehicles, the consolidation of facilities and the budget for space activities.

1. Introduction--Duties of space related organizations

Space activities in Japan are being carried out exclusively for peaceful purposes in both the scientific research and practical application areas in accordance with the Space Development Program which is decided upon by the Space Activities Commission and with the basic plan presented by the Prime Minister based upon the Commission's decision.

1) The Space Activities Commission, established in 1968 as an advisory organ to the Prime Minister, has duties including deliberation and decision on important policies for the nation's space activities, estimation of expenditures and coordination of activities among related administrative organizations.
Since the first Space Development Program was formulated by the Commission in October 1969, the program has annually been reviewed by the Commission and necessary modifications and additions have been introduced by taking into consideration the trends and changes of the national and international circumstances. The most recent review of the Space Development Program was completed in March 1978. Current space activities are being carried out in accordance with this reviewed program.

2) In the area of scientific research, the Institute of Space and Aeronautical Science (ISAS) of the University of Tokyo is taking the leadership in view of its accademic role.
In the area of practical application such as communications, broadcasting, meteorology, navigation, geodesy and remote sensing, the National Space Development Agency of Japan (NASDA), established in October 1969 as the central organ for the nation's space efforts, is responsible for the development of satellites and launch vehicles.
NASDA is also responsible for tracking of all Japanese satellites, regardless of scientific or application ones, for determining and predicting their orbits.

3) All government agencies, national research organizations, universities and private enterprises involved are expected to make their utmost efforts for the effective execution of the space development program. (Attached chart)

2. Activities in the area of scientific research

Since an experimental flight of a small rocket in 1955, the University of Tokyo has made extensive efforts to develop various types of sounding rockets to be used for scientific observation as well as launch vehicles to put scientific satellites into orbit. In addition to them, high-altitude balloons have also been developed for scientific research purposes.

2.1 Sounding rocket project

Through participation in the international programs such as the sounding rocket program of the International Geophysical Year (IGY) 1957-58, the world synoptic rocket soundings program of the International Years of the Quiet Sun (IOS) 1964-65, the observation program of the earth's upper atmosphere and the sun for the International Year of the Active Sun (IAS) 1969-71, etc., Japanese space scientists have made notable contributions to the world progress of space science.
Today, by means of various types of sounding rockets such as single-stage S-210 and S-310, two-stage K-9M and K-10M and three-stage L-3H, space scientists, under leadership of the ISAS of the University of Tokyo, are conducting a wide variety of observations on sun-terrestrial physics, space plasma and magnetosphere, astronomical phenomena and so forth.
Besides ISAS, the Japanese Meteorological Agency (JMA) is using single-stage MT-135P for regular observations of upper atmospheric wind and temperature up to an altitude of 60 km, while the National Institute of Polar Research (NIPR), is using S-210 and S-310 for observations of auroral phenomena and polar ionosphere in Antarctica.

2.2 Balloon project

Since 1966, a high-altitude balloon project has also been carried out by ISAS. Approximately 20 balloons, with sizes ranging from 5,000 m^3 to 200,000 m^3, are flown every year for observations on the primary cosmic-rays solar neutrons, solar infrared radiations, cosmic X-rays, gamma-ray bursts, ionization of atmosphere, ozone, etc.

2.3 Scientific satellite project

Since the first launch in 1970, the ISAS of the University of Tokyo has so far launched 4 test satellites and 5 scientific satellites from its Kagoshima Space Center by means of L and M rockets (the first test satellite was launched by L rocket and all others were by M rockets). A few more satellites are currently being planned to be launched in the near future. (Fig. 1 and Table 1)

2.3.1 Test satellites

(1) Test satellite, "Osumi"

This satellite, weighing 24 kg, is Japan's first satellite, launched on Feb. 11, 1970 into a 5140/350 km and 31° inclination orbit by means of L-4S-5, a four-stage solid rocket modified from three-stage sounding rocket L-3H. When the satellite was injected into orbit, it was nicknamed "Osumi" which is the name of the peninsula where the Kagoshima Space Center is located. The successful launching of "Osumi" gave great confidence to the staff of ISAS in launching a satellite by the four-stage solid rocket M-4S, which had been developed as a satellite launch vehicle.

(2) Test satellite, "Tansei"

This satellite, weighing 65 kg and having similar size and shape to the Scientific satellite No. 1 (MS-F2), was launched on Feb. 16, 1971 into a 1110/990 km

and 30° inclination orbit by the M-4S-2 rocket. The main purpose of this launch waw to confirm the flight performance of M-4S rocket.
The nickname "Tansei" given to this satellite means light blue, the school colour of the University of Tokyo.

(3) Test satellite, "Tansei-2"
This satellite, weighing 56 kg, was launched on Feb. 16, 1974 into a 3240/290 km and 31° inclination orbit by the M-3C-1 rocket. Main objectives of the satellite were to confirm the flight performance of the newly developed M-3C rocket and to conduct a series of tests of the attitude control of the satellite.

(4) Test satellite, "Tansei-3"
This satellite, weighing 129 kg, was launched on Feb. 19, 1977 into a 3810/790 km and 66° inclination orbit by the M-3H-1 rocket. Main objectives of the satellite were to confirm the flight performance of the newly developed M-3H rocket, an up-rated version of M-3C, and to conduct a series of experiments of the spin control of the satellite using cold gas jet, etc.

2.3.2 Scientific satellites
(1) Scientific satellite No. 1 (MS-F2), "Shinsei"
This satellite, weighing 66 kg, was launched on Sept. 28, 1971 into a 1870/870 km and 32° inclination orbit by the M-4S-3 rocket. Main objectives of the satellite, such as the observation of ionospheric plasma, HF solar radiation emission in 5 MHz and 8 MHz band and low energy leakage electrons of the radiation belt and cosmic-ray background, were accomplished satisfactorily. The nickname "Shinsei" means a new life or a new birth.

(2) Scientific satellite No. 2 (REX), "Denpa"
The Radio Exploration Satellite (REXS), weighing 75 kg, was launched on Aug. 19, 1972 into a 6570/250 km and 31° inclination orbit by the M-4S-4 rocket. Main objectives of the satellite were to observe the electromagnetic and plasma waves, electron density and temperature, electrons in 1-10 KeV range, fluctuations in geomagnetic field, and also to conduct experiments on cyclotron instability. The nickname "Denpa" means the electric wave.

(3) Scientific satellite No. 3 (SRATS), "Taiyo"
The Solar Radiation and Thermopheric Structure Satellite (SRATS), weighing 86 kg, was launched on Feb. 24, 1975 into a 3140/260 km and 32° inclination orbit by the M-3C-2 rocket. This satellite discovered various anomalous phenomena in the ionosphere and acquired a large amount of data on solar radiations. The nickname "Taiyo" means the sun.

(4) Scientific satellite No. 5 (EXOS-A), "Kyokko"
The Exospheric Satellite (EXOS-A), weighing 65 kg, was launched on Feb. 4, 1978 into a 3970/630 km and 65° inclination orbit by the M-3H-2 rocket, with objectives of studying magnetospheric plasma and radiations including auroral phenomena in the magnetosphere up to an altitude of 30,000 km during International Magnetospheric Study (IMS) Program 1976-79.
The nickname "Kyokko" means surora. (Fig. 3)

(5) Scientific satellite No. 4 (CORSA-b)
With objectives of observing cosmic X-rays and cosmic heavy primary particles, the Cosmic Radiation Satellite (CORSA) was launched on Feb. 4, 1976 by the M-3C-3 rocket, but was unsuccessful.
A launching of the back-up satellite (CORSA-b) is planned to be carried out in February 1979.

(6) Scientific satellite No. 6 (EXOS-B), "Jikiken"
The EXOS-B, weighing about 99.6 kg, was launched on Sept. 16, 1978 into a

30,102/221 km and 31° inclination orbit by the M-3H-3 rocket, with objectives of observing wave-particle interaction and field phenomena as part of the IMS program. The nickname "Jikiken" means magnetosphere.

(7) Scientific satellite No. 7 (ASTRO-A) and No. 8 (ASTRO-B)

These two satellites, Astoronomical Satellite-A and -B, are planned to be launched in FY 1980 and 1982 respectively by the M-3S rockets. ASTRO-A is to investigate solar flare phenomena, while ASTRO-B, cosmic X and gamma-ray radiations. Prior to these satellites, a test satellite would be launched to confirm the flight performance of the M-3S rocket, an improved version of the M-3H.

(8) Scientific satellite No. 9 (EXOS-C)

This satellite is planned to be launched in FY 1983, with objectives of making optical observation of strato- and meso-sphere and investigating anomalous phenomena in the ionosphere above the south Atlantic, which were discovered by the Scientific satellite No. 3, "Taiyo". (Japan's FY starts in April)

2.3 Other projects

1) SEPAC

With the collaboration of NASA MSFC, the ISAS of the University of Tokyo is working on the Space Experiment with Particle Accelerators (SEPAC) Program which will be carried out onboard the Space Shuttle or the first Spacelab in 1980. As one of preliminary studies of this program, an engineering model of a Magnetoplasmadynamic (MPD) arcjet, together with an electron gun and diagnostic probes were tested at NASDA's Tsukuba Space Center in November 1977. Results obtained at Tsukuba reconfirmed many results obtained from a laboratory test at NASA JSC in December 1976.

2) Deep space exploration

As part of future prospects of Japan's space activities, studies of the exploration of deep space including Jupiter-type planets and astroids as well as Moon and Earth-type planets, are being conducted by a group of Japanese scientists.

3. Activities in the area of practical application

In the area of practical application, NASDA has so far placed 7 satellites into planned orbits. Four of them were launched from its Tanegashima Space Center by means of N launch vehicles and 3 others were launched from a US launch site by means of Delta launch vehicles on re-imbursable basis. Also, several satellites are planned to be launched in the near future. (Fig. 2 and Table 2) For achievements in this area, NASDA is most grateful to US NASA and related organizations for their support.

3.1 Development of engineering test satellite

1) Engineering Test Satellite-I (ETS-I), "Kiku"

NASDA's first satellite, ETS-I, weighing 82.5 kg, was launched by the first N launch vehicle on Spet. 9, 1975 from the Tanegashima Space Center into a 1100/980 km and 47° inclination orbit. Main objectives of this satellite, such as to confirm the flight performance of the N launch vehicle and to acquire over-all satellite launching, tracking and operation technologies were successfully achieved. The nickname "Kiku" means chrysanthemum, a representative Japanese flower.

2) Engineering Test Satellite-II (ETS-II), "Kiku-2"

This satellite, weighing 130 kg, was launched by the N launch vehicle from the Tanegashima Space Center on Feb. 23, 1977 and inserted into a geostationary

orbit over the equator at 130° East longitude on March 5. With this achievement, NASDA acquired necessary technologies for launching, tracking and control of a geostationary satellite.
Series of propagation tests of radio waves from the satellite to ground stations in the region of millimeter and quasi-millimeter were conducted satisfactorily.

3) Engineering Test Satellite-III (ETS-III)
Main objectives of this satellite are to conduct a series of tests of onboard subsystems, including a three-axis stabilization subsystem, an active thermal control subsystem, ion propulsion devices, etc. The ETS-III is scheduled to be launched in FY 1981 by the N launch vehicle into a circular orbit of about 1,000 km and 50° inclination.

4) Engineering Test Satellite-IV (ETS-IV)
Main objectives of this satellite are to confirm the flight performance of the N-II launch vehicle, an improved version of the current N launch vehicle, and to conduct a series of tests of onboard equipment, including pulsed plasma propulsion devices. The ETS-IV is planned to be launched in Jan.-Feb. period of 1981.

3.2 Development of ionosphere sounding satellite

1) Ionosphere Sounding Satellite (ISS), "Ume"
This satellite, weighing 139 kg, was launched by the second N launch vehicle on Feb. 29, 1976 from the Tanegashima Space Center into a 1010/990 km and 70° inclination orbit. Main objectives of this satellite were to make daily observation of the world-wide distribution of critical frequencies of the ionosphere by radio waves, to make measurement of plasma characteristics and positive ion density in the upper ionosphere and to utilize the results of such observations and measurements in the radio-wave forecasting and warning necessary for efficient operations of short-wave communications.
The satellite operated normally for about one month and obtained many valuable data, but it terminated the communication linkage with ground stations due to a malfunction of onboard power source subsystem.
The revamped satellite ISS-b, named "Ume-2", was launched on Feb. 16, 1978 into about the same orbit as the original "Ume". "Ume-2" is presently working satisfactorily and sending a large amount of worthy data to the ground, as shown in Fig. 4. The nickname "Ume" means plum blossoms, one of Japan's seasonal flowers.

3.3 Development of meteorological satellite

1) Geostationary Meteorological Satellite (GMS), "Himawari"
This satellite, weighing 315 kg on orbit, was launched by NASA's Delta 2914 from the Eastern Test Range at Cape Canaveral on a re-imbursable basis on July 14, 1977. After being injected into a transfer orbit under NASA's responsibility, the satellite was inserted into a geostationary orbit at 140° East longitude under NASDA's responsibility.
The nickname "Himawari", which means a sun-flower, was given to the satellite when it was injected into a transfer orbit.
For the purpose of participating in the Global Atmospheric Research Program (GARP), jointly undertaken by the World Meteorological Organization (WMO) and International Council of Scientific Union (ICUS), the "Himawari" is designed for photographing cloud pictures, measuring temperature of sea surface and collecting other meteorological data in the Western Pacific region.
After completion of about three-month pre-operational check-outs on orbit, the satellite was handed over to the Japanese Meteorological Agency (JMA) for its mission operation. (Fig. 5)
Himawari's data products are distributed to domestic and international users by various methods including the satellite FAX transmission.

2) Geostationary Meteorological Satellite-2 (GMS-2)

The GMS-2, which has about the same performance as that of the original GMS, is planned to be launched in Aug.-Sept. period of 1981 as a successor to the original GMS, with objectives of enhancing the observation of weather satellites and contributing to the improvement of world weather services.
The GMS-2 is to be launched by the N-II launch vehicle, an improved version of the N launch vehicle, from the Tanegashima Space Center into a geostationary orbit at about 140° East longitude.

3.4 Development of communications satellite

1) Experimental Communications Satellite (ECS)

The ECS has about the same dimensions and weight as the ETS-II. Main objectives of the ECS are to conduct via-satellite communication tests in the area of millimeter wave band. The ECS is scheduled to be launched in February 1979 by the N launch vehicle from the Tanegashima Space Center into a geostationary orbit at 145° East longitude.

2) Medium-capacity Communications Satellite for Experimental Purpose (CS), "Sakura"

This satellite, weighing 340 kg on orbit, was launched by Delta 2914 from Cape Canaveral on Dec. 14, 1977 on re-imbursable basis and then inserted into a geostationary orbit at 135° East longitude under NASDA's responsibility. Main objectives of this satellite are to make transmission experiments of telephone and television signal by using innovative 20/30 GHz together with conventional 4/6 GHz frequency ranges. With the aid of carefully shaped antenna, the coverage of 20/30 GHz frequencies focuses on the main inlands of Japan, while 4/6 GHz frequencies cover all the Japanese territorial region including isolated islands such as Okinawa and Ogasawara. (Fig. 6)
After completion of preliminary check-outs on orbit, the CS was handed over to the Ministry of Posts and Telecommunications for its mission operation and is now functioning satisfactorily.
The nickname "Sakura" means cherry blossoms, the national flower of Japan.

3) Communications Satellite-2 (CS-2)

With objectives of contributing to the development of technologies in connection with the via-satellite communication system and of meeting the increasing demands of user organizations, it is being considered to launch the CS-2 during FY 1982 by the N-II launch vehicle.

3.5 Development of broadcasting satellite

1) Medium-scale Broadcasting Satellite for Experimental Purpose (BSE), "Yuri"

This satellite, weighing 350 kg on orbit, was launched by NASA's Delta from Cape Canaveral on April 8, 1978 on re-imbursable basis and inserted into a geostationary orbit at 140° East longitude under NASDA's responsibility. Main objectives of this satellite are to make image and transmission experiments of voice and color television signals by using 12/14 GHz frequency ranges which cover remote and urban areas of the Japanese mainland and off-shore islands. Similar to the CS, the BSE is equipped with a carefully shaped antenna. And on the ground, together with various types of large antennas, a small antenna, having a diameter of less than 1 meter is to be tested for individual receiving purposes. (Fig. 7)

3.6 Development of geodetic satellite

1) Geodetic Satellite-I (GS-I)

With objectives of establishing new data to connect Japan's geodetic network with those of other parts of the world and to determine the precise position of isolated islands. The GS-I, a balloon-type satellite having the function of reflecting laser light as well as a laser ranging equipment, is planned to be launched during FY 1982 by the N launch vehicle into a circular orbit of about 1,500 km altitude.

3.7 Development of Earth observation satellite

1) Marine Observation Satellite-I (MOS-I)
With objectives of observing the oceanic phenomena, particularly the color and temperature of the surface of the sea surrounding Japan, and of acquiring technology common to the via-satellite Earth observation system, it is considered to launch the MOS-I during FY 1983 by the N-II launch vehicle into a sun-synchronous orbit.

2) Landsat ground station
As part of the development program of Japan's Earth observation satellite system and also as part of the international cooperation with the establishment of world-wide via-satellite remote sensing system, the construction of Landsat ground station is under progress by NASDA.
The station, located in Saitama-ken, near Tokyo, is planned to start its operation before the end of FY 1978. Major facilities installed at the station include subsystems for data receiving, recording and processing. With these subsystems, it will be possible to correct radiometric and geometric distortions existing in coming Landsat image and then to produce computer compatible tapes, films and papers. These products will be available on request at reasonable prices.

3.8 Studies on other satellites
Studies are being made on various satellites such as Electro Magnetic Environment Observation Satellite (EMEOS), Aero and Marine Environment Satellite (AMES), Advanced Communications Test Satellite-G (ACTS-G) and Broadcasting Satellite-2 (BS-2). These satellites are considered to be launched by the N-II or more uprated launch vehicle.

3.9 Studies on material processing in space
Through experiments on Skylab, it was proved that the high quality composite materials could be processed in the zero-gravity environment. The development of appratus for the first material processing test (FMPT), which will be carried out onboard Space Shuttle, are being conducted by a joint group of scientists of the National Research Institute for Metal, NASDA, etc. As part of preliminary studies, a flight test of a small furnace mounted on a two-stage rocket, TT-500, is being planned.

3.10 Studies on manned space activities
Feasibility studies on manned space activities are being conducted by a group of scientists, aiming to develop associated techniques first by relying on manned spacecraft of the United States. The first project will presumably be planned for around 1983.

4. Research and development of satellite launch vehicle

Since the first successful launch of test satellite "Osumi" by the L rocket in 1970, the M and N launch vehicles have marked high successful records in launching scientific and applications satellites. The performance and reliability of these vehicles are considered to improve on a continuous basis in the future. (Figs. 8 and 9)

4.1 L and M rockets

As mentioned before, by efforts of the ISAS of the University of Tokyo, the size and performance of sounding rockets have gradually been increased since 1955 and, in 1966, a three-stage solid rocket L-3H was flown up to an altitude of 1,800 km. Then in February 1970, a four-stage L-4S, which is composed of L-3H with two strap-on boosters and the fourth stage spherical motor, launched Japan's first satellite, "Osumi", into orbit.

This success gave confidence to the staff of the ISAS in launching scientific satellites by their four-stage solid rocket M-4S. M-4S is the first generation of M rocket series, having a total length of 23.6 m, the first stage diameter of 1.41 m and a lift-weight of 43.6 tons. By M-4S rockets, three satellites were launched successfully.

Then, with objectives of improving the accuracy of injection into orbit, the second generation of M rocket series, named M-3C, was developed. M-3C is a three-stage rocket, equipped with the secondary fluid injection thrust vector control system, SITVC, on its second stage. By M-3C rockets, two satellites were launched successfully and another satellite is planned to be launched in the near future.

The third generation, named M-3H, is an up-rated version of M-3C. Its second and third stages are almost similar to those of M-3C, while the first stage motor is made about one-third longer and this elongation brings the increase in launch capability of M-3H. So far, three satellites have been successfully launched by M-3H rockets.

The fourth generation, named M-3S, is an improved version of M-3H. M-3S is equipped with SITVC on both the first and second stages. At least three satellites are currently planned to be launched by M-3S rockets.

4.2 N and H launch vehicles

1) The first generation of satellite launch vehicle series developed by NASDA is called the N launch vehicle or the N-I launch vehicle. It is a three-stage radio guided vehicle with propulsion systems employing liquid propellant LOX and RJ-1 for the first stage and N_2O_4 and A-50 for the second stage and solid propellant for the third stage and strap-on boosters. The overall length of the vehicle is about 33 m, maximum diameter is about 2.44 m and lift-off weight is about 90 tons. With this configuration, the N launch vehicle has the capability of launching a satellite weighing about 130 kg into a geostationary orbit or several hundred kilograms into a low earth orbit.

Through all phases of the design and development of the N launch vehicle, efforts have been made to maintain the planned schedule by employing well proven technologies and avoiding any unknown risky factors. Along this line, necessary technologies and equipment have been introduced from the USA to support Japan's own development capability. As mentioned before, four N launch vehicles have so far been launched without any failure to place four satellites into planned orbits. The N launch vehicles are also planned to be used for launching a few more satellites in the near future.

2) As an improved version or the second generation of the original N launch vehicle, NASDA is working on the development of the N-II launch vehicle. With the increase of the number of strap-on boosters, extension of the length of the first stage liquid propellant tankage, improvement of the performance of the second stage liquid engine and so forth, the N-II launch vehicle is expected to have a capability of launching a geostationary satellite weighing about 350 kg or a sunsynchronous satellite weighing several hundred kilograms.

The N-II launch vehicles are currently planned to be used for launching ETS-IV and GMS-2 in FY 1980 and 1981 respectively and also being considered to launch several satellites thereafter.

3) It is described in the current Space Development Program that the H-I launch vehicle, equipped with a cryogenic propulsion system and capable of launching a satellite weighing more than 500 kg into a geostationary orbit, should be developed by the end of the first half of 1980s.
In accordance with this Program, NASDA is conducting research and development works on the LOX and LH_2 propulsion system having a thrust level of 100 kN in vacuum condition. With this engine system on the second stage, the H-I launch vehicle is expected to meet the above-mentioned payload requirement.

5. Consolidation of facilities

5.1 Launching facilities

In Japan, there are two launching sites: the University of Tokyo's Kagoshima Space Center, located at 131°05' E and 31°15' N, and NASDA's Tanegashima Space Center, located at 131°58' E and 30°24' N.
The Kagoshima Space Center, with total area of approximately 710,000 m^2, is used primarily for launching scientific satellites and sounding rockets, while the Tanegashima Space Center, approximately 8,650,000 m^2, is used primarily for launching applications satellites and small-size rockets. Mainly because of safety reasons, satellite launch vehicles as well as small rockets are launched from these space centers in the direction ranging from east to south.

5.2 Tracking stations

Functions of tracking stations are classified in two categories from their operational purposes: vehicle tracking and satellite tracking.

1) The vehicle tracking is carried out mainly for safety purposes to moniter the flight of launch vehicles if they are flying normally along the planned paths. For these purposes, both the Kagoshima and Tanegashima Space Centers have their own optical and radio tracking stations.
In addition, NASDA has two down-range tracking stations: one is a fixed station located on Chichi-Jima Island in the Ogasawara (Bonin) Islands and the other is a mobile station located on either Kwajalein Island in the Marshall Islands or Christmas Island in the Line Islands, depending on the flight mission (Kwajalein is used for medium altitude mission like that of ETS-I or ISS and Christmas for geosynchronous mission). For the installation of this mobile station, Japan is very grateful to USA and UK for their support

2) Tracking of satellites for the determination and/or the forecast of their orbits is undertaken by NASDA.
NASDA's tracking network is an integrated system consisting of the Central Tracking Station at the Tsukuba Space Center and tracking and data acquisition stations at Katsuura, Okinawa, Masuda, and Uchinoura which belongs to the Kagoshima Space Center. The Ogasawara Tracking Station and other mobile stations are also in place as down-range stations, as mentioned before. Satellite data obtained at all stations in the network are brought together at the Tsukuba Space Center for data processing, and the data related to orbit determination and/or forecast are transmitted back to the stations to improve data acquisition operations.

For the tracking of vehicles and satellites beyond the visible region of Japanese stations, NASDA is asking for the support of tracking network of foreign countries, especially that of US NASA. Data obtained at those foreign stations are also transmitted to the Tsukuba Space Center for processing.
Data obtained at user's stations for their mission operations are transmitted to to the Tsukuba Space Center according to their necessities. (Fig. 10)

5.3 Other facilities

Facilities needed for the research and development of satellites and launch vehicles are prepared at related organizations including the University of Tokyo, NASDA, the National Aerospace Laboratory, Radio Research Laboratory, etc. NASDA has the prime responsibility to build large-type facilities that can be commonly applied to different kinds of research and development objects, for the purpose of ensuring effective control and data processing. Such facilities are accessible to other research and development agencies for common use.

6. Budget for space activities

Annual budget appropriated for space activities in Japan have shown strinking growth in the past years as development programs have progressed. The budget for FY 1978 is approximately ¥94,900 million, while the budget ten years ago was approximately ¥7,240 million. Presently, about 80% of the total space budget in Japan is allocated to NASDA, about 10% to the University and the remaining 10% to various agencies. It is anticipated that the budget for space activities would continue to increase, although the increasing rate may not be so high as has been in the past. (Fig. 11)

7. Concluding remarks and acknowledgement

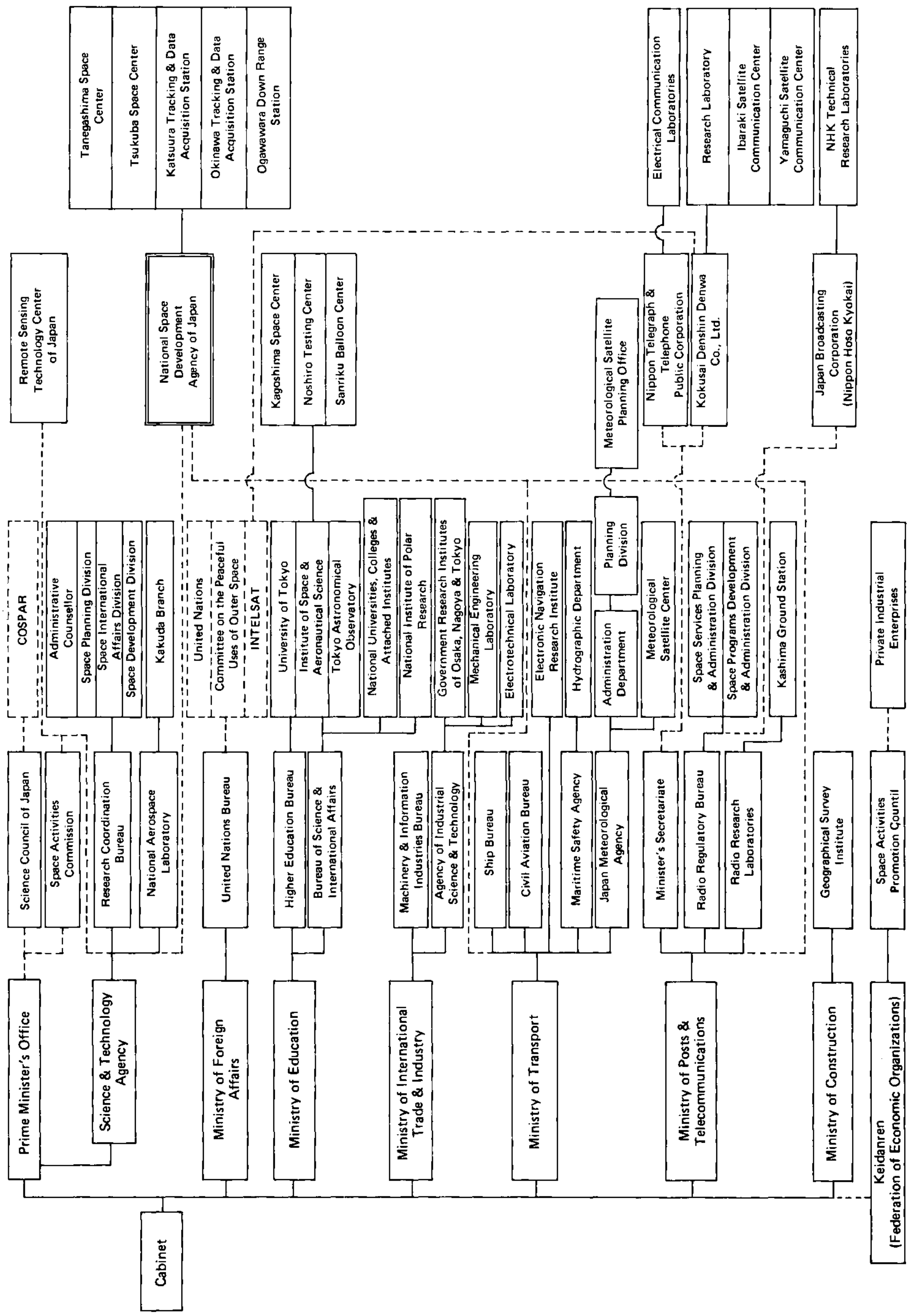
As mentioned earlier, space activities in Japan are being carried out in both the scientific research and practical application areas with the joint efforts of government organizations, universities and private enterprises in accordance with the Space Development Program which is decided upon by the Space Activities Commission. In addition to this Space Development Program, the Space Activities Commission, considering that Japan is entering a new space era in which more active developments in science and applications are to be promoted, issued in March 1978 the "Outline of Japan's Space Development Policy" which presents the guiding principle for Japan's space activities for the next fifteen years.
The policy stressed the following points.

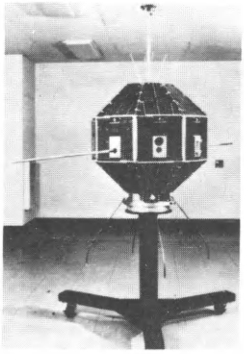
(1) Japan's space activities should be confined to peaceful purposes and should be carried out in response to various social needs and considering available national resources.
(2) Japan should develop the necessary technical capabilities to carry out comprehensive space program, although it is not necessary to produce everything domestically.
(3) In parallel with the domestic projects, Japan should actively participate in international collaborations and, further as a member of the international society, should share her due responsibility for the future space activities of humankind.

Before closing this paper, the author, as the President of the National Space Development Agency of Japan, wishes to express his gratitude for the cooperative support extended to Japan's space program by many organizations and people both domestic and foreign.

The author wishes also to extend his personal thanks to professors of the University of Tokyo and the NASDA staff, especially Dr. Yasuhiro KURODA, for their support in the preparation of this paper.

SCHEMATIC CHART OF SPACE-RELATED ORGANIZATIONS IN JAPAN





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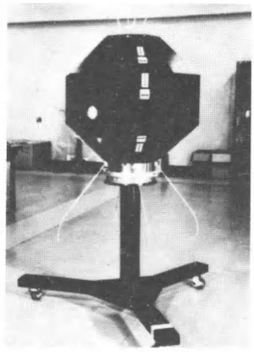
Feb. 11, 1970



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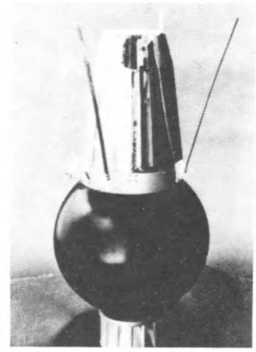
Feb. 16, 1971



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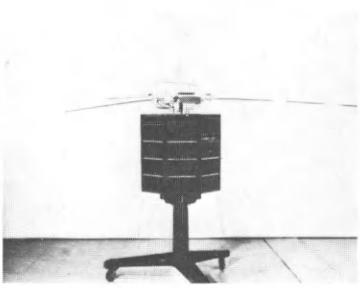
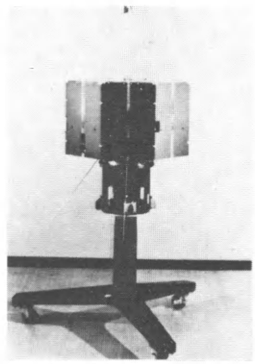
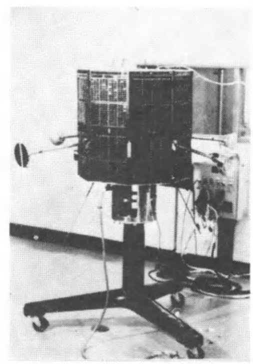
Sept. 28, 1971



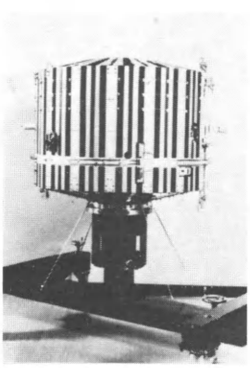
DENPA
Aug. 19, 1972



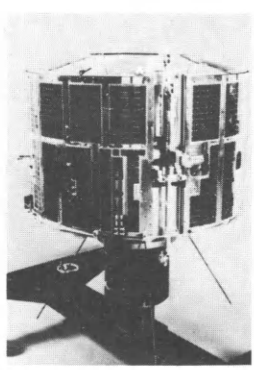
TANSEI 2
Feb. 16, 1974



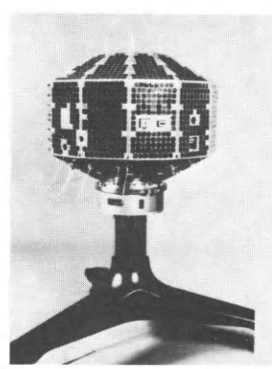
TAIYO
Feb. 24, 1975



TANSEI 3
Feb. 19, 1977



KYOKKO
Feb. 4, 1978



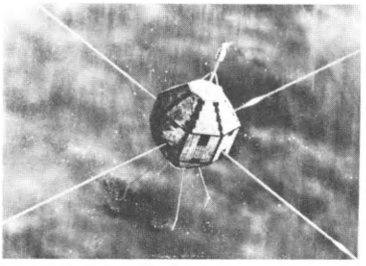
JIKIKEN
Sept. 16, 1978

Fig. 1. Satellites in the area of scientific research (name and launch date)

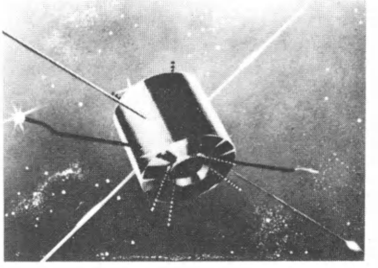
Table 1 Satellites in the area of scientific research

(* planned to be launched)

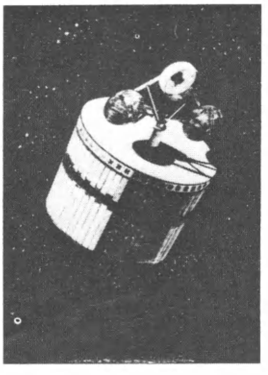
Satellite name	Launch date	Weight (kg)	Apogee/Perigee (km)	Inclination (deg.)	Launch vehicle	Missions
Osumi	Feb. 11, 1970	24	5140/350	31	L-4S-5	Preliminary launching test for the following M launch vehicles
Tansei	Feb. 16, 1971	63	1110/990	30	M-4S-2	Testing of housekeeping and function of the instrument system on-board the satellite
Shinsei (Scientific Sat.1:MS-F2)	Sept. 28, 1971	66	1870/870	32	M-4S-3	Observation of the HF solar radio wave emission, ionospheric plasma and cosmic rays
Denpa (Scientific Sat.2:REXS)	Aug. 19, 1972	75	6570/250	31	M-4S-4	Observation of plasma waves, plasma density, electron particle rays, electro-magnetic waves and geomagnetism
Tansei-2	Feb. 16, 1974	56	3240/290	31	M-3C-1	Measurement of characteristics of launch vehicle and engineering tests on satellites
Taiyo (Scientific Sat.3:SRATS)	Feb. 24, 1975	86	3140/260	32	M-3C-2	Observation of solar soft X-rays, solar vacuum u.v. radiation, u.v. terrestrial corona lines
Tansei-3	Feb. 19, 1977	129	3810/790	66	M-3H-1	Measurement of characteristics of launch vehicle and experiments of the spin axis control of the satellite using cold gas jet, etc.
Kyokko (Scientific Sat.5:EXOS-A)	Feb. 4, 1978	126	3970/630	65	M-3H-2	Observation of electron density and temperature, electron energies, aurora particles, and imaging of aruora in u.v. region
Jikiken Scientific Sat. No.6 (EXOS-B)	Sept. 16, 1978	85		3	M-3H-3	Measurement of electron density, particles, plasma wave, etc.
*Scientific Sat. No.4 (CORSA-b)	1978	95	650/550	31	M-3C	Observation of cosmic X-ray, cosmic heavy particles, etc.
*Scientific Sat. No.7 (ASTRO-A)	1980	180	600/350	31	M-3S	Observation of solar hard X-ray flares, solar particles X-ray bursts, etc.
*Scientific Sat. No.8 (ASTRO-B)	1982	180	600/350	31	M-3S	Observation of X-ray stars, gamma-ray bursts, soft X-ray nebulae, etc.



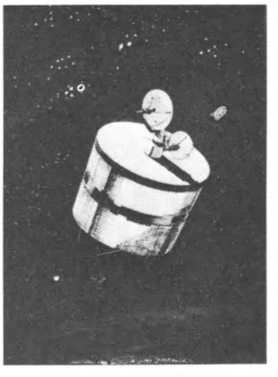
KIKU (ETS - I)
Sept. 9, 1975



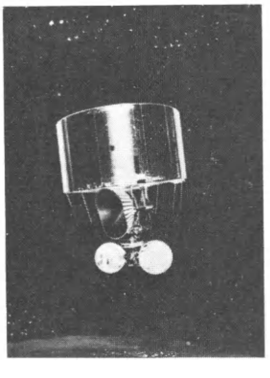
UME (ISS) & UME-2 (ISS-b)
Feb. 29, 76 & Feb. 16, 78



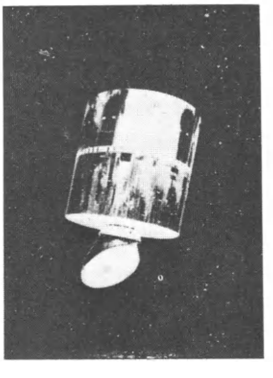
KIKU - 2 (ETS - II)
Feb. 23, 1976



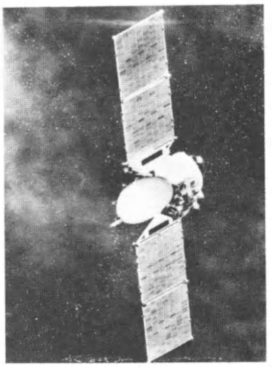
(ECS)
scheduled: FY 1978



HIMAWARI (GMS)
July 14, 1977



SAKURA (CS)
Dec. 15, 1977



YURI (BS)
April 8, 1978

Fig. 2 Satellites in the area of practical application (name and launch date)

Table 2 Satellites in the area of practical application

(* planned to be launched)

Satellite name	Launch date	Weight (kg)	Apogee/Perigee (km)	Inclination (deg.)	Launch vehicle	Missions
Kiku (Engineering Test Sat. -I: ETS-I)	Sept. 9, 1975	83	1100/980	47	N-1	Confirming launching technology, satellite tracking and controlling technology, testing of antenna extension, etc.
Ume (Ionosphere Sounding Sat.: ISS)	Feb. 29, 1976	139	1010/990	70	N-2	Observation of worldwide distribution of critical frequencies of ionosphere, etc.
Kiku-2 (Engineering Test Sat. -II: ETS-II)	Feb. 23, 1977	130	Geostationary orbit		N-3	Confirming technology for launching geostationary satellites, tracking and controlling geostationary satellites, etc.
Himawari (Geostationary Meteorological Sat.: GMS)	July 14, 1977	315	Geostationary orbit		(launched by NASA)	Meteorological observation, and data collection and distribution, etc.
Sakura (Medium-Capacity Communications Sat. for Experimental Purpose: CS)	Dec. 15, 1977	340	Geostationary orbit		(launched by NASA)	Establishment of operational technology of satellite communication system, etc.
Ume-2 (Ionosphere Sounding Sat.: ISS-b)	Feb. 16, 1978	141	1222/976	70	N-4	Observation of worldwide distribution of critical frequencies of ionosphere, etc.
Yuri (Medium-Scale Broadcasting Sat. for Experimental Purpose: BSE)	April 8, 1978	355	Geostationary orbit		(launched by NASA)	Establishment of operational technology of satellite broadcasting system, etc.
*Experimental Communications Sat. (ECS)	1978	130	Geostationary orbit		N	Performing space communication experiments, etc.
*Engineering Test Sat.-IV (ETS-IV)	1980	640	35600/190	20	N-II	Confirming performance of N-II Launch Vehicle, etc.
*Geostationary Meteorological Sat.-2 (GMS-2)	1981	335	Geostationary orbit		N-II	Meteorological observation, and data collection and distribution, etc.
*Engineering Test Sat.-III(ETS-III)	1981	375	1000/1000	45	N	Performing preliminary experiments of 3-axis attitude control, solar paddle, active thermal control, etc.

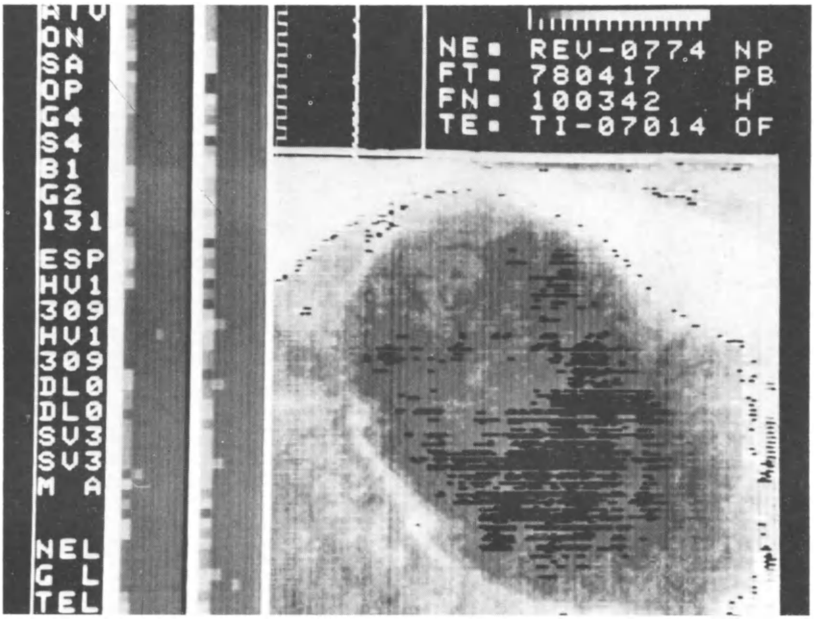


Fig. 3. A Quick-look Display of Auroral Television Picture Obtained by "Kyokko" (EXOS-A)

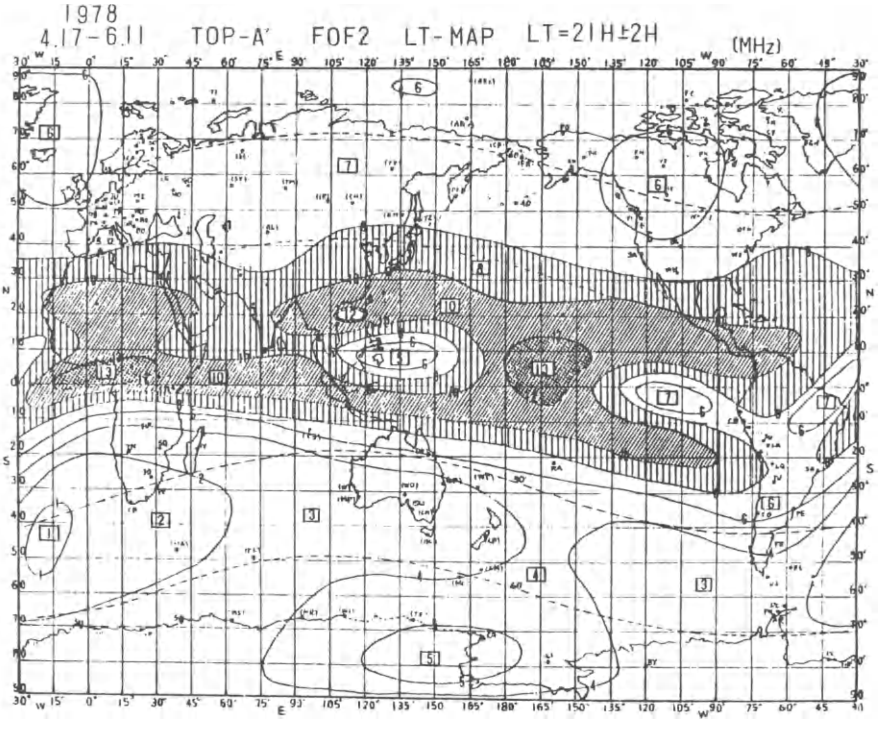
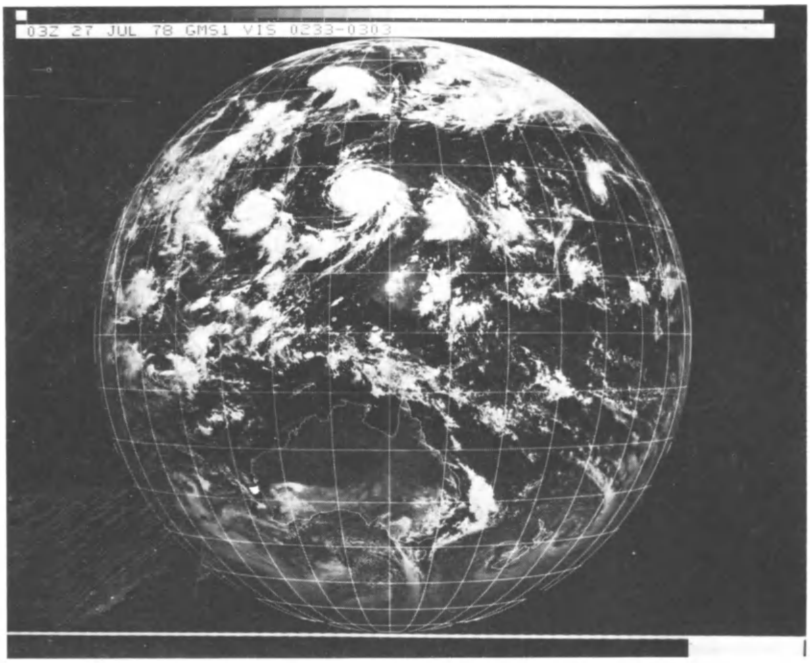
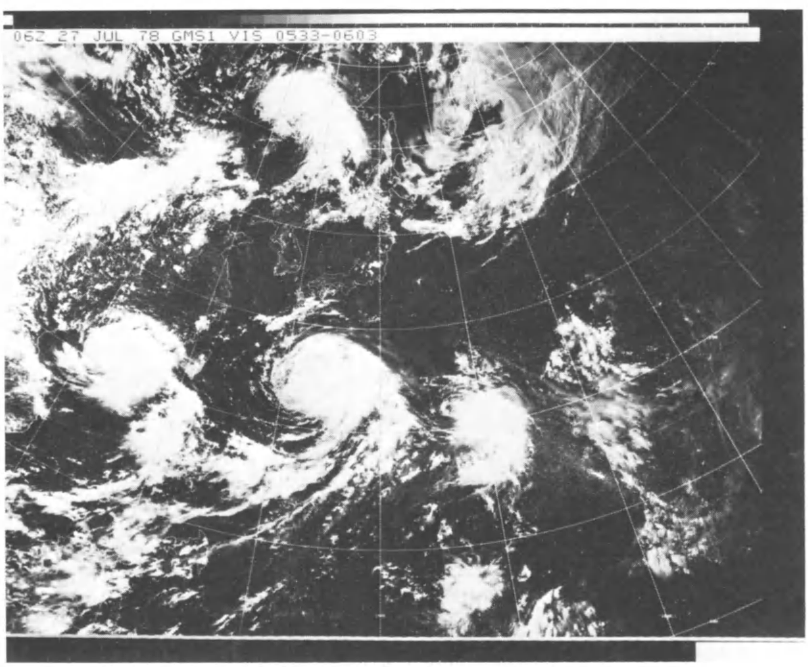


Fig. 4. World-wide Distribution of Critical Frequencies, Obtained by "Ume - 2" (ISS-b)



(a) Full Disc



b) Polar Stereo

Fig. 5 Cloud Pictures taken by "Himawari" (GMS)

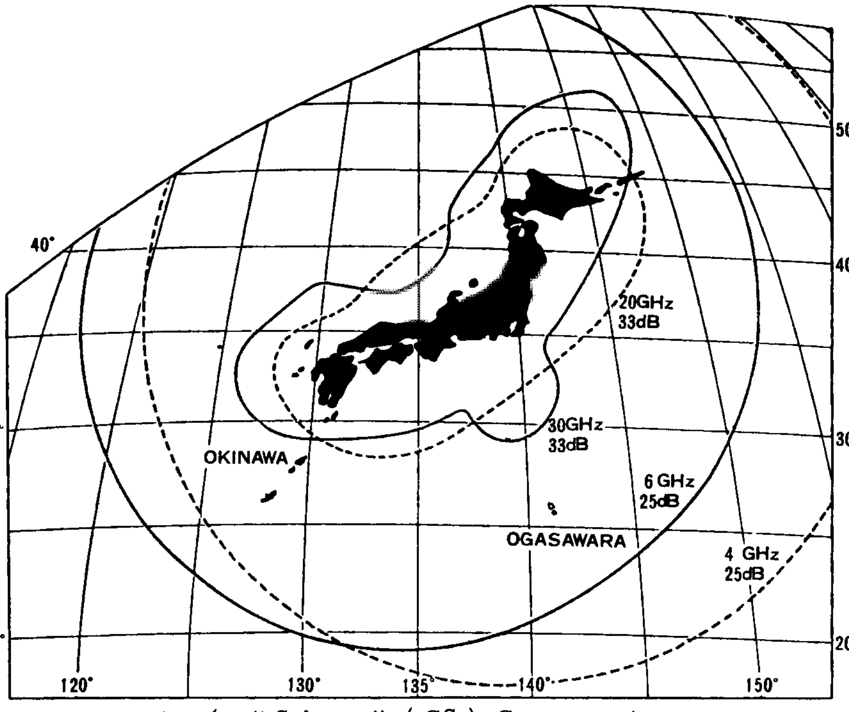


Fig. 6 " Sakura " (CS) Coverage Area

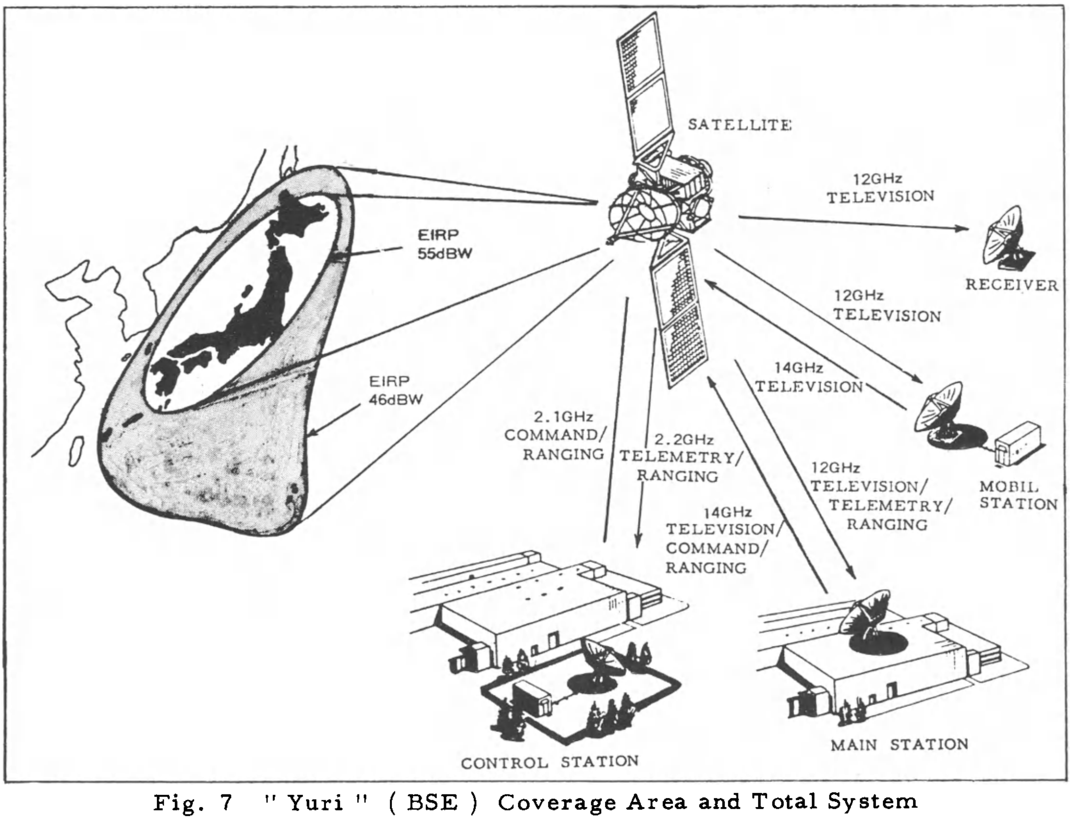
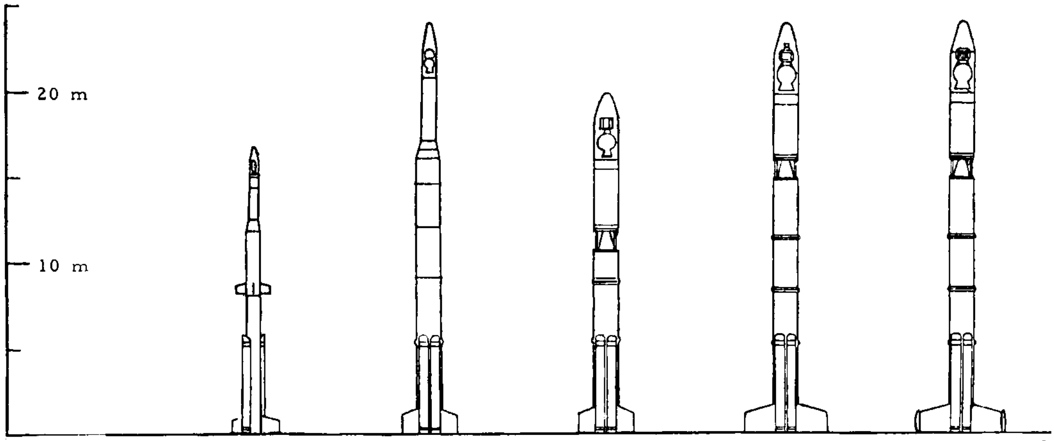


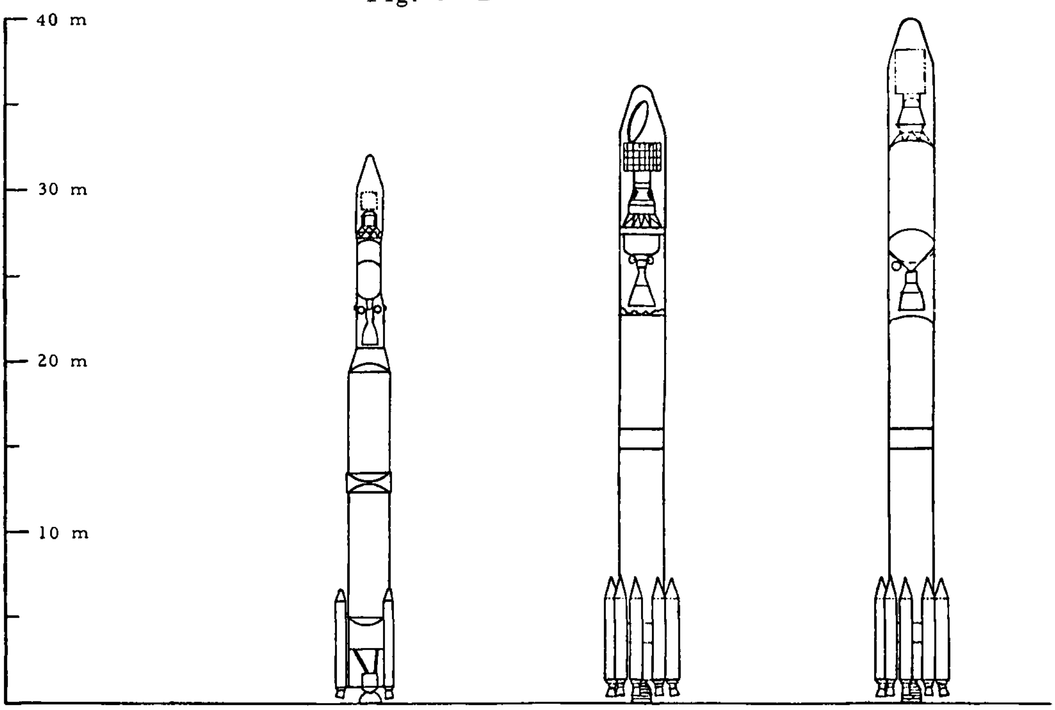
Fig. 7 " Yuri " (BSE) Coverage Area and Total System



		L-4S	M-4S	M-3C	M-3H	M-3S
LENGTH	m	16.5	23.6	20.2	23.8	23.8
DIAMETER	m	0.74	1.41	1.41	1.41	1.41
WEIGHT	ton	9.4	43.5	41.5	48.7	
PAYLOAD ※	kg	24	75	86	134	

※low earth orbit.

Fig. 8 L and M Rockets



		N	N - II	H - I
LENGTH	m	33	35	40
DIAMETER	m	2.44	2.44	2.44
WEIGHT	ton	90	136	140
PAYLOAD ※	kg	130	350	500

※ geostationary orbit

Fig. 9 N and H Launch Vehicles

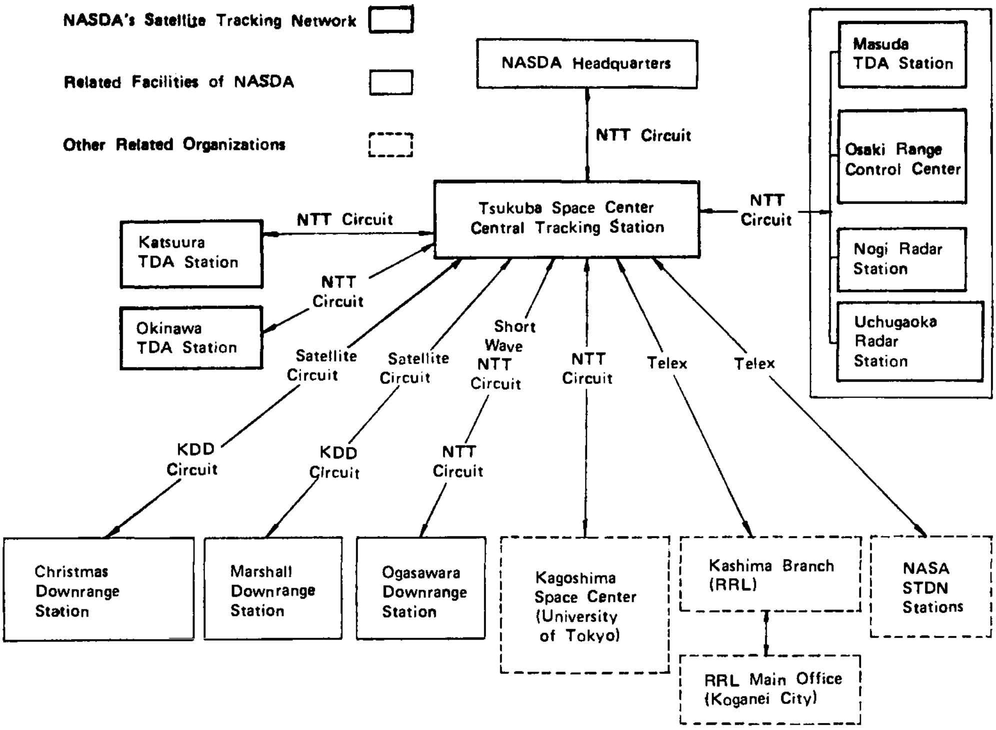


Fig. 10 Tracking System Block Diagram

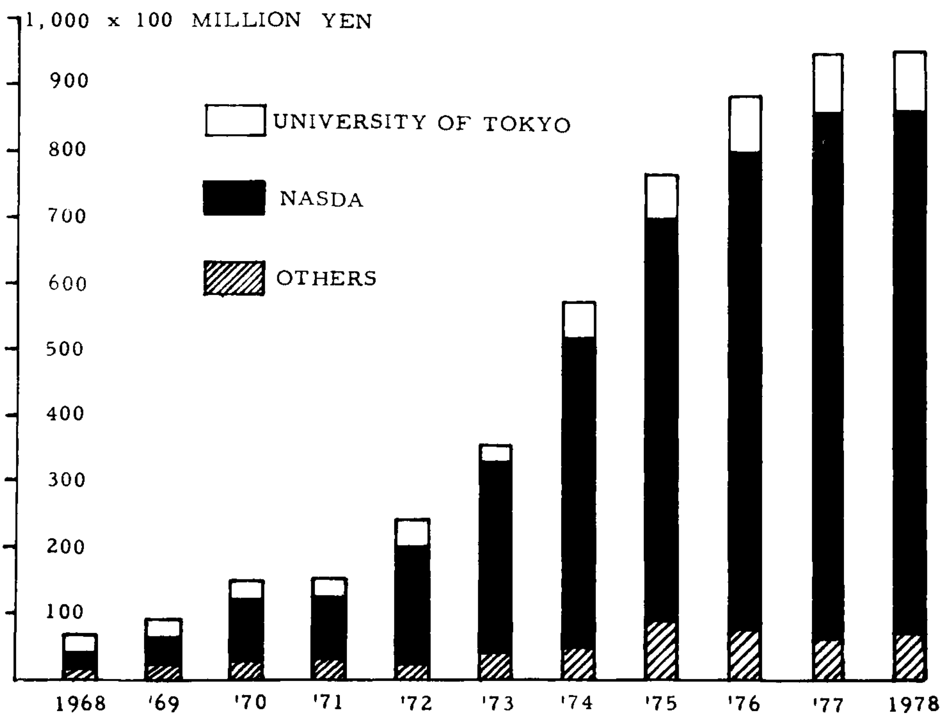


Fig. 11 Budget for Space Activities

THE CANADIAN SPACE PROGRAM

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Canada's first ventures into space was for research purposes. Four scientific satellites, beginning with Alouette-1, launched by NASA in 1962, have added significantly to man's knowledge of the atmosphere. Since then the emphasis has been on applications to promote national goals.

COMMUNICATIONS

It was recognized very early that a domestic communication satellite system of even a few channels would make television service available to any point in the wide expanse of Canada and would reach numerous areas previously unserved.

A mixed industry/government communications satellite corporation, known as TELESAT, was established in 1969. This company established the world's first domestic communications satellite system with its series of ANIK satellites serving more than 70 earth stations, covering the length and breadth of the country.

Telesat's new Anik B series, the first of which is to be launched next month, will operate in the 14/12 gHz range as well as the 6/4. This new band will eliminate interference with the terrestrial system on the 6/4 band allowing more power to be used thus making possible the use of smaller antennas as small as 3.6 metres.

The Canadian Broadcasting Corporation, the Trans Canada Telephone System and CN/CP Telecommunications are the main customers of Telesat.

In order to ultimately reduce the cost and size of earth stations, the Department of Communications designed and built a powerful experimental satellite called CTS-1 which was launched by NASA last year. This is the most powerful communications satellite yet put in orbit and is the precursor of the direct broadcast satellite. Such a satellite will give television broadcasting a quantum jump by reaching all remote areas of the world at relatively low cost.

The Department of Communication's next satellite will be an H/F satellite called MUSAT. It will be for government and defense communications. Its chief feature is that it can be used for point-to-point communications mobile vehicles such as ships and aircraft, as well as with portable ground stations. Funding for this satellite is not yet approved.

SPACE SHUTTLE

In 1969 NASA invited other nations to participate and share in the development of the Space Shuttle. Europe responded by proposing and subsequently building Spacelab. Canada's contribution is the Shuttle's remote manipulator system SRMS designed and built by Spar Aerospace of Toronto at a cost of about $75million. This program was proposed and is managed by the National Research Council. The SRMS is an arm-like device which will be used to deploy payloads, satellites, and other space devices from the cargo bay of the space Shuttle orbiter and also retrieve recoverable payloads. This manipulator has to be able to handle payloads up to 18.3 m long, 4.6 metres in diameter and 30,000 kg in weight.

SEARCH AND RESCUE SATELLITE /SARSAT/

Every year Canada spends millions of dollars in searching for downed aircraft in the north and for boats and ships in distress. Several years ago, Emergency Locator Transmitters were developed in Canada which are shaped like discs and will automatically fly off and start transmitting when the aircraft crashes. ELTs on boats and ships are activated by flipping a switch. Even with these transmitters, search aircraft have to fly back and forth for many miles searching for the signal. Experiments were done which showed the special satellites could be designed for detecting and relaying the positions of these ELTs. An advanced plan now exists with the United States, France and the USSR awaiting funding for such a satellite.

METEOROLOGY

The Atmospheric Environment Service is fully plugged into the WMO GARP satellite program and is reading out and disseminating data to its many weather offices: all the NOAA and SMS/GOES satellite data. SMS data will be sectorized before transmittal to the weather offices. They are hoping to install a TIROS-N station in the Arctic at Resolute Bay but have not yet obtained funding.

These satellites, of course, have other uses than for plugging the data into the world synoptic weather forecasting system. They are being used for predicting crop yields, for estimating soil moisture, for show mapping, and predicting floods caused by snow melting. In northern Canada and the North West Atlantic we use them for ice charting as well as for data relay on stream gauges.

REMOTE SENSING

This is being covered by Dr.Strome of the Canada Centre for Remote Sensing in a parallel session now going on, and preprints of his paper are available. Let me just summarize by saying that in Canada we regard SEASAT as the forerunner of a world family of ocean-oriented satellite, which together with ships, aircraft, and data buoys will feed a network of ocean information and management centre distributed around Canada's Pacific, Arctic, and Atlantic coast, which will carry out, in a coordinated manner, the function of: vessel traffic Management, fisheries control, ice reconnaissance and ship routing search and rescue and ocean pollution monitoring. The key to the problem in providing frequent near-real-time data.

Similarly we regard LANDSAT as the precursor of a world family of land-oriented satellites which together with ground data platforms, aircraft, and ground truth parties of geographers foresters, biologists, hydrologists, and agricultural scientists will feed a network of land information and management centre judiciously distributed over Canada's land mass, with due regard to political boundaries and mandaters. They will carry out, in a coordinated fashion the function of forest monitoring and management, wildlife monitoring and management, hydrologic monitoring and management and crop monitoring, but not management. Presumably farmers will still do the managing.

Here again the key to the problem is in providing adequate near-real-time data for the type of management I am talking about. Mapping and archival data would be a natural fall out of such a system.

AID TO DEVELOPING NATIONS IN REMOTE SENSING

I had thought originally that Aid to Developing Nations was to be a key topic in this session so I had prepared a paper on a combined US French Canadian Remote Sensing Program in West Africa. It is also in the documentation centre.

CURRENT AND FUTURE SPACE ACTIVITY IN ITALY

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ABSTRACT

A brief review of the current space activities in Italy is given, followed by a tentative look at the plans for the next five years.

KEYWORDS

Space Research - Spacelab - Balloons - Space Telecommunications - Remote sensing.

Italy exerts its major effort in space through its affilation to the European Space Agency (ESA), partecipating not only in the compulsory program but also in all major optional endevours. The national program is conducted under the management of the National Research Council (C.N.R.), the entire activity being coordinated and supervised by the Ministry for Scientific and Technological Research.

The global expenditure for space activity has, for contingent reasons, fluctuated considerably through the years, but considering years 1977 and 1978 only, the figures shown in Table 1 indicate a level of 65 billion liras/year, (about 80 million U.S. dollars), 45 billion allocated to the ESA programs and 20 billion to the national activities.

The major single international involvement is the italian partecipation in the development of Spacelab, conducted under the ESA-NASA agreement, and in which Italy's share is about 18% of the ESA quota of the project. The italian industry provides the main structure and thermal control.

The national program can be classified under four headings, namely:

1 - The SIRIO Project
2 - Spacelab participation
3 - National laboratories activity
4 - San Marco Program

All of these activities have obvious international implications.

TABLE 1. Italian Space Expenditure
1977 and 1978

	Million Liras 1977 (final)	1978 (estimated)
1. SIRIO Program	8.750	26.110
2. National Laboratories	1.200	2.390
3. C.R.A. (Aerospace Research Center)	--	1.500
4. International (ESA) Program:		
a) - Mandatory basic program	11.831	14.200
b) - Meteosat	4.712	4.400
c) - Telecommunication (OTS)	5.025	2.200
Telecommunication (ECS-HSAT)	--	4.100
d) - Spacelab (R&D)	16.800	21.600
Spacelab Spice (Utilisation)	--	400
e) - Ariane (R&D)	834	1.600
Ariane (production)	--	600
f) - Marots	690	--
g) - Earthnet	361	400
h) - ASTP	--	500
TOTAL	50.203	80.000

The SIRIO Project has concluded its first (development) phase with the succesful launch from Cape Kennedy on August 27th 1977. It operates ever since satisfactorily, and an intensive experimental activity is currently being carried out with it, by a number of agencies and laboratories in Italy, Austria, Finland, France, Germany, The Netherlands, United Kingdom and in the U.S.A. Coordination of the esperiments is effected by the C.S.T.S. (Center for experimental Space Communications) in Milano, while the main station for telemetering, telecommand and satellite control is located at the Space Telecommunication Center of Fucino (near Rome), a main space ground facility of which more will be said.

SIRIO is a spin-stabilized geostationary satellite, locked at 15° West over the atlantic, and is dedicated to investigating the use of ultrahigh frequencies in the 12.5-18 GHz range. It therefore fills the gap between the 10-14 GHz range currently investigated by the european OTS satellite launched last May, and the 20-30 GHz range of present and future experimentation by other (U.S. and Japanese) satellites.

Although nominally the life of SIRIO should end in 1979, there is good hope that its activity can be extended further, so that it will collect very significant statistical data on propagation, and will experiment various form of transmission in digital form and devices for the reduction of information redundancy.

Bringing now our attention on the italian partecipation to Spacelab, besides what already said of the important rôle of the italian space industry to the development of the vehicle, the national research laboratories will fly six experiments on the first spacelab mission. One of the experiments is concerned with high-energy particle physics, one will perform ballisto-cardiographic measurements on the human body, two experiments concern metallurgical process under quasi zero-gravity conditions. An important experiment will investigate various aspects of fluid convection in a micro-gravity environment and finally a sixth experiment will study the forces acting between clean metal surfaces coming into contact of which still little is known, taking advantage of the better defined experimental conditions which a gravityless environment permits. Finally Italy is engaged in supplying a "Fluid Physics Module" up to ESA specifications. This is a facility made available to all spacelab experimenters who will investigate in the field of fluid physics.

Italy is presently in the process of selecting experiments proposed for the following spacelab missions, and to asses the financial needs to support them. Moreover the italian industry is negotiating with NASA a partecipation in the development of a "PAM L" launcher, which will operate from Spacelab.

Coming to the activity of the national laboratories, there are six such institutions devoted specifically to basic space research as listed in table 2, located in Milano, Firenze, Bologna, Roma (two units) and Palermo. The CNR also supports space research carried out by several university centers, astronomical observatories, engineering schools and soforth. The main activity of the national laboratories has been, and still is, to prepare, often in collaboration with other european (or american) counterparts, the payloads for ESA or NASA satellites, inasmuch as Italy has not had untill now a national satellite program with the eception of SIRIO, wich must be considered as an experimental technological satellite, and a few small San Marco satellites developed and launched in collaboration with NASA, and of which more will be said.

TABLE 2.

- Laboratorio di Fisica Cosmica e Tecnologie Relative
  MILANO
- Istituto di Ricerca per le Onde Elettromagnetiche
  FIRENZE
- Laboratorio per lo Studio e la Tecnologia delle Radiazioni Extraterrestri
  BOLOGNA
- Laboratorio per lo Studio del Plasma nello Spazio
  FRASCATI (Roma)
- Laboratorio di Astrofisica Spaziale
  FRASCATI (Roma)
- Gruppo Italiano di Fisica Cosmica - Laboratorio per lo Studio delle Alte Energie
  PALERMO

A brillant example has been the important italian partecipation in providing the COS B payload, taking part in the so called "Caravan" laboratory consortium. Experimentation and interpretation of COS B data is still a current activity in the italian laboratories. In a similar way Italian has partecipated in providing the payloads of both GEOS, of Helios A and B, ISEE, and will participate in many of the experiments scheduled for I.U.E.

At present Italy is examining its participation to the activity of the large space satellite (ST) to be launched from Spacelab supposedly in 1984. The industry hopes to take part in the construction of the payload segment assigned to ESA (Faint Object Camera etc.) and the laboratories will join other european institutions in participating to the observational programs and to the data interpretation activity.

The entire future of ESA's scientific program is still in a fluid state at present, and Italy is waiting that the new projects should be selected and finalized in order to take part in them. It is worthwhile mentioning that Italy has recetly conducted for ESA a phase A study for an ambitious astrometric satellite (tentatively named Hypparcos) and would be willing to partake both in the construction and in its use if such a project should be selected in 1979.

Special attention should be given to the activity of the Stratospheric Balloon Launching Base established by C.N.R. at Milo, a site near Trapani, on the western tip of Sicily. The base has succesfully flown the first stratospheric transatlantic flight in the summer of 1975 (with British and American partnership) and subsequently organized a series of transmediterranean flights (launch from Sicily, payload recovery in Spain). The latter program, called "Odyssea", is sponsored by CNES (France), CONIE (Spain) and CNR (Italy).

The advantages offered by these flights are their relevant and fairly predictable duration (80-100 hours for the transatlantic, 18-23 hours for the transmediterranean flights) and their reliability (all flights to date have been completed,only one payload over nine flights has been lost before recovery). Cost, compared to other vehicles available for space research, is quite moderate (in the order of 150.000 U.S. $ per flight for a transatlantic , 60-80.000 $ for a transmediterranean flight, considering a scientific payload in the order of .5 .8 tons and a flight altitude of 40 km).

The present drawback of the present state of the art is the short period of the year (three summer months) in which reliable high altitude winds (30-40 km) are known to blow westwards. It is therefore recommended that the winterly eastward wind should be investigated and tested, and that some suitable eastern recovery ground should be made available. In the meanwhile there is a strong demand from the scientific community to intensify the flights's frequency, improving the technical facilities both on the ground and on board. It goes without saying that access to these flights is open to qualified institutions from countries other than the sponsoring ones, compatibly with the (for the present) limited number of flights which can be flown during one summer campaign.

Coming to the important field of earth observation, one must mention the "Terra project" by which Italy has established at the above mentioned space ground facility at Fucino a center equipped to receive and process the data from the Landsat satellites, concerning the area covering the whole of Europe, North Africa down to the middle Sahara region and the Eastern Atlantic ocean. This station is at present the only one operating in the mediterranean area and supplies, under an agreement with ESA, to all qualified requesting parties, earth data under various form such as synthetized photomaps,false color selections, information in digital form, after a certain amount of pretreatment of the data received.

The "Terra" facilities and services are operated by the Telespazio Corporation, a company licensed by the Ministry of Communications to operate commercial space communication systems and is affiliated to Intelsat. The "Terra" project organization is presently expanding its services to receive, process and supply data obtained from other satellites, such as Meteosat and H.C.M.M. and eventually others which will be operating in the near future.

Experimental research activity in the remote sensing field is carried out in a C.N.R. laboratory in Milano, a University Institute in Naples and in CSATA, a software institution in Bari. Moreover, Italy is in the process of organizing its national and regional agencies to exploit the data available from meteorological, earth resources and other environmental satellites, and to encourage training of specialists in the use of space-collected data. In this context training courses open to technicians from emergent countries have been held in Rome under FAO sponsorship.

Finally we want to mention a small group in Rome specializing in planetary sciences, which cooperates closely with the Vicking project analyzing and interpreting data from Mars.

Turning our attention to the program commonly known as San Marco, it can be recalled that it has been the first space activity developed in Italy in the early sixties, with NASA collaboration. The program, which is operated by the "Centro Ricerche Aerospaziali" (C.R.A.) of the University of Roma, under C.N.R. supervision, is centered on the activity of the "Oceanic Equatorial Launching Base" established by the Italian government in international (shallow) waters off the coast of Kenya. The choice of the site is dictated by the obvious advantages offered by equatorial launches in obtaining low-altitude equatorial orbits, as well as various types of quasi-stationary high altitude orbits specially suited for many useful scientific missions.

The base is equipped to launch Scout-class vehicles and has been operated successfully since 1964 in launching a series of aeronomical satellites (the San Marco series) as well as some american astronomical satellites of the S.A.S. series, some of which have played an astounding rôle in opening a totally new era in cosmic investigation (as in the well known "URURU" case). The San Marco base has also ground based facilities from where the passage of satellites can be followed and transmitted data can be received and elaborated. These facilities are currently used in the early phases of both NASA and ESA launches, and fills a well known gap in the ground station network around the world.

At present two San Marco launches are expected to take place between 1979 and 1980, and other launches are foreseen in connection with NASA, ESA, or national programs still to be approved.

Having completed a quick and far from exhaustive survey of current space activities in Italy we can give an equally general glance on the plans for the near future. At present the Ministry for scientific and technological Research is preparing a National five-year plan (1979-1983), with the help of all the interested agencies and institutions, to be presented to the political body for approval. Obviously the plan, as presently drafted, can be subject to major changes, so that the indications which follow are only tentative. Moreover, much of the content of the proposed plan may have to be changed to accomodate important decisions which ESA will make only in 1979 and which can influence heavily the national choices.

The present draft of the national five-year plan for space considers a total budjet of the order of 220 billion liras (250 millions U.S. $). Adding to this amount a 50-60 million dollars per year which represents our partecipation to ESA, we obtain a total of about 100 million $ a year, which represents the level of Italy's yearly effort for space for the next few years.

The proposed national plan allocates about 50% of the total budjet to space telecommunications, 30% basic research, 20% to space transportation, earth observation and for the ground segment. Such a partition confirms that Italy intends to continue its relevant effort in the field of space communications (initiated with the SIRIO project). There are a few candidate projects now under preliminary study. One project concerns a direct-television broadcasting satellite, another concerns an advanced technological satellite operating at 20-30 GHz for point-to-point high traffic communication. The final choice will depend on many factors, including the possibility of bilateral or multilateral international partnership and on ESA's final choices for the communication program. The italian effort tends to consolidate a global managerial capability to develop and handle space projects (a capability first shown with SIRIO), and to gradually effect a transition from experimental to operational satellites.

The basic scientific program will continue its active partecipation in the opportunities offered by ESA and NASA activities, providing payloads to satellites, putting experiments on spacelab missions, taking part in the ST activity and so on. These activities include the operation of the San Marco base in Kenya and the stratospheric balloon base in Sicily.

Within the budjet limitations, a few Scout-launched satellites are foreseen involving NASA partnership, and the possibility of a light national scientific satellite is presently investigated.

The italian industry interested in propulsion, which has proven itself by providing the A.B.M. motors for SIRIO, GEOS and other ESA satellites, all of which operated succesfully, will try to extend its capabilities partecipating to certain phases of the PAM L and ARIANE projects.

An effort will also be made to develop a space-geodesic know-how, in order to partecipate to such activities such as the V.L.B.I.

On the international scene, Italy intends to support ESA activities, taking part into various optional multilateral enterprises, thus giving to its national space industry a chance to keep abreast in various fields of advanced space technology.

OVERVIEW OF THE SPACE PROGRAM OF THE FEDERAL REPUBLIC OF GERMANY

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ABSTRACT

After a brief presentation of the goals and the technology utilized, the present status of the program is described. The program is characterized by concentration on the activities within ESA and on bilateral cooperation. Priority is given to the preparation of commercial applications of space technology; continuity has been achieved with regard to the promotion of space science. The development and future utilization of Spacelab are of special importance. In conclusion, a few outstanding aspects of expected results are described.

KEYWORDS

Space Program of the Federal Republic of Germany, European Space Agency, Space Science, Space Technology, Spacelab, Applications Satellites.

The following goals and measures of the space program have been laid down in the "Space Program of the Federal Republic of Germany 1976 - 1979" * and continue to be in force.

1. Goals

In the framework of the promotion of space research and technology, the Federal Government pursues the following goals:

- Development of new technologies and processes by means of the reusable space laboratory SPACELAB;
- Contribution to the solution of long-range weather forecasting and climate research as well as the surveying of raw materials and foodstuff sources as well as to environmental monitoring.

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* The program can be obtained from the Ministry's press section (Pressereferat des Bundesministeriums für Forschung und Technologie, Postfach 200706, 5300 Bonn 2)

- Advancement of the exploration of solar terrestrial relations, of astronomy and astrophysics as well as biomedicine by means of space flight technology;

- Extension of the German and European potential in internationally competitive communications satellite systems.

2. <u>Implementation and Cooperation</u>

In view of the generally supranational nature of space tasks, the space program is characterized by a concentration on the activities within the European Space Agency ESA and on bilateral cooperation, above all with NASA. The Federal Government pursues the following aims:

- A long-term intensification of the scientific program within ESA because here cooperation seems particularly successful. Because of the shortage of experiment flight opportunities, however, it is still necessary to give support to usually bilateral projects.

- ESA's preparatory and launching services with the transportation systems the Agency has itself developed should be carried out both for its own programs and for customers.

- ESA should carry out experimental application projects only at the request of and in accordance with the demand of user organizations. In the course of the transition to the operational phase, the tasks are progressively to be taken over by the users. The commercial production and distribution of satellites should be left to industry.

3. <u>Technology being Utilized</u>

For the implementation of the above goals, the Federal Government makes ample use of the wide range of space flight technology:

- As regards space transportation systems, it is using, or planning to use

    * sounding rockets, which it is able to launch from foreign launching pads via the "Mobile Rocket Base" (MORABA) of the German Aerospace Research and Test Establishment (Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V. DFVLR) although it does not build the rockets itself.

    * conventional launchers. Within ESA, the Federal Republic is participating in the development and production of ARIANE and in the European funding of the rocket launching site in Kourou/Guyana.

    * the advanced reusable space transportation system SHUTTLE/SPACELAB of NASA/ESA. The Federal Republic is participating in the development of SPACELAB, the European contribution to this system, with a share of over 53 %.

In accordance with these transportation systems, the Federal Republic is developing, or participating in, the various types of payloads and/or spacecraft:

* Sounding rocket programs are scientific programs in their own right as well as supporting satellite measuring programs, and they are used in the technological preparation of SPACELAB utilization programs. Payloads are in some cases recovered with parachutes.

* Automatic satellites and space probes for scientific and application-oriented missions are at present a priority of the program. Major contributions to space flight technology have here been made for example by the US-German solar probe program HELIOS with a nearness to the sun so far unattained, with technological progress having been made above all in the thermal balance. The Franco-German communications satellite project SYMPHONIE has led to new developments in terms of three-axis stabilization and the exact geostationary positioning with a liquid-apogee motor; on the basis of the latter experience, i.a. the propulsion system for the positioning of the probe will be government-provided for NASA's Jupiter Orbiter and Probe GALILEO.

  Furthermore, there is a national technology program which has the following priorities:

  - solar cells and solar generators
  - surface coating for thermal control
  - components and systems for earth surveying (IR detectors, remote sensing of atmospheric trace gases with CO_2 lasers, remote sensing with microwaves SAR (synthetic aperture radar)
  - components and systems for attitude control (magnetic bearing momentum wheels, hydracine engines, electrical ion engine RIT 10)
  - large-surface lightweight structures on the basis of carbon fibre reinforced plastics technology
  - cryogenic cooling systems with liquid helium.

  In the field of communications satellites, special attention is at present given to the development of components and subsystems for direct television broadcasting satellites.

  With the DFVLR, the Federal Republic of Germany has at its disposal a satellite ground support facility GSOC. ESA's satellite control center (ESOC) and a ground station of ESA are also situated in the Federal Republic of Germany.

* The future availability of SPACELAB as a reusable and man-operated orbital system means the introduction of a new technique into space flight. SPACELAB, as an experimental platform, will be able to further and improve the utilization of space systems for research and application purposes and it will also be able to open up new applications in the life sciences and in technological research and development, in particular under zero-gravity conditions, since many technological processes are influenced by gravity to some extent.

The future utilization of the SPACE SHUTTLE as a space transportation system with less stringent volume and weight limitations and with the possibility of astronaut flights give us reason to expect increased performance and economic efficiency, provided that the launching costs can be kept within adequate limits.

4. Current Status of the Programs

4.1 Applications satellites

The two Franco-German communications satellites SYMPHONIE (in the 4 to 6 GHz range), which are the first European civilian communications satellites, have been used for telecommunications experiments since their launching in December 1974 and August 1975 respectively, such as TV program transmission, transmission of long-distance calls, high speed data transmission and the testing of a time division multiple access (TDMA) technique and for demonstration purposes and educational television experiments. Tests have been carried out for the United Nations with small mobile antennas for the rapid establishment of communication links in disaster areas; a vehicle of the German Red Cross fitted out for such purpose is available for emergencies. In May 1977, SYMPHONIE 1 was moved to a new geostationary position (49° E) and has been utilized for a new series of demonstrations in the Middle East, since June 1977 for experiments under the Indian STEP program and since April 1978 for experimental broadcasts with the People's Republic of China.

Within the framework of ESA, the Federal Republic is participating in the European Communications Satellite Program TELECOM (11/14 GHz range). The objective of this program is the development and introduction of an operational European satellite system for the transmission of long-distance public communication traffic and the distribution of TV programs. The Orbital Test Satellite OTS was launched in May 1978. A recently developed TDMA technique for 120 megabits per second, which was pretested with SYMPHONIE at bit rates of 60 Mbit/s, is used in experiments of the German Federal Postal Services with OTS. Also, equipment is tested for the digital transmission of a telephone and/or sound channel on a carrier frequency and a technique for the purely digital transmission of a picture at a bit rate of 34 Mbit/s within a bandwidth of 17 MHz. The development and construction of the European operational communications satellite ECS, whose first launching is scheduled to take place in 1981 with an ARIANE launcher, was agreed in March 1978. The final decision on the establishment of a satellite system is expected to be taken before the end of this year by Interim-EUTELSAT, Operating Company of the European Postal Administrations.

The Federal Republic is also participating in the maritime communications satellite program MAROTS of ESA, which is designed to improve radio links between ship and shore stations. MAROTS, which was originally planned as an experimental satellite, is to be converted to a frequency suitable for a world-wide operational system and subsequently, at the end of 1980, launched with the last experimental launching of ARIANE.

Together with a second satellite which is to be launched in 1981 it is considered as a contribution to the planned INMARSAT system. Appropriate operational ship terminals and search and rescue equipment have been developed in the Federal Republic for these maritime satellite systems. An experimental ship station has - in the course of several measuring campaigns with NASA's technology satellite ATS-6 - yielded important findings on the potential applications of maritime satellite systems up to an elevation of 0 degrees. An operating and utilization program with operational ship terminals in cooperation with German ship owners is in preparation.

Under the national technological promotion program for communications satellites, above all for television broadcasting satellites for direct television reception, support has been given to modular-designed functional models for a payload module and a satellite platform module as well as home reception equipment and digital transmission techniques. Priorities are high-power (100 to 450 W), high-efficiency (approx. 40 % including electronic power conditioning devices) transmission amplifiers, large ultra light-weight modular solar generators (up to 5 kW per wing), purely digital attitude/orbit control systems and TM/TC monitoring systems. With the allocation of transmission frequencies, EIRP (effective isotropic radiated power), polarisation, coverage zones and orbit positions for direct television broadcasting satellites by the World Adminstrative Radio Conference WARC 77,interest in satellites of high transmission efficiency for reception with small antennas (home and community receive antennas) has increased considerably. Thus, project definition studies for direct television broadcasting satellites are at present underway. With German participation, ESA is studying an experimental satellite compatible with ARIANE while, in the Federal Republic, a SPACE SHUTTLE-optimized preoperational satellite which is compatible with both the SPACE SHUTTLE and ARIANE, and in conformity with WARC 77 recommendations, is studied.

Another application-oriented ESA program carried out with German participation is the meteorology satellite METEOSAT.

The purpose of the METEOSAT program is to collect, process and disseminate meteorological data by means of a geostationary satellite and associated ground facilities. METEOSAT 1, which was launched in November 1977, is one of Europe's contributions to the Global Atmospheric Research Program (GARP). At present ESOC's large-scale computer facility (Darmstadt) has reached full operating capacity. METEOSAT 2 is to be launched with an ARIANE experimental launch in 1980 in order to prolong the useful life of the satellite system. Interpretation of the data in the Federal Republic is to be done by the Deutscher Wetterdienst (German Meteorological Service) and by a group of meteorologists at various universities. The photographic data received from METEOSAT provide one of the main sources of information for the daily weather forecasts in the Federal Republic.

4.2 Space science

Space science is to help

- explain the origin and age of the earth, the solar system and the universe (astronomy and astrophysics),

- study the relations between the sun and the earth, i.e. the processes going on in the sun, in interplanetary space and in the earth atmosphere (solar terrestrial relations),

- explore the influences of space radiation and zero-gravity on man and on biological organisms.

In the field of astronomy and astrophysics, mainly the following measures are carried out for the various wavelengths:

- For investigations in the infrared range, a cooled infrared telescope for SPACELAB missions is being developed.

- For investigations in the ultraviolet range, the Federal Republic is participating in the evaluation of measurements taken by the ESA-NASA-UK satellite "International Ultraviolet Explorer" (IUE) (launched in January 1978). In addition, sounding rockets are used also.

- For investigations in the X-ray spectral range the Federal Republic is participating in ESA's X-ray satellite EXOSAT, which is to be launched in 1981 with an ARIANE. An 80cm-X-ray telescope is being developed for SPACELAB missions. In addition, sounding rockets and balloons will also be used.

- For investigations in the gamma ray range, the Federal Republic is participating in the ESA satellite COS-B, which has been operational since August 1975; it is carrying out sounding rocket launchings, and it will take part in the planning and perhaps the scientific payload of the GAMMA RAY OBSERVATORY (GRO) of NASA.

Furthermore, German astronomers and astrophysicists will be given an excellent research opportunity in all spectral ranges from the ultraviolet to the infrared range in the 80s via ESA's participation in the NASA SPACE TELESCOPE PROGRAM.

In the field of solar terrestrial relations, above all the following measures are being carried out:

- In the magnetosphere, measurements will be carried out from sounding rockets, from aircraft and from the ground under the International Magnetospheric Study Program by the international scientific community. The Federal Republic is taking part in the geostationary ESA satellites GEOS 1 and 2 (launched in April 1977 and July 1978 respectively) as well as in the ESA-NASA satellite INTERNATIONAL SUN EARTH EXPLORER ISEE B (launched in October 1977). The FIREWHEEL probe is to be launched in 1979 with an ARIANE experimental launching. Furthermore, the ACTIVE MAGNETOSPHERIC PARTICLE TRACER EXPERIMENT (AMPTE, 1981) is planned together with NASA.

- In the interplanetary space, measurements are being continued with the two solar probes HELIOS 1 and 2 (launched in December 1974 and January 1976 respectively) beyond the nominal mission duration. The Federal Republic is participating with experiments in the dual probe project of ESA/NASA SOLAR POLAR MISSION (scheduled launching in 1983) and in the SOLAR MAXIMUM MISSION of NASA.

- For observation of the sun, sounding rockets are used. Under the US-Italian project SAN MARCO D, the extreme UV radiation is to be measured.

- In planetary research, the Federal Republic is taking part in the Jupiter Orbiter and Probe GALILEO (to be launched in 1981/82 with the SHUTTLE). The Federal Government is making available both some experiments for the exploration particularly of Jupiter's atmosphere and a propulsion system for the positioning of the Jupiter Orbiter and probe.

In the field of the bio-sciences experiments are being prepared for the first SPACELAB mission, above all vestibular studies with the SPACE SLED, which is being developed by ESA, and other studies of biological objects.

4.3 Space transportation systems including SPACELAB utilization

At the present time, SPACELAB is the most important space project for the Federal Republic of Germany and, together with ARIANE, also for ESA. The flight unit is to be delivered to NASA by the end of January 1980 so that it will be ready for its first flight in December 1980.

One of the objectives of the SPACELAB research laboratory is to provide the facilities that will enable experimenters to conduct their orbital experiments in situ. The modular design ensures considerable mission flexibility. Three main fields of endeavour are envisaged:

- pure science experiments in astronomy, astrophysics and the earth sciences,

- applied science experiments, for instance in telecommunications, navigation, meteorology, remote sensing or medicine, and

- technological experiments covering the wide range from investigations into the properties of materials to the experimental manufacturing of special products under zero-gravity and ultra-high vacuum conditions.

At present the Federal Republic is planning participation in five SPACELAB flights:

- The first joint SPACELAB payload of ESA and NASA (flight 1980/81),
- The two demonstration missions planned by ESA in 1982 and 1983.
- Two additional missions are planned predominantly for the particular German demand; they are to be carried out jointly with NASA and also other countries: in 1982 a dedicated mission for a technology research laboratory, and in 1983 for astrophysics and high energy physics.

The first SPACELAB payload will consist of 60 European, 15 American and 1 Japanese experiments from the life sciences, atmospheric, solar and plasma physics, astronomy, earth observation and materials sciences.

For another four missions, the Federal Minister for Research and Technology called - jointly with ESA - for proposals to be submitted for experiments in April 1978. 276 proposals were submitted, approximately half of them from the Federal Republic of Germany. Materials science is leading with 106 proposals.

Preliminary work for materials sciences and space processing will be carried out with the sounding rocket program TEXUS. A materials science laboratory is being developed for the first SPACELAB payload. Simple and small self-contained packages are in preparation for SHUTTLE flights.

In the field of remote sensing of the land, the oceans and the atmosphere, SPACELAB is an experimental platform for the technological development of suitable sensor systems. For the first SPACELAB mission, a metric camera and a microwave experiment are in preparation. An airborne LIDAR system is envisaged for design testing as a phase preceding a SPACELAB experiment; instruments for the passive probing of the atmosphere are to be developed.

Mention has already been made of the development of telescopes as scientific SPACELAB payloads.

The Federal Republic is also participating in ESA's other major space transportation system, the launcher ARIANE, although with a smaller share than in SPACELAB. Under this launcher development project for the transportation of payloads up to 900 kg into a geostationary orbit, rocket engine developments and structural work, the integration of the second stage and testing of the propulsion systems of the second and third stages are being carried out. For 1979 and 1980, four test and qualification launchings are envisaged. In addition, the manufacturing of five launchers has been agreed: three for ESA satellites, one for a French satellite and one reserve launcher

5. Expected Results

In this paper, only a few outstanding aspects can be pointed out:

- Space science not only has a recognized role in basic research, but also provides the opportunity, for example in gamma and X-ray astronomy, to obtain fundamental new findings.
- In communications satellite technology, direct broadcasting is a new medium. There are, in principle, no technical difficulties for its implementation. Its future introduction will depend on decisions to be made by the bodies in the Federal Republic responsible for broadcasting.

- Since the operation of METEOSAT has exceeded the expectations of the German Meteorological Service, there will be no difficulty for the meteorological services in taking up operation of a meteorological satellite. In addition, it is to be expected that the European industry will be able to perform the tasks involved in the development of future meteorological satellites.

- The potential inherent in the new SPACE SHUTTLE/SPACELAB system has - above all in materials science - yielded productive ideas and thus already in the preliminary phase advances in this field. An assessment of potential further developments, such as space stations or space manufacturing, will not be possible until after the first space flights have taken place.

- Therefore an urgent task is the utilization of the new spacecraft that will be available in the near future, and not a continuous development for its own sake.

FIRST SPACELAB FLIGHT — A STATUS REPORT OF THE JOINT ESA/NASA MISSION

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ABSTRACT

The Space Shuttle is being produced in the United States under the auspices of NASA, whereas the Spacelab is being developed under the management of ESA, as Europe's contribution to the advanced Space Transportation System (STS).

The first operational flight of the Spacelab is scheduled for December 1980.

The primary objectives of this mission are to verify the performance of Spacelab, Spacelab/orbiter interfaces and Spacelab/payload interfaces, and to determine the Spacelab induced environments. The secondary objectives are to obtain valuable scientific and application data from a multidisciplinary payload and to demonstrate the broad capability of Spacelab for Space research.

The selection of the instruments has been conducted in close cooperation between NASA and ESA. The final First Spacelab Payload (FSLP) composition has been officially announced by NASA Associate Administrator and ESA Director General on February 15, 1977. In total 41 instruments have been selected, 17 by NASA and 24 by ESA, which cover 8 scientific and application research disciplines: material sciences, Space technology, life sciences, atmospheric physics, plasma physics, solar physics, Earth observation, and astronomy. These instruments will be accommodated within a long module plus single pallet configuration of Spacelab.

The mission will last about seven days. The orbit inclination will be 57° and the altitude 250 kilometers.

NASA has the overall responsibility for the operations of the mission, with mission management assigned to the Marshall Space Flight Center (MSFC). Within the European Space Agency (ESA), project responsibility for the European activities is assigned to Spacelab Payload Integration and Coordination in Europe (SPICE).

From February 1977, joint engineering activities included the evaluation of the instrument requirements, detailed payload accommodation studies, timeline analyses (preparation of the mission operation plan), definition of the flight application software requirements, and safety analyses. The preliminary design reviews of all instruments have been completed. The preliminary design of the total payload will

be completed in October 1978 and will result in detailed interface specification between the instruments and the STS/Spacelab.

The sequence of integration has been determined. The ground operations requirements are being established. The necessary facilities and support equipment, in NASA and in Europe, have been defined.

In the area of the flight operations, the preliminary design review of the P.O.C.C. (Payload Operations Control Center) will be held in November 1978. The payload operation philosophy is in process of development. The post-mission data handling requirements have been identified.

Two payload specialists, one from NASA and one from ESA, will be on-board to operate the instruments. Two candidates have been selected in NASA and three in ESA. The training phase has started on July 1, 1978.

OVERVIEW

Spacelab

The Spacelab development program is a joint undertaking of the National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). The purpose of Spacelab is to include in the space transportation system (STS) a payload carrier with maximum flexibility to accommodate multi-disciplinary payloads. The basic elements are the module and pallet. The module is a pressurized cylinder, which provides housing for the functional systems that support the payload, a crew work area, and rack space for mounting those experiments that must operate within a controlled pressurized environment. In addition to the module, pallets are provided for mounting experiments that operate outside the pressurized environment. Basic services such as power, thermal control, data management, airlock, etc., are included to provide support to the payload.

The first spacelab to be flown at the end of 1980 will be a joint NASA/ESA mission.

General Objectives of Spacelab Mission 1

According to article XI 3 (G) of the Memorandum of Understanding (MOU) between NASA and ESA for a cooperative programme concerning development, procurement and use of a Space Laboratory in conjunction with the Space Shuttle System (August 14, 1973), the experimental objectives of the first spacelab payload (FSLP) have been jointly planned on a cooperative basis.

- The primary objectives are to verify the Spacelab system and subsystem performance capabilities, verify Spacelab/Orbiter and Spacelab/experiments compatibility, and determine the spacelab induced environment.

- The secondary objectives are to obtain valuable scientific and application data from the NASA/ESA multi-disciplinary payload and to demonstrate to the user community the broad capability of Spacelab for scientific research.

Selection of Experiments

In 1976, an announcement of opportunity was released by NASA on the one hand and by ESA on the other hand. The very numerous proposals (172 NASA, 100 ESA) were submitted to a detailed scientific and technical evaluation. The final composition of the First Spacelab Payload (FSLP) has been officially announced by NASA Associate Administrator and ESA Director General on February 15, 1977. In total 41 facilities/ experiments have been selected, 17 by NASA and 24 by ESA. They cover 8 science and application disciplines: atmospheric physics, Earth observation, Astronomy, Solar Physics, Space Plasma Physics, Materials Science, Space Technology, and Life Science. Each Agency will provide approximately one-half of the payload.

Organization

NASA has the overall responsibility of the mission. Programme management responsibility has been assigned to the NASA Office of Space Science. The Associate Administrator, Office of Space Science, has assigned responsibility within his organization to the Solar Terrestrial Division. Mission management has been assigned to the Marshall Space Flight Center (MSFC) which has established the Spacelab Payload Project Office.

To manage the European activities, ESA has set-up the Spacelab Payload Integration and Coordination in Europe (SPICE), an organizational element of its Spacelab Programme Office. SPICE coordinates the development of the European experiments, performs the acceptance and the pre-integration of the European payload complement, trains the payload specialists on the payload portion, and provides the primary interface with the Mission 1 manager at MSFC.

Spacelab Configuration

The Spacelab configuration planned for the first mission will include the long module and one pallet, as shown in fig. 1. The mission will be for a duration of 7 days, with an orbit inclination to be selected between 28.5 to 57 degrees from the Eastern Test Range, and at an altitude of approximately 250 kilometers.

To satisfy the primary objective of verifying the Spacelab, a series of tests have been identified and designated as verification flight test (VFT) by the Spacelab Program. These tests are designed to check out Spacelab performance in a series of flight attitude. These attitudes are (a) nominal -- the orbiter payload bay pointing toward the earth, (b) cold case -- orbiter bay pointing to deep space, (c) hot case -- orbiter bay pointing at the sun. These and similar VFI tests did, in some manner, dictate the type experiments selected for this mission.

PAYLOAD COMPOSITION

The selected investigations are listed here below.

NASA Payload Complement

Experiment Number	Title	Principal Investigator
Atmospheric Physics:		
1 NS 001	An imaging spectrometer observatory	M. R. Torr, U. of Michigan, USA
1 NA 009[(x)]	Atmospheric trace molecule spectroscopy	C. B. Farmer, JPL, USA

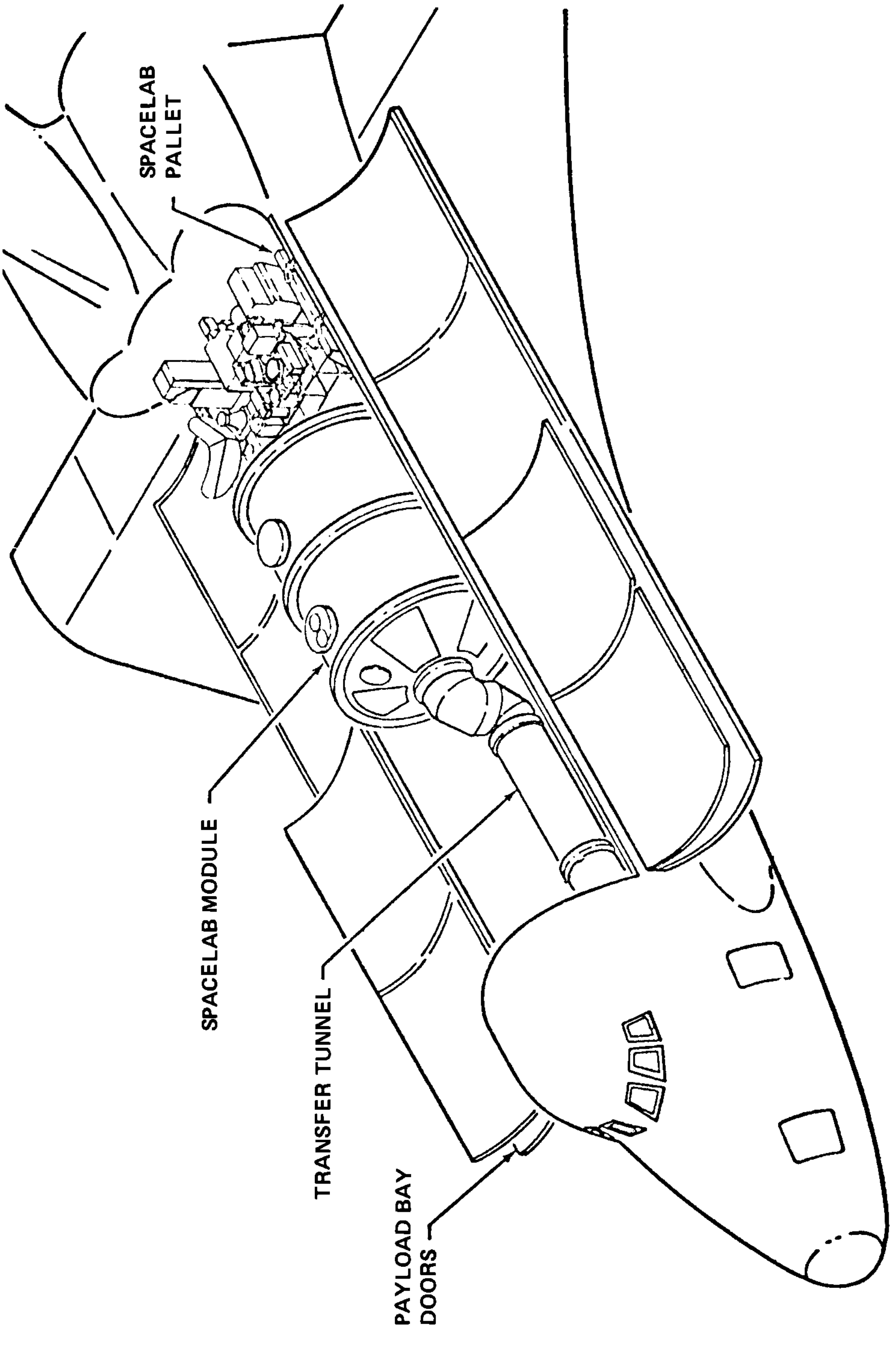


FIGURE 1. SPACELAB CONFIGURATION FOR MISSION 1

Experiment Number	Title	Principal Investigator
Astronomy:		
1 NS 005	Far ultraviolet astronomy using the FAUST telescope	C. S. Bower, Berkeley, USA
Solar Physics:		
1 NA 008	Active cavity Radiometer	R. C. Wilson, JPL, USA
Space Plasma Physics:		
1 NS 002	Space experiments with particle accelerators	T. Obayashi, U. of Tokyo, Japan
1 NS 003	Atmospheric emission photometric imaging	S. B. Mende, Lockheed Palo Alto Research Laboratories, USA
1 NS 004	Studies of the ionization of solar and galactic cosmic ray heavy nuclei	S. Biswas, Tat Institute of Fundamental Research, India
Space Technology:		
1 NT 001	Wetting, Spreading and operating characteristics of bearing lubricants in zero-gravity	C. H. T. Pan, Shaker Research, USA
1 NT 002	Geophysical fluid flow equipment	J. E. Hart, U. of Colorado, USA
Life Sciences:		
1 NS 100	Life Science minilab facility	NASA/JSC, USA
1 NS 102	Vestibular experiments	L. R. Young, MIT, USA
1 NS 104	Vestibulo-spinal reflex mechanisms	M. F. Reschker, NASA/JSC, USA
1 NS 103	The influence of space flight on erythrokinetics in man	S. L. Kimzey, NASA/JSC, USA
1 NS 105	Effect of prolonged weightlessness on humoral immune response of humans	E. W. Voss, U. of Illinois, USA
1 NS 101	Nutation of heliantus annuus in a micro-gravity environment	A. H. Brown, U. of Pennsylvania, USA
1 NS 006	Radiation environment mapping	E. V. Benton, U. of San Francisco, USA

European Payload Complement

Experiment Number	Title	Principal Investigator
Atmospheric Physics:		
1 ES 013	Grille spectrometer	M. Ackermann, IASB, Belgium A. Girard, ONERA, France
1 ES 014	Waves on OH emissive layers	M. Hersé, CNRS, France
1 ES 015(x)	Temperatures and winds measurement	G. Thuillier, CNRS, France
1 ES 017	Lyman alpha H & D	J-L. Bertaux, CNRS, France
Earth Observation:		
1 EA 033	Metric camera	
1 EA 034	Microwave Remove Sensing Experiment (MRSE)	Multi-users facilities developed by W. Germany
Astronomy:		
1 ES 022	Very wide field camera	G. Courtès, CNRS, France
1 ES 023	Spectroscopy in X-Ray astronomy	R. Andresen, ESA/ESTEC
Solar Physics:		
1 ES 016	Solar spectrum	G. Thuillier, CNRS, France
1ES 021	Solar constant	D. Crommelynck, IRM, Belgium
Space Plasma Physics:		
1 ES 020	Phenomena induced by charged particle beams	C. Beghin, CNRS-CNET, France
1 ES 019	Low energy electron flux	K. Wilhelm, Max Planck Inst. W. Germany
	DC magnetic field measurement	R. Schmidt, U. of Kiel, W. Germany
1 ES 024	Isotopic stack	R. Beaujean, U. of Kiel, W. Germany

(x) 1 NA 009 and 1 ES 015 not currently in Mission 1 accommodation study

Experiment Number	Title	Principal Investigator
Materials Science:		
1 ES 300	Material Science Double Rack (MSDR) and associated experiments	Multi-users facility developed by W. Germany. The experiments (36) are provided by 9 Member States.
Life Sciences:		
1 ES 200	Space Sled vestibular	ESA
1 ES 201	Sled experiments: "effects of rectilinear accelerations, optokinetics and caloric stimulations in space"	R. von Baumgarten, J. Gutenberg Universität, W. Germany
1 ES 026	Central venous pressure	O. H. Gauer, U. of Berlin, W. Germany
1 ES 032	Blood samples	- id -
1 ES 031	Lymphocyte proliferation	A. Cogoli, Switzerland
1 ES 028	Ballistocardiographic research	A. Scano, U. of Rome, Italy
1 ES 030	Personal miniature electrophysiological tape recorder	H. Green, Clinical Research Center, Great-Britain
1 ES 025	Mass discrimination	H. Ross, U. of Stirling, Great-Britain
1 ES 027	Advanced biostack experiment	H. Bücker, Institut für Flugmedizin, Abteilung Biophysik, W. Germany
1 ES 029	Microorganisms and biomolecules in space environment	G. Horneck, Institut für Flugmedizin, Abteilung Biophysik, W. Germany

(x) 1 ES 015 not currently in Mission 1 accommodation study

The atmospheric physics investigators will be performing studies of the Earth's environment through surveys of composition, temperature, and motion of the atmosphere. These investigations will employ a remote sensing technique to study the emissions or absorptions from the atmospheric gases to determine their sources, flow patterns, and decay mechanisms.

The Earth observations experiments will demonstrate advanced measuring systems (metric camera and microwave remote sensing experiment) which will be used on future Spacelab missions.

The investigations in Astronomy and Solar Physics will study astronomical sources of radiation in the ultraviolet and x-ray wavelengths, performing both surveys and detailed studies of specific objects.

The solar experiments will measure the energy output of the Sun using three different methods. These instruments will be cross-calibrated so that meaningful comparisons can be made. The goal of these experiments will be to determine quantitatively any variations in the solar energy output.

Experiments in the Space Plasma Physics group will study the plasma envelope which surrounds the Earth.

The Material Sciences and Technology investigations will demonstrate and use the capability of Spacelab as a technological development and test facility.

The Life Sciences investigations will be concerned with the effects of the space environment (microgravity and hard radiation) on human physiology and on the growth, development, and organization of biological systems. In this low-gravity environment a special category of vestibular function experiments will probe the interaction between man's vestibular system and brain, with a goal being the understanding of the causes of space motion sickness.

ACCOMMODATION STUDY

The accommodation analyses have now reached the preliminary design phase. The basis for this study has been the Spacelab Payload Accommodation Handbook and the Experiment Requirements Documents.

Configuration

The lay-out of the pallet mounted experiments was accomplished taking into account the following priority:

(1) physical placement of the verification flight instrument components;
(2) physical placement of experiments and support equipment (e.g., cold plates);
(3) achieving view angles;
(4) providing or preventing experiment interaction (e.g., adjacent metallic surfaces with different potential which cause reflected light);
(5) grouping European experiments together for pre-integration in Europe where this does not compromise the scientific results.

The pallet configuration can be shown in fig. 2. The majority of experiments require a secondary structure in order to provide the proper viewing angles. So the European experiments (except the Grille Spectrometer) are mounted on a modular pallet support structure which is being developed by ESA, while the US experiments are mounted on the NASA orthogrid platform.

The pallet is obviously crowded; however most experiment requirements have been met.

- The module lay-out has been defined in a manner to provide dedicated racks to the experiment developers where feasible: that is the case in particular for the Material Science Double Rack, the Life Science Minilab, the Verification Flight Instrument. In addition, NASA and European experimenters have been separated to the extent possible in order to allow the pre-integration in Europe. Figures 3 and 4 respectively describe the module racks port side and starboard side.

Mass Status

The following table indicates the current mass status.

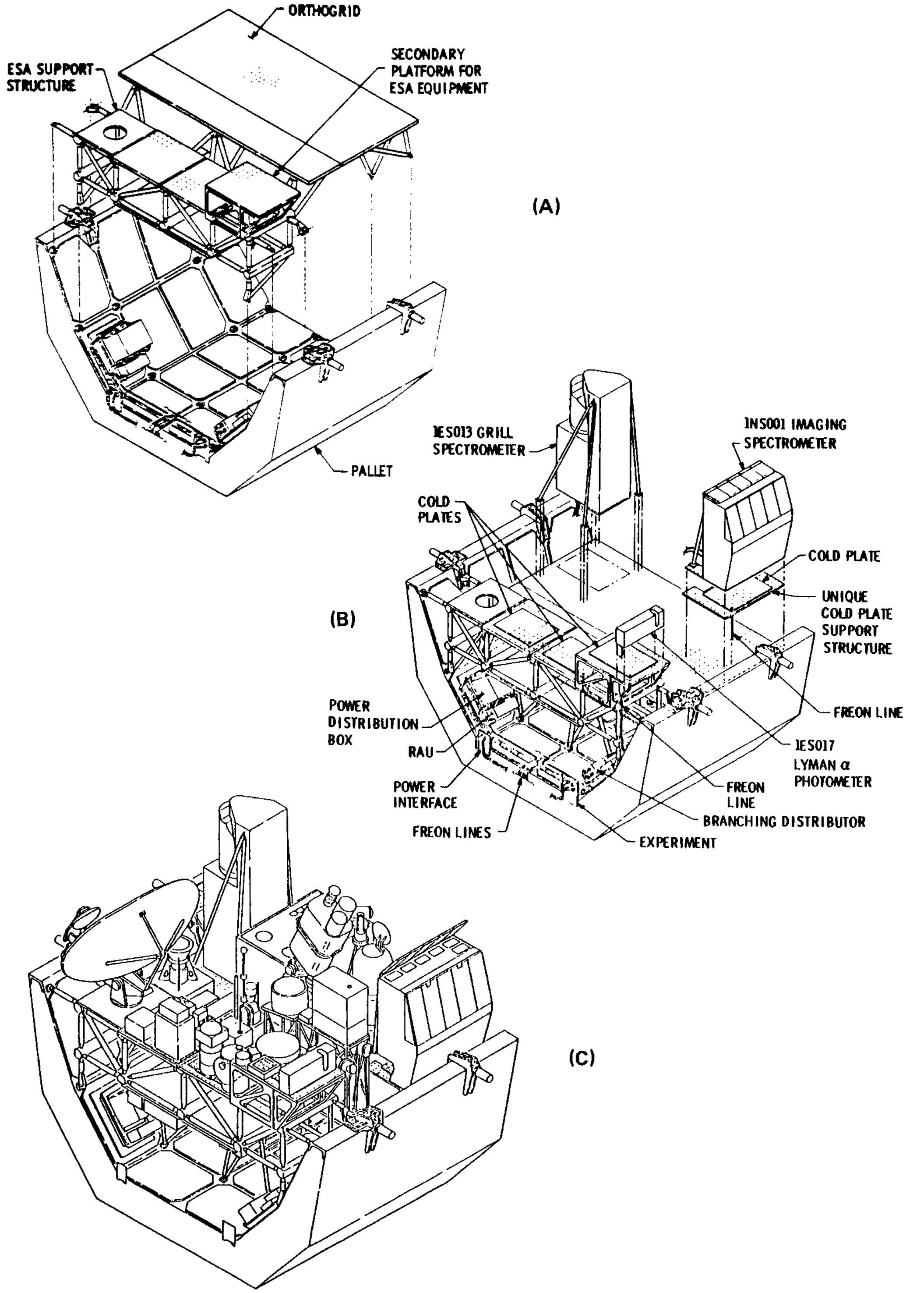
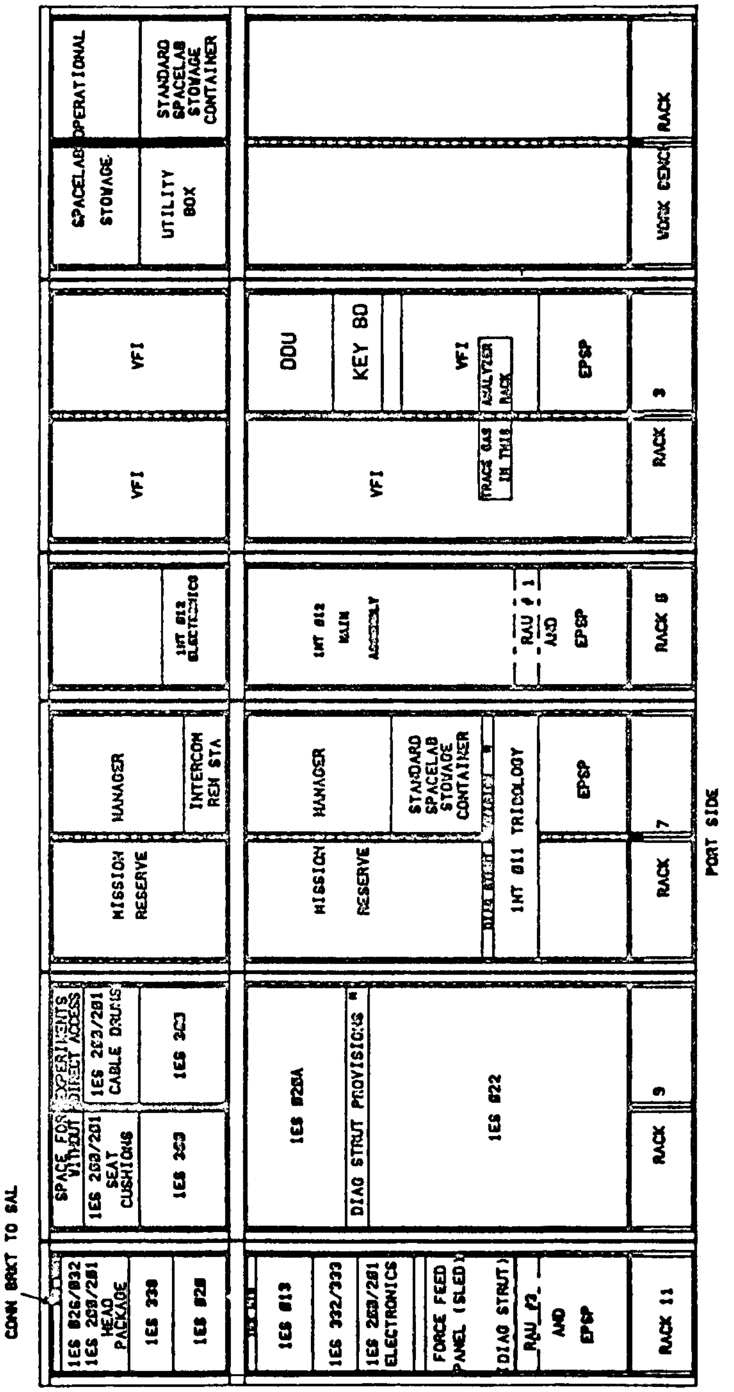


FIGURE 2 PALLET CONFIGURATION



NOTE: * TENTATIVE LOCATION OF DIAG STRUTS. EXACT LOCATION AND NUMBER OF STRUTS TO BE DETERMINED THROUGH ANALYSIS

FIGURE 3. MODULE LAY-OUT. PORT SIDE.

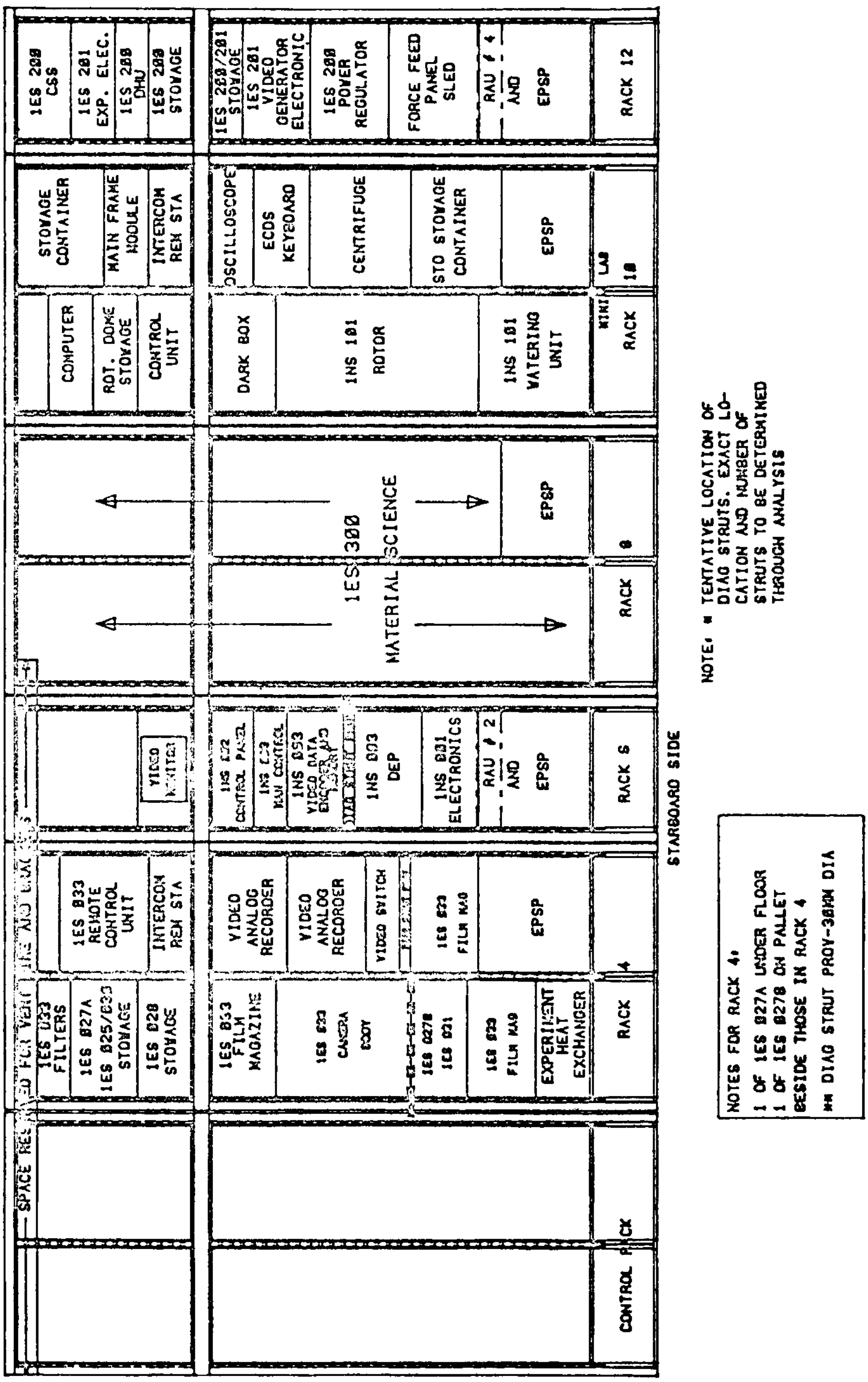


FIGURE 4. MODULE LAY-OUT. STARBOARD SIDE.

Items	Allocation (kg)	Current Status (kg)
• STS provided payload chargeable		
- Mission Dependent Equipment	1400	1400
- 2nd payload specialist and equipment	268	268
• Payload provided payload chargeable		
- NASA experiments	1392	1265
- European experiments	1392	1391
- Mission Peculiar Equipment	1198	1071
Total	5650	

The Mission Dependent Equipment (MDE) is defined as that hardware included in the Spacelab baseline which is required to support experiments (cold plates, Power Distribution Boxes, ...). The Mission Peculiar Equipment (MPE) is defined as that hardware which is not supplied by Spacelab or the experiment developer (pallet support structure, cabling and tubing support hardware, pallet freon lines, ...). The total mass allocation for the payload is 5650 kg including a limit mass for Mission Dependent Equipment of 1400 kg. A mass penalty of 268 kg for a second payload specialist and his equipment is also charged to the payload. The mass available for experiments and Mission Peculiar Equipment is therefore 3982 kg.

Timeline

A timeline has been established taking into account the different constraints: (1) mission profile (7 days from launch to landing, launch date: December 3, 1980); (2) spacelab verification flight test requirements have priority over experiment requirements; (3) orbital parameters; (4) crew composition; (5) inflight activities constraints (experiments operation phase, crew utilization guidelines, attitude requirements, no extra-vehicular activities, etc. ...).

The results of this timeline demonstrate the feasibility of the accommodation of all experiments within the resources limits (energy, crew time) and will be henceforth the basis for developing the Mission Operations Plan.

The following table show the operation time and energy presently allocated to each discipline.

Disciplines	Operation Time (hours)	Energy (kWh)
Atmospheric Physics	145.25	10.194
Earth observation	19.41	3.472
Astronomy	248.33	2.647
Solar Physics	53.86	1.369
Space Plasma Physics	594.01	14.854
Material Science	477.74	43.274
Technology	23.86	2.949

Disciplines	Operation Time (hours)	Energy (kWh)
Life Sciences	840.23	22.984
Total	2402.69	101.743

Experiment Interface Specifications

All the other aspects of the accommodation study are now completed at preliminary design level (the Integrated Payload Initial Design Evaluation takes place in the first week of October at ESA/SPICE) so that all engineering interface specifications of the experiments can be frozen: electrical power, electrical networks, CDMS (Command and Data Management System) resources allocation, mechanical environment, thermal environment.

Mission Peculiar Equipment

The design and development phase of the Mission Peculiar Equipment will start on both sides (NASA and ESA) shortly after the Integrated Payload Initial Design Evaluation.

FLIGHT OPERATIONS

Flight operations encompass all those activities both on-board and on-ground, from launch to landing of the space shuttle which are necessary to: accomplish the mission objectives, enhance scientific return, ensure crew and vehicle safety.

Crew Composition

The crew composition is as follows.

- Commander, who will be in overall command of the mission.

- Pilot, who will have the same functions as the commander and will act as second in command.

- Two mission specialists, who will be responsible to the Commander and the Pilot for the management of all verification flight test (VFT) operations, and for the management and coordination of all support systems provided by the Orbiter and Spacelab to the Spacelab payload.

- Two payload specialists, who will be responsible for the scientifc aspects of all on-board operations.

All crew members except the Payload Specialists will be career astronauts drawn from the Astronaut Corps at NASA's Johnson Space Centre (JSC, Houston). The Payload Specialists, one European and one American will be drawn from the Specialists already appointed by NASA (2 candidates) and ESA (3 candidates).

Ground Based Flight Support

The real time ground based Space Transportation System mission support is provided by the Mission Control Centre (MCC) and the Payload Operations Control Centre (POCC) both located at NASA's Johnson Space Centre.

The functions of the Mission Control Centre are: flight direction, launch and recovery control, flight plan development, vehicle systems monitoring and control, trajectory control, control of operational communications with the crew, control of data downlink and command uplink, Spacelab systems monitoring and control.

The functions of the Payload Operations Control Centre are: payload operations coordination, payload flight planning, provision of facilities to enable experimenters to monitor and in exceptional cases control their experiments, payload communications with the payload crew, control of voice/data to remote payload centres.

In summary the MCC supports operations of the Oribiter and the Spacelab systems, the POCC supports operations of the Spacelab payload.

In addition to transmission to the real time control centres, Orbiter, Spacelab and payload data is also routed to NASA's Goddard Space Flight Centre (GSFC) where it is recorded and formatted on computer compatible tapes for distribution to experimenters for futher scientific analysis. All the European data will be combined on a Master Data Record (MDR) and shipped to the European Post-Mission Data Handling Centre for subsequent dissemination into individual experimenter data records (ERD's).

Orbital Communication Links (fig. 5)

The primary data link from the orbiter to the various ground control centres is in the KU frequency band and has a maximum band width of 50 megabits per second. The data is transmitted from the orbiter via one or two geosynchronous Tracking and Data Relay Satellites (TDRS) to the TDRS system tracking station at White Sands, New Mexico. From White Sands, the data is relayed via an US domestic communications satellite Domsat to JSC and GSFC. The command-data uplink to Spacelab follows the reverse path and has a maximum bandwidth of 2 kilobits per second.

Operations of the Experiments

Basically, the operations of experiments can be classified in terms of four categories of control loop.

(1) Microprocessor control loop: the experiment is controlled by an internal microprocessor; no crew intervention. Time constant $\sim$ microseconds.

(2) CDMS software control loop: the experiment is controlled by the Spacelab CDMS (Control and Data Management System) and the software running in the Spacelab experiment computer. No crew intervention. Time constant $\sim$ 10 milliseconds.

(3) CDMS/Payload crew control loop: the decision making process is performed by the payload crew using the information provided to them on the Spacelab experiment computer display screen. The control action is communicated to the experiment by means of command(s) input via the spacelab experiment computer keyboard. Time constant $\sim$ minutes.

(4) POCC (Payload Operations Control Centre) control loop. The experiment data is received at the POCC. The experimenter in the POCC decides up the control action and communicates it to the experiment either via the payload crew, using the voice link, or in exceptional circumstances directly to the experiment via the CDMS. Time constant $\sim$ between minutes for single experiments and a few hours

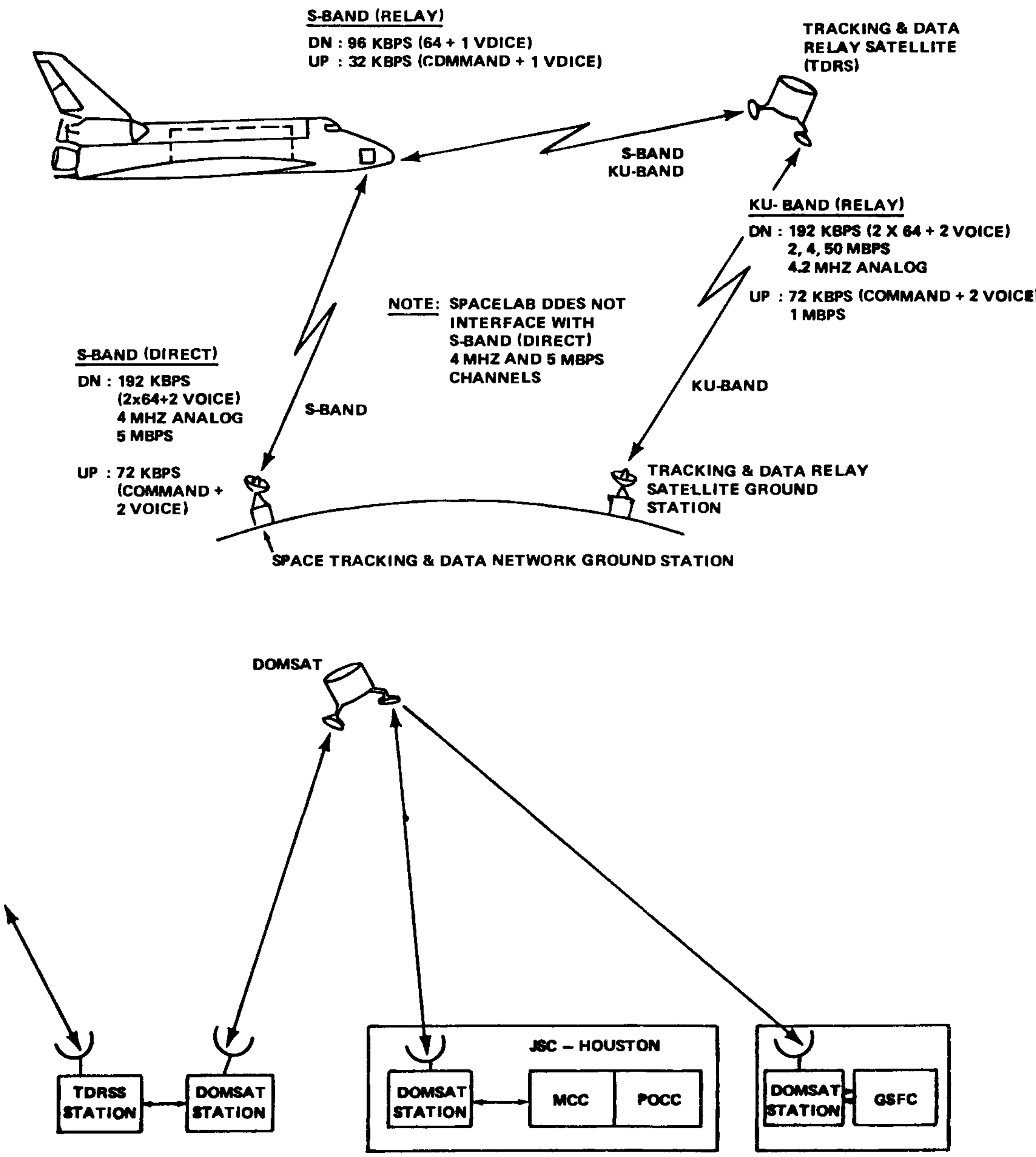


FIGURE 5. ORBITAL COMMUNICATION LINKS.

for high rate data experiments.

Presently, the detailed payload flight operations philosophy is defined and will be presented to the Investigators at the next session of the Investigators Working Group (Marseille, October 9-12, 1978).

The preliminary design review of the POCC will take place in November 1978 at NASA's Johnson Space Centre.

The post-mission data handling requirements are now in the definition phase.

GROUND OPERATIONS

Prior to centralized integration, each experiment developer has to deliver a flight qualified experiment package (to NASA/MSFC for the American experimenters, to ESA/SPICE for the European experimenters).

a) Integration at NASA

The overall physical integration cycle is depicted in fig. 6. It consists of integration levels IV, III, II, I.

- The level IV integration task will be performed at NASA/MSFC in two main phases. During the first phase, the NASA experiments and their associated mission peculiar equipment will be installed on the NASA pallet support structure and in the NASA designated module racks. In parallel, a similar phase will be performed in Europe for the European experiments (see paragraph b). The purpose of the second phase, "combined level IV", is to integrate the European and NASA payload complements in order to deliver to Kennedy Space Centre (KSC) an ESA-NASA payload fully operational, compatible, and therefore ready for the on-line level III-II integration.

- The level III-II integration activities consist in the verification of the interfaces between the Spacelab support segment and the experiment segment, experiment racks and pallet. They will take place at KSC in the Operations and Check-out (O&C) building.

- The level I integration task consists of verifying the interfaces between the Spacelab vehicle and the Orbiter. It will be performed at the launch complex of KSC: Orbiter Processing Facility (OPF) and pad.

b) Pre-integration in Europe

ESA/SPICE assumes the responsibility for pre-integration of the European experiments. It is presently planned to perform the following activities at the Europe integration centre:

(1) verification of the interfaces compatibility between the individual European experiments (and their associated mission peculiar equipment) with the Spacelab flight hardware; (2) verification of the interfaces compatibility of the whole European payload complement (hardware and software) prior to shipment to NASA/MSFC for the combined level IV phase.

All Ground integration requirements have been defined and are now under final review in collaboration with the experimenters.

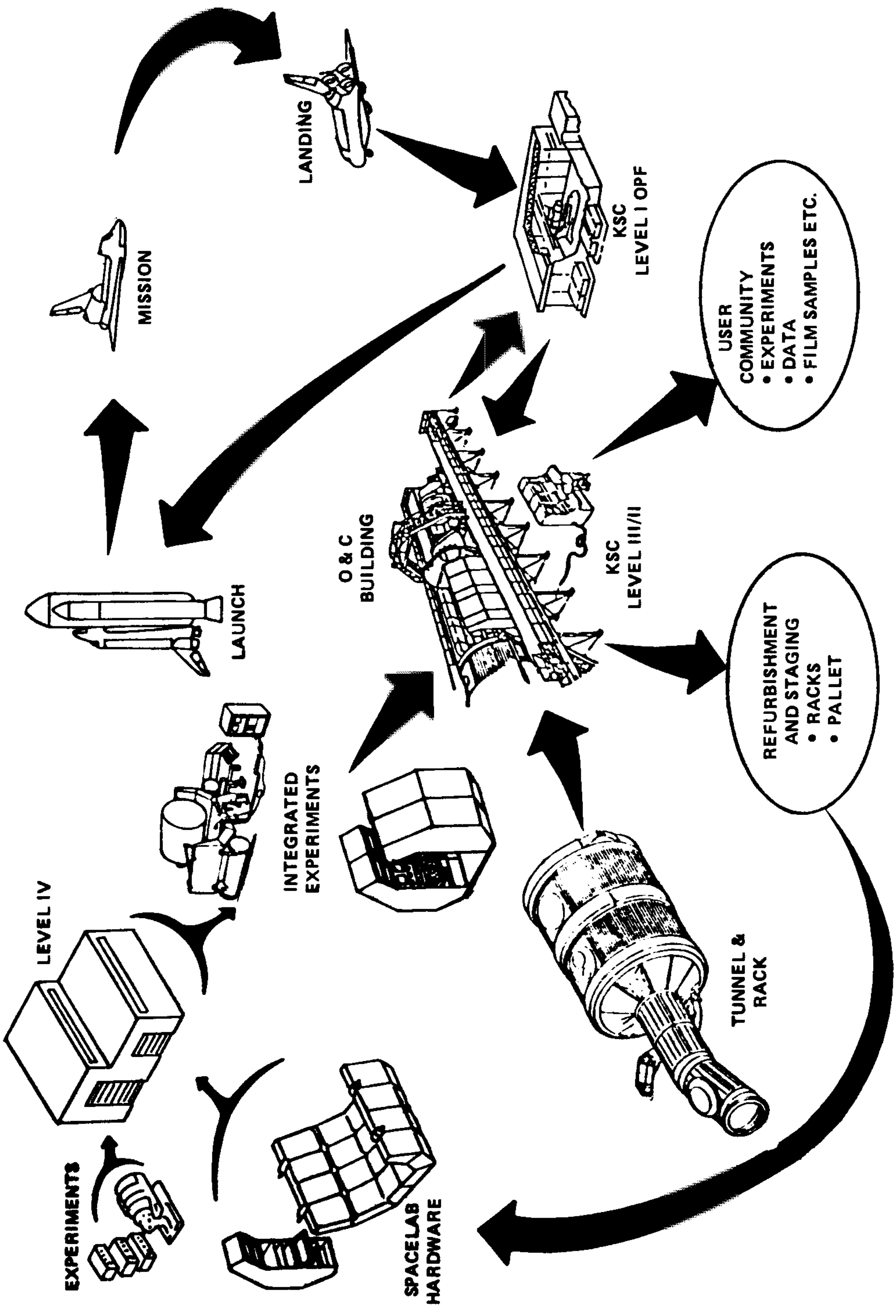


FIGURE 6. INTEGRATION CYCLE AT NASA

The equipment and facilities which are necessary to perform these integration tasks are identified.

SAFETY

The STS (Space Transportation System) safety policy requires that the basic payload design assures the elimination or control of any payload hazard. Safe payload operations with a minimum dependence on the Orbiter and crew for safing actions is an STS goal. The safety implementation flow consists of five phases: (1) identify the hazards; (2) define the requirements of implementation and the verification approach; (3) assess the requirements implementation and verify it by analysis and (or) tests; (4) review the safety compliance data prior to commence the level IV integration of the experiments; (5) analyse and assess the integrated payload safety (flight readiness review). The first phase has been performed in 1977 and the second phase is presently in process of completion.

PAYLOAD SPECIALISTS TRAINING

In total, five payload specialists have been pre-selected for Spacelab Mission 1: two by NASA and three by ESA. Their names have been officially announced at the end of the first half of 1978. Finally two payload specialists will fly: one American, one European.

The payload specialists are submitted to two categories of training: mission dependent and mission independent.

- The most important part of the training is mission dependent, i.e. related to the operations of the payload experiments. The crew training on the NASA part is conducted by NASA's Marshall Space Flight Centre, on the European part of the payload it is conducted by ESA/SPICE. It consists of the following: familiarization with the scientific objectives and the hardware of each experiment, familiarization with the man-machine interface on experiment level, system level training, active participation in payload integration and check-out activities. A mission simulation will be performed in the final months prior to the launch.

- In addition to the payload operations, all flight personnel must possess certain fundamental skills and that is precisely the purpose of the mission independent training. The latter is carried-out by NASA's Johnson Space Centre. It mainly consists of a familiarization with: the Space Transportation System, the Orbiter and Spacelab systems, the crew's living and working environment on-board, the pre and post-launch operations, the safety and emergency procedures, the survival operations and medical aspects.

The phase of familiarization with the scientific objectives has commenced on July 1, 1978 and is proceeding in the most satisfactory manner.

SCHEDULE

The major milestones of Spacelab Mission 1 current schedule are the following:

February 15, 1977	:	Payload selection
October 1977	:	Integrated Payload Requirements Review
October 1978	:	Integrated Payload Initial Design Evaluation

March 1979	:	Integrated Payload Flight Design Operations Review
October 1979	:	Start pre-integration in Europe
March 1980	:	Start combined level IV at MSFC
June 1980	:	Start level III-II-I at KSC
December 3, 1980	:	Launch

THE VOYAGER PROGRAM*

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ABSTRACT

On August 20 and September 5, 1977, Voyager spacecraft were launched on voyages of exploration to the outer planets of our solar system. Each spacecraft will fly close to Jupiter and Saturn, and one of the spacecraft may fly to Uranus. The spacecraft carry eleven scientific instruments, which will yield a wide range of scientific information about Jupiter, Saturn, their satellites, and the environment around these giant planets.

This paper describes the Voyager mission, its scientific experiments and instruments, and the spacecraft. Also included is a summary of the events which have occurred thus far in the flight of these spacecraft.

INTRODUCTION

Two spacecraft, Voyagers 1 and 2, were launched from Cape Canaveral, Florida, by Titan IIIE/Centaur D-IT vehicles on flyby missions to Jupiter and Saturn and their satellites. The Voyager Project is managed by the Jet Propulsion Laboratory, California Institute of Technology, for the National Aeronautics and Space Administration.

The first of the two spacecraft was launched on August 20, 1977, targeted for a July 1979 arrival at Jupiter. It was followed on September 5, 1977, by the second launch. The second craft, designated Voyager 1, will arrive at Jupiter 4 months ahead of the first, beginning its early observation phase in January 1979. Therefore, the first launched craft, because it will arrive at the target planet last, is designated Voyager 2. These launches marked the beginning of an era in American deep space exploration as, with the advent of the Space Shuttle, future spacecraft will be launched by the Shuttle Orbiter.

During the planned 8-1/2 years of the mission, Voyager will gather information on about 15 bodies and interplanetary space. Although the primary targets are the planets Jupiter and Saturn, their satellites are also of interest, and may provide insight into the formation and evolution of the solar system. Thus, the Voyager mission plan includes the study of at least 11 of these satellites. An option exists to use the gravity of Saturn to send Voyager 2 to Uranus; arriving in 1986,

*The research described in this paper was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100.

Voyager would provide the first close look at the recently discovered rings of Uranus.

The Voyager spacecraft will continue their flight through and out of the solar system. Each spacecraft is carrying a copper-plated, aluminum-jacketed "Sounds of Earth" recording. Included with the 12-inch disc are a cartridge and needle, and instructions on how to play the record. In addition to greetings in 60 human languages, a sound essay on the evolution of our planet, and a selection of music, the record includes data that can be reconstructed to form 115 photographs and diagrams, 20 of which are in color.

SCIENCE

Jupiter and Saturn are the two largest planets in the solar system. As compared to Earth, Jupiter is five times farther from the sun and more than 11 times larger in diameter. Jupiter has 14 known satellites, varying from the four planet-sized Galilean satellites to the "asteroid" class of irregular satellites.

Saturn is ten times farther from the sun and more than nine times larger in diameter than Earth. Saturn has ten known satellites -- mostly small except for Titan, which is larger than the planet Mercury and is known to have an atmosphere more dense than that of Mars. Saturn also has the well-known rings, thought to consist of ice or ice-coated particles that vary from microscopic to fist-sized or larger. Both Jupiter and Saturn consist primarily of hydrogen and helium. They have no solid surface, except at the tremendous internal pressure and temperature wherein a metallic form of hydrogen may exist. Jupiter has an intense magnetic field and trapped radiation, more intense and of significantly different structure than that of Earth.

Altogether, the 11 scientific experiments onboard Voyager will provide data to advance significantly our knowledge of the surface characteristics, atmospheric composition, ionospheres, masses, sizes, and surrounding fields of Jupiter, Saturn, and many of their satellites. The Voyager scientific instruments include some of the most advanced instruments of their kind ever flown. Both spacecraft carry medium- and high-resolution (narrow-angle) television cameras. The narrow-angle camera will provide the best photographs yet taken of Jupiter, with such resolution that it will take 40 camera frames to record the Great Red Spct (40,000 kilometers by 13,000 kilometers). It will also be used for extremely precise navigation during planetary approach by allowing the spacecraft trajectory to be calculated from pictures of planetary satellites against a star background. The spacecraft will also carry spectrometers and photometers for atmospheric and other analyses, a radio receiver to measure planetary radio emissions, sensors to measure fields and particles, and a high-precision Earth-to-spacecraft radio link for communication, navigation, and scientific investigations. The experiments, instruments used, Principal Investigators, and objectives are given in Table 1.

MISSION PLAN

Voyager 1 is on a faster trajectory than Voyager 2 and will begin its observation activities in January 1979, more than 16 months after launch, some 60 days and about 60 million kilometers from Jupiter. Its closest approach will be in March 1979, at a distance of 286,000 kilometers from the visible surface of the planet. The Voyager 2 closest approach will be in July 1979 at a distance of 645,000 kilometers. At Jupiter, Voyager 1 will be 690 million kilometers from Earth; radio

TABLE 1 Summary of Voyager Science Experiments

Experiment (Principal Investigator)	Instrument	Primary Experiment Objectives
Imaging Science (B. A. Smith, Arizona)	Wide- and narrow-angle TV cameras	Imaging of planets and satellites at resolutions and phase angles not possible from Earth. Atmospheric dynamics and surface structure
Infrared Radiation (R. A. Hanel, GSFC)	Infrared interferometer spectrometer and radiometer	Energy balance of planets. Atmospheric composition and temperature fields. Composition and physical characteristics of satellite surfaces and Saturn rings
Photopolarimetry (C. F. Lillie, Colorado)	Photopolarimeter	Methane, ammonia, molecular hydrogen, and aerosols in atmospheres. Composition and physical characteristics of satellite surfaces and Saturn rings
Ultraviolet Spectroscopy (A. L. Broadfoot, KPNO)	Ultraviolet spectrometer	Atmospheric composition including the hydrogen-to-helium ratio. Thermal structure of upper atmospheres. Hydrogen and helium in interplanetary and interstellar space
Radio Science (V. R. Eshleman, Stanford)	Uses telecommunication radio subsystem	Physical properties of atmospheres and ionospheres, planet and satellite masses, densities, and gravity fields. Structure of Saturn rings
Cosmic Ray Particles (R. E. Vogt, Caltech)	Cosmic-ray telescopes	Energy spectra and isotopic composition of cosmic-ray particles and trapped planetary energetic particles
Low-Energy Charged Particles (S. M. Krimigis, JHU/APL)	Low-energy charged-particle detectors	Energy spectra and isotropic composition of low-energy charged particles in planetary magnetospheres and interplanetary space
Magnetic Fields (N. F. Ness, GSFC)	Magnetometer	Planetary and interplanetary fields
Planetary Radio Astronomy (J. W. Warwick, Colorado)	Uses dipole antenna and receiver	Planetary radio emissions and plasma resonances in planetary magnetospheres
Plasma Particles (H. S. Bridge, MIT)	Plasma subsystem	Energy spectra of solar-wind electrons and ions, low-energy charged particles in planetary environments, and ionized interstellar hydrogen
Plasma Waves (F. L. Scarf, TRW)	Plasma wave subsystem	Electron densities and local plasma wave/charged-particle interactions in planetary magnetospheres

signals between Earth and the spacecraft will take 38 minutes each way. Figure 1 shows the Earth-to-Jupiter phases for both spacecraft. Dates and times given are for Voyager 1.

In early February 1979, a 4-day "movie" sequence will record ten revolutions of the planet, photographing the entire disk. After the "movie" phase, the far-encounter phases will provide unique observation opportunities for the four largest satellites (Io, Europa, Ganymede, and Callisto) and a crossing of the bow shock of the Jovian magnetosphere, of special interest to all fields and particles instruments.

For Voyager 1, near encounter will be a 39-hour period packed with close-range measurements. After closest approach, three Jovian satellites will also receive close-range scrutiny by the various instruments. Passing from the visible surface

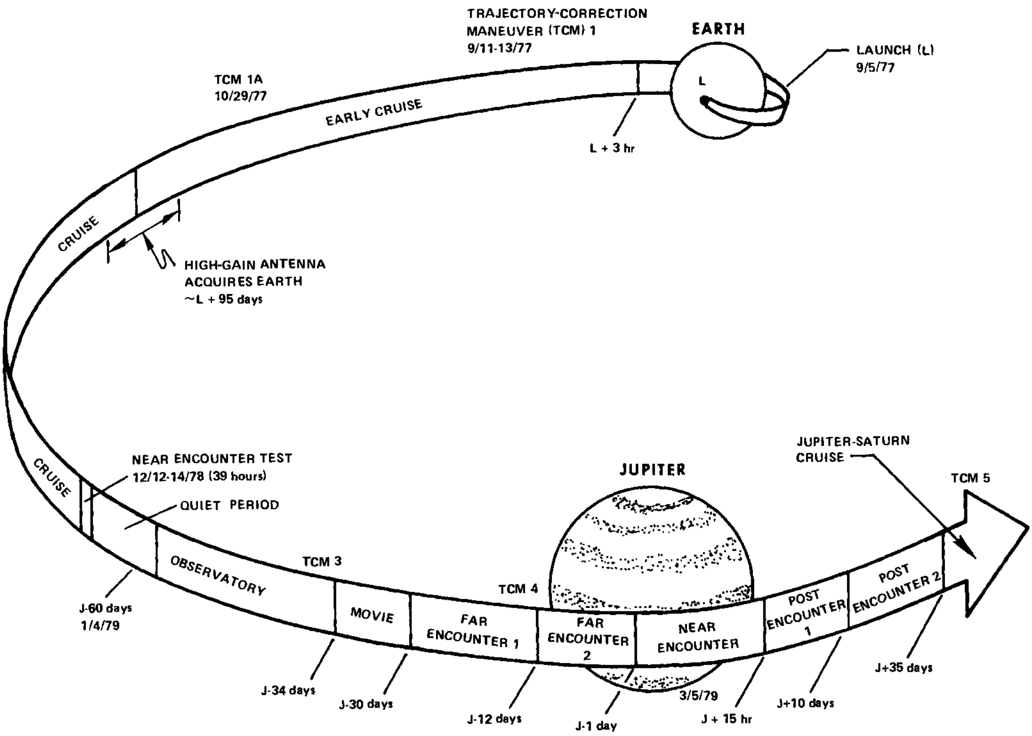

Fig. 1. Planned Earth-to-Jupiter phases for Voyager 1

of Jupiter, Voyager 1 will then pass around the back side of the planet, going out of view of Earth for about 2 hours.

The cameras are scheduled to take hundreds of color images of the planet; these images are recorded on the spacecraft's tape recorder and transmitted to Earth daily. Ultraviolet, infrared, and polarimetry observations are also made. Magnetic-field, plasma-wave, and radio-astronomy measurements are taken, and charged-particle sensors observe solar phenomena.

Observations will continue during post-encounter phases. Using the gravity of Jupiter to "slingshot" it on its way, Voyager 1 will continue onward toward the ringed planet Saturn, about 800 million kilometers and 19 months distant.

Voyager 2 will follow the same profile except that it will be farther from the planet Jupiter. It will follow modified far-encounter, near-encounter, and post-encounter sequences to accommodate command-transmission constraints due to spacecraft receiver problems.

Voyager 1 will enter Saturn's domain in October 1980 and will make scientific observations similar to those made at Jupiter. Of special interest will be the well-known rings of Saturn. Its satellites are also of considerable scientific interest.

In June 1981, Voyager 2 will enter Saturn's domain. It will survey the same satellites and rings as Voyager 1, but from different distances. If all goes well and if primary Saturn science goals have been met by Voyager 1, Voyager 2 may use the gravity of Saturn to boost itself toward Uranus, providing the first observations of that planet by a spacecraft. It would arrive at Uranus in January 1986, more than 4 years beyond Saturn.

The Voyager trajectories are planned around eight trajectory-correction maneuvers (TCM) with each spacecraft between launch and Saturn encounter. Mission requirements call for extremely accurate maneuvers to reach the desired zones at Jupiter, Saturn, and the target satellites. The total velocity increment capability for each spacecraft is about 170 meters per second.

To achieve the desired maneuver and flyby accuracies for a multi-planet/satellite encounter mission, very precise navigation is required. Dual-frequency ranging will be conducted during planetary operation phases of the mission and during cruise when the Deep Space Network's 64-meter antennas are tracking. Special three-way dual-frequency ranging cycles will be conducted while two ground stations on different continents are tracking the spacecraft.

SPACECRAFT DESCRIPTION

Voyagers 1 and 2 (Fig. 2), designed by the Jet Propulsion Laboratory, are Mariner-class, three-axis, attitude-stabilized spacecraft whose key features include radioisotope power sources, subsystem redundancy, onboard computer control and fault detection, a 3.7-meter antenna with S- and X-band telecommunications (the largest antenna ever flown on a planetary mission), accurate scan-platform pointing for remote sensing, and instruments for conducting the 11 scientific investigations.

Each spacecraft consists of a Mission Module (the planetary vehicle, referred to here as spacecraft) and a Propulsion Module, which injects the spacecraft into the Jupiter transfer trajectory. The spacecraft mass, after injection, is 825 kilograms, including a 105-kilogram science instrument payload. The Propulsion Module mass is 1207 kilograms.

The basic spacecraft structure is a ten-sided aluminum framework with ten electronics compartments. The high-gain antenna, supported above the structure by tubular trusswork, has an aluminum honeycomb core, and is surfaced on both sides by graphite/epoxy laminate skins. Temperature control assemblies are fastened to the outer faces of the electronics compartments.

The scientific instruments required to view the planets and their satellites are mounted on a two-axis scan platform at the end of the science boom for precise pointing. Other body-fixed and boom-mounted instruments are aligned for accurate interpretation of their measurements.

Data storage capacity on the spacecraft is about 536 million bits of information -- approximately the equivalent of 100 full-resolution pictures.

As a result of the severe Jupiter radiation environment measured by Pioneers 10 and 11, appropriate radiation hardening, parts selection, circuit design evaluation, and shielding actions were taken to strengthen the Voyager resistance to radiation effects. Also, because of the great distance of Saturn from the sun, solar cells

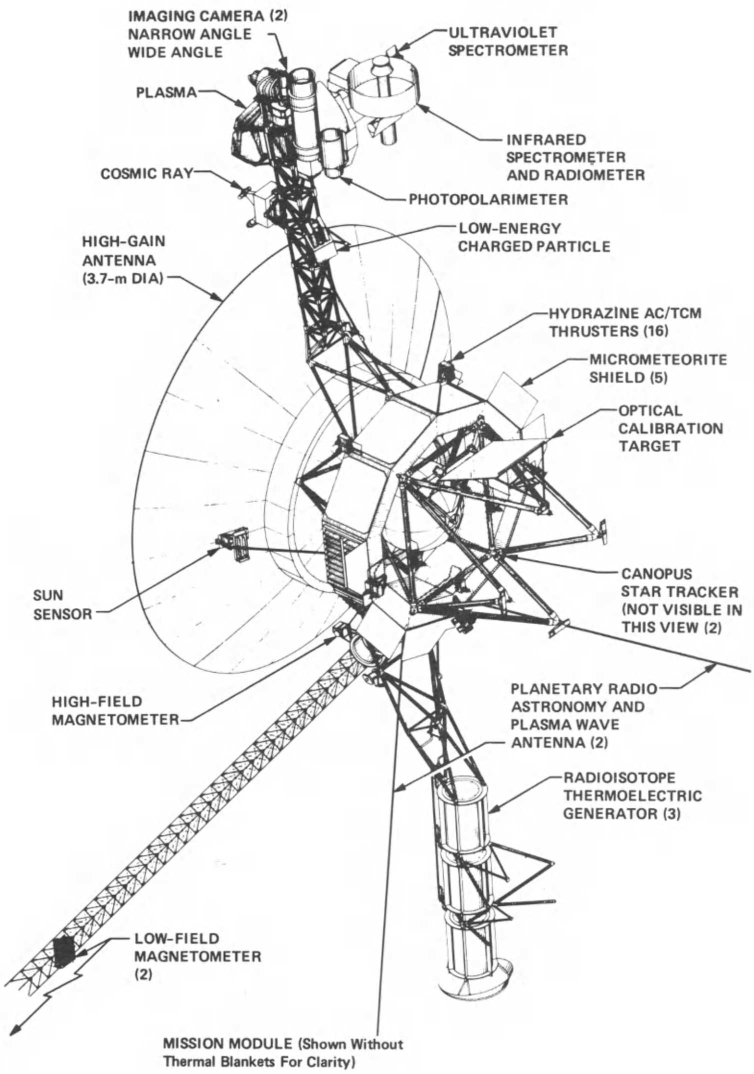

Fig. 2. Voyager spacecraft configuration.

have been replaced by plutonium oxide fueled radioisotope thermoelectric generators (RTG) that convert 7200 Watts of heat to the nearly 400 Watts of electrical power needed during Saturn encounter. Each RTG unit, contained in a beryllium outer case, has a mass of 39 kilograms.

The basic structure of the Propulsion Module is a 43.5-kilogram aluminum semi-monocoque shell. The cylinder is suspended below the spacecraft. The hollow of the structure contains the solid rocket motor that delivers the final powered stage of flight. The rocket, having a mass of 1123 kilograms, develops an average 15,300 pounds of thrust during its 43-second burn duration.

Eight hydrazine engines are mounted as outriggers from the structure to provide attitude control during the solid motor burn and before Propulsion Module separation. Hydrazine fuel is supplied from the spacecraft.

Steel alloy/gold foil plume deflectors extend from the Propulsion Module structure to shield the RTGs and scan platform from rocket exhaust during engine firing.

TRACKING

The Deep Space Network (DSN) is responsible for tracking and communications with the Voyagers. Each DSN location (Goldstone, California; Madrid, Spain; and Canberra, Australia) has one 64-meter-diameter and two 26-meter-diameter antennas. These three multi-station complexes are strategically located at widely separated longitudes so that the spacecraft is always in view.

Data transmitted from the spacecraft to Earth are sent at S-band (2295 megaHertz) and X-band (8400 megaHertz) radio frequencies. Commands and ranging signals transmitted from Earth to the spacecraft are sent at S-band (2113 megaHertz) only.

FLIGHT EVENTS

Voyager 2. Voyager 2 was launched at 10:29:45 a.m. EDT on August 20, 1977. The launch vehicle performed flawlessly, and spacecraft separation occurred normally. Sun acquisition was achieved at 04:00:30 p.m. EDT, stabilizing the spacecraft on two axes, with the third axis on roll inertial command. On August 24, Voyager 2 acquired the star Canopus, stabilizing the spacecraft on three axes in celestial lock.

Shortly after launch it appeared that the science boom had not deployed fully. An attempt was made, by simultaneously pitching the spacecraft and jettisoning the dust cover on the infrared interferometer spectrometer (IRIS) by means of small explosive devices, to provide enough of a jolt to fully open the boom hinge and allow the locking pin to drop into position. Later, measurements made by the plasma instrument and by the TV camera indicated that the boom had essentially fully deployed, and the condition of the boom now appears to be normal.

In early September, the photopolarimeter was turned off because the analyzer wheel was sticking. It was determined that the sticking was due to a failure in the multiplexer chip which selects the wheel position. It was not until late February that the problem was resolved and the filter wheel was freed, and the operation of this instrument now appears normal.

On October 11, a trajectory-correction maneuver (TCM) was performed, adjusting the aiming point for Ganymede, a Jovian satellite, to within a few percent. Studies during the following 2 months indicated that there was sufficient fuel to support the 1986 Uranus encounter. The second TCM was performed on May 3, 1978.

On April 5 the main radio receiver failed, apparently due to a failure in the power supply. The spacecraft automatically switched to the backup or redundant receiver, and, while this receiver functioned, its performance was not normal. Analysis indicated that a capacitor in the frequency tracking loop had shorted, and that the range of frequencies over which the receiver would track was greatly reduced. Fortunately, the range was wide enough (± 100 Hertz) that communication could be established by continuously tuning the frequency of the ground transmitter, and the spacecraft could be successfully commanded.

Voyager 1. Voyager 1 was launched at 08:56:01 a.m. EDT on September 5, 1977, 16 days after Voyager 2. Sun acquisition was achieved about 2 hours into the flight, followed several hours later by Canopus acquisition.

The final Jupiter trajectory insertion boost of the Propulsion Module provided a bonus by requiring less than 2 kilograms of hydrazine for attitude control from an allotted 14 kilograms. This fuel savings also occurred on Voyager 2, giving both spacecraft an extra measure of fuel for subsequent attitude control or trajectory-correction purposes.

Voyager 1 executed its first TCM in mid-September. The maneuver appeared normal, but orbit determination revealed a 20% decrement in the velocity increment. Further analysis indicated that this was caused by a greater than expected impingement of the thrusters' exhaust on the structure. This effect was also observed in October when its second TCM was performed.

During the September 13 sequence, the scan platform was pointed at deep space and the scientific instruments were turned on. On September 18, Voyager 1 television cameras recorded images showing Earth and its moon together in a single frame (Fig. 3). This picture, taken from a distance of 11.66 million kilometers, is the first picture to show the entire Earth-moon system.

Voyager 1's second TCM, to "clean up" small flight path inaccuracies, was executed on October 29, compensating for the undervelocity in the first maneuver.

During sequence verification tests on December 14 and 15, observations showed that the filter wheels of the cameras were not stepping properly, and the cameras were turned off. In February, diagnostic tests identified a bad memory location in the Flight Data Subsystem computer. A spare memory location was used, enabling the cameras to step normally.

On February 23, the scan platform slowed and stopped during an azimuth test. A sequence of slews moved the platform away from the area in which it had stalled, ending at the most favorable position possible in case it stalled again. Subsequent tests and analyses strongly suggested that a small piece of plastic material had become lodged in the gear train between the motor and the actuating shaft. Because the plastic known to be in this region is soft, it was concluded that the best course of action was to drive the gears through the obstruction. This was done, and no further abnormalities have been detected.

As of this writing, both Voyager spacecraft are fully functional. Although, primarily in the period immediately following launch, some anomalies occurred, the reserves of capability have enabled both spacecraft to recover fully. Both Voyagers 1 and 2 are capable of obtaining the desired scientific data and of accomplishing the intended scientific mission.

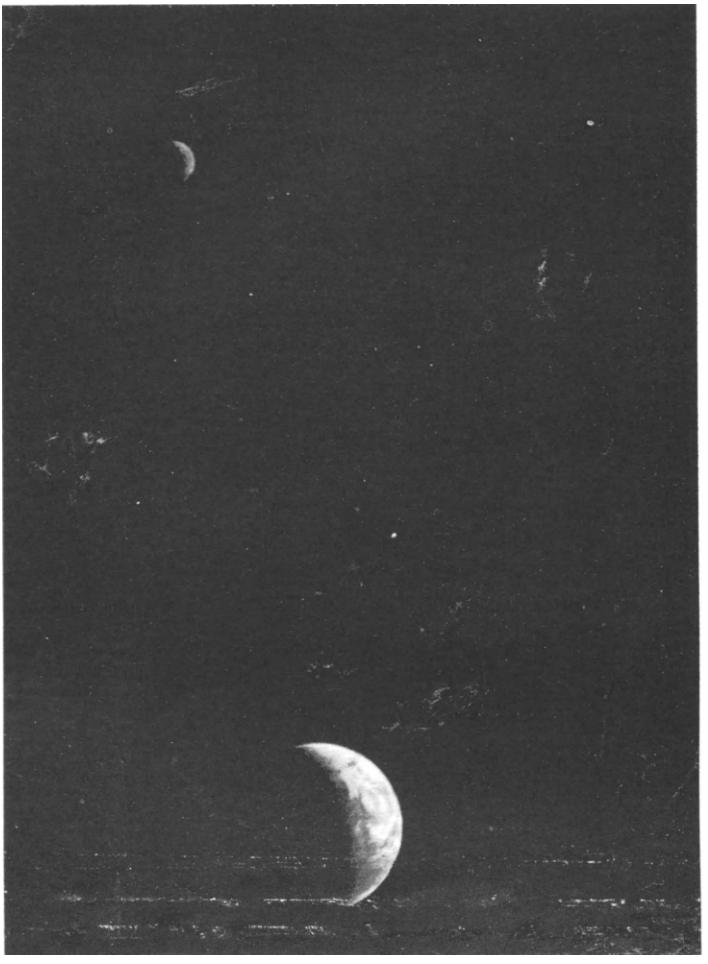

Fig. 3. Picture of Earth and its moon recorded by Voyager 1 on September 18, 1977.

THE INTERNATIONAL SOLAR POLAR MISSION

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ABSTRACT

The Solar Polar, or Out of Ecliptic, Mission is a two spacecraft project to be conducted jointly by NASA and ESA. The primary objectives are to investigate as a function of solar latitude the properties of the solar corona, the heliospheric magnetic field, solar and non-solar cosmic rays and the interstellar/interplanetary neutral gas and dust. In order to perform these measurements the two spacecraft will be injected into heliocentric orbits approximately at right angles to the ecliptic plane. In this way the two spacecraft will pass nearly over the poles of the sun.

The method by which these orbits will be obtained is to utilise the large gravitational field of Jupiter to deflect each spacecraft out of the ecliptic plane. Following launch using the Shuttle and the Inertial Upper Stage rocket the two spacecraft are injected into interplanetary trajectories and targeted towards Jupiter so as to pass slightly North and South of the Jovian equator. The gravitational field of the planet then causes them to go into heliocentric orbits of the desired inclination to the ecliptic, one spacecraft northwards and the other southwards. After passing over the poles of the sun, the two spacecraft cross the ecliptic plane and pass over the other pole. The complete mission time, from launch to the second solar polar passage is approximately five years.

The paper to be presented describes the scientific mission, the experimental payloads of the two spacecraft and gives an outline of a possible configuration for the European spacecraft. It also deals with the management of the joint ESA/NASA project and the projected schedules for the project development from the present time to the launch in February 1983.

KEYWORDS

Spacecraft description
Solar Polar mission
Polar exploration of sun
Out of ecliptic
Mission survey
International cooperation
Solar corona
Solar wind
Solar cosmic rays
Interstellar matter
Heliospheric magnetic field

PROJECT HISTORY

Although the International Solar Polar Mission (ISPM) is relatively recent in that it is only just entering its industrial phase, it has in fact been under consideration for a considerable time. As is normal for studies of this duration it has also undergone a number of name changes and it is desirable to clarify these before entering into the main descriptions of the mission.

Although discussions on the possibility of an out-of-ecliptic mission have been taking place since the late 1950's the story may be said to have begun in earnest in 1971/72 when ESRO, the predecessor of ESA, performed an in house study entitled "Out of the Ecliptic Plane Mission". During the years 1973 and 1974 this was studied jointly with NASA for an "Out of Ecliptic and Solar Stereoscopic Mission". In 1976, still in cooperation with NASA, it took form as the "Out of Ecliptic Mission" and last year NASA proposed that it should be called the "International Solar Polar Mission". A variety of modes of cooperation have been considered and the final one selected is remarkably close to that which led to the successful launch in October 1977 of the International Sun Earth Explorers 1 and 2. There will be two spacecraft, one designed and integrated under JPL supervision, acting for NASA, the other designed and integrated in Europe under the supervision of ESA. NASA will be responsible for providing the launch in February 1983 using the Space Transportation System. This for ISPM comprises the Shuttle plus the three stage IUS (Inertial Upper Stage) which will have been used for the first time one year earlier for the Galileo Mission.

ESA has completely authorised the programme and the Invitation to Tender for the Industrial Study Phase is currently being considered by potential contractors who must submit their quotations by 27 October of this year. At the time of writing (September 1978) Congressional approval of the project has been received and Presidential signature is momentarily awaited. JPL are currently conducting competitive definition studies for their spacecraft. For these reasons it is not possible to give details of the possible flight configurations of the spacecraft or details of the subsystems which will actually be flown. The descriptions which follow are those resulting from feasibility studies and in-house studies at ESA and JPL. It will in fact be approximately this time next year before the hardware contractors in USA and Europe are selected and the details of their designs become public. Nevertheless, from a conceptual point of view both of the designs presented are valid.

MISSION MOTIVATION

In view of the number of spacecraft which have been launched in the last two decades, it is somewhat surprising to recall that, with one exception, all of them have been confined essentially to the ecliptic plane and that, therefore, observation of the sun has been limited to solar latitudes within $\pm 7^{\circ}$ of the solar equator, which is inclined at that angle to the ecliptic. The exception is Pioneer 11 which reached a solar latitude of 17° before declining again towards the ecliptic plane. What has been studied to date is therefore an extremely small, and non-representative, portion of the solar environment.

Fig. 1 illustrates the explored region of the solar environment compared to the various regions of solar latitude where differing coronal behaviour is to be expected. According to J A Simpson (University of Chicago), the regions close to the solar equator and the solar poles are expected to exhibit quite different phenomena to the zone from 10° to 40° latitude (the so-called "Solar Activity Zones") where much more violent particle phenomena are likely to be observed. Furthermore, due to the solar rotation period of approximately 27 days, any long term phenomena on the solar surface are obscured from view for 50% of the time.

It is the objective of the ISPM to explore the heliosphere and view the sun over the full range of heliographic latitudes. This mission will therefore replace our current parochial view with a more accurate assessment of the total solar environment.

It is not within the scope of this paper to deal at any length with the various scientific objectives of ISPM. However, the following list of principal study areas, whilst not exhaustive, gives some feeling for the problems to be attacked by ISPM.

- the solar corona
- the solar wind
- structure of the sun-wind interface
- heliospheric magnetic field
- solar and non-solar cosmic rays
- interstellar and interplanetary neutral gas and dust.

It is also envisaged to make use of the spacecraft telemetry system to make radio science observations.

Among the secondary scientific objectives of the mission one might mention interplanetary physics observations for the initial Earth-Jupiter phase, when the separation between the two spacecraft will be accurately known, and of the order of 0.01 AU, and measurements of the Jovian magnetosphere during the fly-by phase.

The most fundamental aspect is that we will go with multi-displinary, well-instrumented spacecraft to regions where no spacecraft has ever been before. As has been true of all exploratory missions, we are bound to discover phenomena that cannot be anticipated a priori.

MISSION DESCRIPTION

The two spacecraft will be launched mated together with the Shuttle/IUS combination in the early days of February 1983. Once the Shuttle is in orbit the two spacecraft and the IUS will be separated from it and the IUS fired so as to put the spacecraft on an interplanetary trajectory towards Jupiter. Following burn out and separation of the IUS the two spacecraft are separated and they are targeted by means of the on-board propulsion system to go slightly north and south of the Jovian equator.

Using the gravitational field of Jupiter the two spacecraft undergo a sling-shot effect and are thrown out of the ecliptic plane so as to go over the polar regions of the sun. After crossing the poles the two spacecraft re-cross the ecliptic plane and traverse the other polar region. The mission is considered to have concluded when the solar latitude of each spacecraft falls below 70° for the second time. The details of the mission are still being evolved, but in approximate terms, we can say that the Jovian encounter will occur some 16 months after launch in May/June 1984, the first polar crossing will be in late 1986 and, for financial reasons, the mission will be constrained to conclude not later than September 30th 1987. For convenience the two spacecraft are known as the north going and south going spacecraft, depending upon which solar polar area they first explore. It is not yet decided which of the spacecraft will go north and which south. Fig. 2 illustrates the mission profile.

In defining the mission, account has been taken of a number of limiting parameters and also of uncertainties in STS performance and the spacecraft weight. For thermal reasons we do not wish to go closer to the sun than 1 AU (at perihelion) whilst the scientists do not wish to be further from the sun than 2 AU at maximum latitude. Obviously, there is a desire to carry out simultaneous observations from North and South and so the spacecraft solar orbits are approximately mirror image. Table 1 gives some characteristics of the currently envisaged mission but work on its optimisation continues and it will probably be some time before the final details are established. This optimisation study is being performed in close collaboration between analysts in JPL and ESTEC.

THE SCIENTIFIC PAYLOAD

The Invitation to scientists in USA and Europe to participate in the ISPM mission was made in April of last year and created considerable interest. A total of 85 experiment proposals were received, both for experimental hardware and for theoretical studies, and these were screened and analysed by a joint ESA/NASA board. Finally, the hardware investigations shown in Table 2 were selected for the mission, subject in some cases to reexamination at the conclusion of the study phase in 1979. The names listed show, however, only the top of the iceberg. All of the principal investigators listed have co-investigators from other institutes and frequently from other countries, so that the total number of scientists listed as PI or COI is in excess of 200 from a total of 65 universities and research institutes in 13 different countries.

Special mention should be made of a number of selected radio science and interdisplinary investigations, which do not furnish hardware to the spacecraft. The former utilises the uplink and downlink RF system of the spacecraft to conduct their experiments, particularly near solar conjunction, whilst the latter make, as the name suggests, correlative investigations using the data acquired by the various hardware experiments.

SPACECRAFT CONFIGURATIONS

(Note: As stated earlier, the configurations shown are those resulting from earlier feasibility and in-house JPL and ESA studies).

At first sight the external configurations of the NASA spacecraft (Fig 3) and the ESA spacecraft (Fig 4) appear very similar. This is largely because they are dominated by the radioisotope thermal generator (RTG) which provides the power throughout the 4½ year mission, and the high gain antenna of approximately 1.5 metres diameter. Each spacecraft also carries a magnetometer boom of several metres length mounted on the opposite side of the spacecraft to the RTG.

The major difference between the two spacecraft is the despun platform on the NASA spacecraft which carries the coronagraph/X Ray XUV telescope. This three axis stabilised section will track the sun with an accuracy of 3 arc seconds. The rest of the NASA spacecraft and the whole ESA spacecraft will spin at approximately 5 rpm during the operational part of the mission. However, the spacecraft designs will have to cope with a 70 rpm spin during the IUS powered flight.

Fig 5 shows the NASA spacecraft experiment layout in which most sensor units are external to the main spacecraft body. The ESA spacecraft, on the other hand, tends to have the experiments contained within the body of the spacecraft with the sensors protruding through gaps in the overall spacecraft shell. This has led to the curiously shaped spacecraft body shown in Fig 6.

One of the major problems to be overcome is the successful mechanical interfacing of the two spacecraft with each other and with the IUS to establish a well balanced and structurally sound launch configuration. Following meetings between JPL and ESA, it has been decided to have the JPL spacecraft as the lower one (interfacing with the IUS) and to have a four point interface between the two spacecraft via an inter-spacecraft adapter. The not-inconsiderable problems of how to resolve the mutual coupling between the Shuttle-IUS-NASA S/C-ESA S/C are currently being examined. Fig. 7 shows the IUS and the two spacecraft in the Shuttle bay.

One of the major drivers on spacecraft design is the fact that the two spacecraft travel out to Jupiter before turning back towards the sun. Apart from the obvious problems of thermal control over such a large range of solar radiation environments, the distance leads to two other considerable difficulties. The first of these is the maintenance of radio communication and data handling over the 800 million kilometers. The scientists wish to have almost 100% data recovery but for reasons of network overload the NASA Deep Space Network will not be able to maintain continuous coverage of the two spacecraft. It will therefore be necessary to store most of the scientific data on board during periods when no link exists and to transmit it, interleaved with real time data, when this is possible. As a result, an on-board storage capability of the order of 30,000,000 bits will be needed.

The other problem raised by the enormous distances is the question of transit time of the signals. At furthest distance from the earth the round-trip time for an RF signal is approximately 1½ hours. This has two complications. Firstly, the spacecraft will have to contain a self-safing capability so that in the event of temporary malfunction no permanent danger can ensue and secondly, if for any reason the spacecraft orientation moves outside the relatively narrow beamwidth (0.8°) of the 1.5 metre X band on board antenna so that contact with the earth is lost, a search mode can be initiated with a built-in lock-on device. This implies the need for a spacecraft which is at least semi-intelligent. The RF system itself will be S band command uplink and X band data downlink using a transmitter power of approximately 20W. The NASA spacecraft will also have a S band downlink capability of lower power, largely for use by the radio science investigators.

The propulsion system will be hydrazine and, apart from maintaining the spin rate and almost daily manoeuvres to keep the spacecraft pointing to the earth it will have three or more major manoeuvres to make. The first of these will take place a few days after the spacecraft have separated from the IUS and from each other. Once the trajectory has been established with sufficient accuracy a manoeuvre will be executed to target the two spacecraft towards Jupiter and slightly North and South of the Jovian equator. Subsequently, it is anticipated that one or more trimming manoeuvres will be necessary. About ten days before Jupiter encounter for each spacecraft, which is planned to be about 2 days apart, there will be a precise targetting to the required location in order that the Jovian gravitational field can place the spacecraft into the desired solar orbit.

PROJECT MANAGEMENT

In conclusion, a few words should be said about the method by which the two agencies plan to execute the project. It would be futile to pretend that no problems exist in designing, planning and building two spacecraft several thousand miles apart. The approach has therefore been to minimise so far as possible the interfaces so that JPL and ESA can operate as independently as possible, each using its own procurement procedures and design approaches. In this way, because of pressure on timescales and cost, it is planned that the two flight spacecraft, the two RTG, the IUS and the Shuttle will meet each other for the first time at ETR, just prior to launch.

The overall control of the project is executed by a Joint Working Group, consisting essentially of the two Project Managers and the two Project Scientists. A procedure exists for referral of any disagreements to a higher level but, so far, this has not been necessary, and hopefully, will continue so until project termination. Overall liaison with the participating scientific community is established and maintained by means of a Science Working Team, co-chaired by the two Project Scientists, who meet approximately twice a year to discuss and advise on the scientific aspects of the mission.

This has been a very superficial overview of a mission which will take exploration of space into completely new areas for the first time and hopefully, help to resolve some of the many existing unknowns about the solar system. As the project advances, there is scope for several detailed papers upon specific areas which are unique to ISPM. In particular, the science payloads and the mission optimisation are worthy of presentation. I hope that in the near future this will be done and that, somewhat later, you will receive papers containing novel scientific results achieved by this exciting mission.

TABLE 1 Mission Summary

In Ecliptic

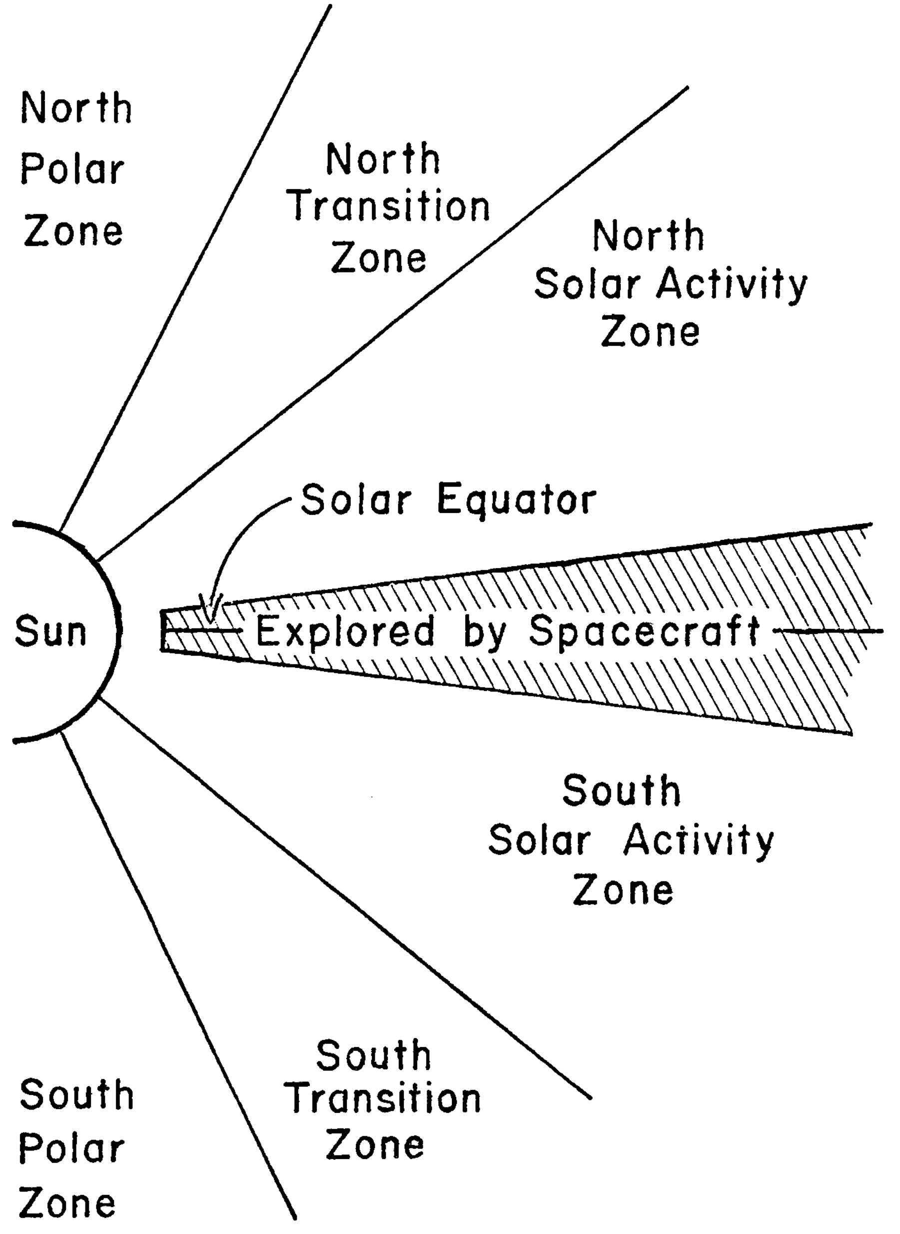
Launch Period	February 3 - 13, 1983
Launch Energy	114 - 120 km^2/sec^2
Jupiter Encounter Date	25 May 1984
Closest Approach to Jupiter	6.0 R_J

Ex-Ecliptic (Nominal Mission)

	South S/C	North S/C
Perihelion Date	9 March 1987	4 March 1987
Perihelion Distance	1.2 AU	1.2 AU
Maximum Solar Latitude	79^o	89.5^o
Total Time above 70^o Latitude (days)	188	237
Heliocentric Range at Maximum Latitude	1.8 - 2.0 AU	2.0 AU
Mission Termination	30 Sept. 1987	30 Sept. 1987

TABLE 2 Selected Hardware Investigations

Principal Investigator	Institute	Measurement
NASA Spacecraft		
M H Acuna	NASA/GSFC	Magnetic Field
H Rosenbauer	MPI Lindau	Solar Wind Plasma
H Rosenbauer	MPI Lindau	Interstellar Gas
E C Stone	Caltech.	Energetic Particles/Cosmic Rays
R G Stone	NASA/GSFC	Radio Observations
T L Cline	NASA/GSFC	Solar XRays/Cosmic Gamma Bursts
H Giese	U. Bochum	Zodiacal Light
R M MacQueen	H A O Boulder	Coronagraph/XRay XUV Telescope
ESA Spacecraft		
P C Hedgecock	Imperial College, London	Magnetic Field
S Bame	Los Alamos Sci. Lab	Solar-Wind Plasma
G Gloeckler/J Geiss	U Maryland/U Bern	Solar Wind Ion Composition
L Lanzerotti	Bell Laboratories	Low Energy Electrons and Protons
J A Simpson	U Chicago	Solar Particles/Cosmic Rays
R G Stone	NASA/GSFC	Plasma Waves/Radio Observations
K C Hurley/M Sommer	CESR Toulouse/MPI Garching	Solar XRays/Cosmic Gamma Bursts
E Grün	MPI Heidelberg	Cosmic Dust



Idealized Meridional Diagram of Solar Regions Connecting with the Interplanetary Medium

Fig 1

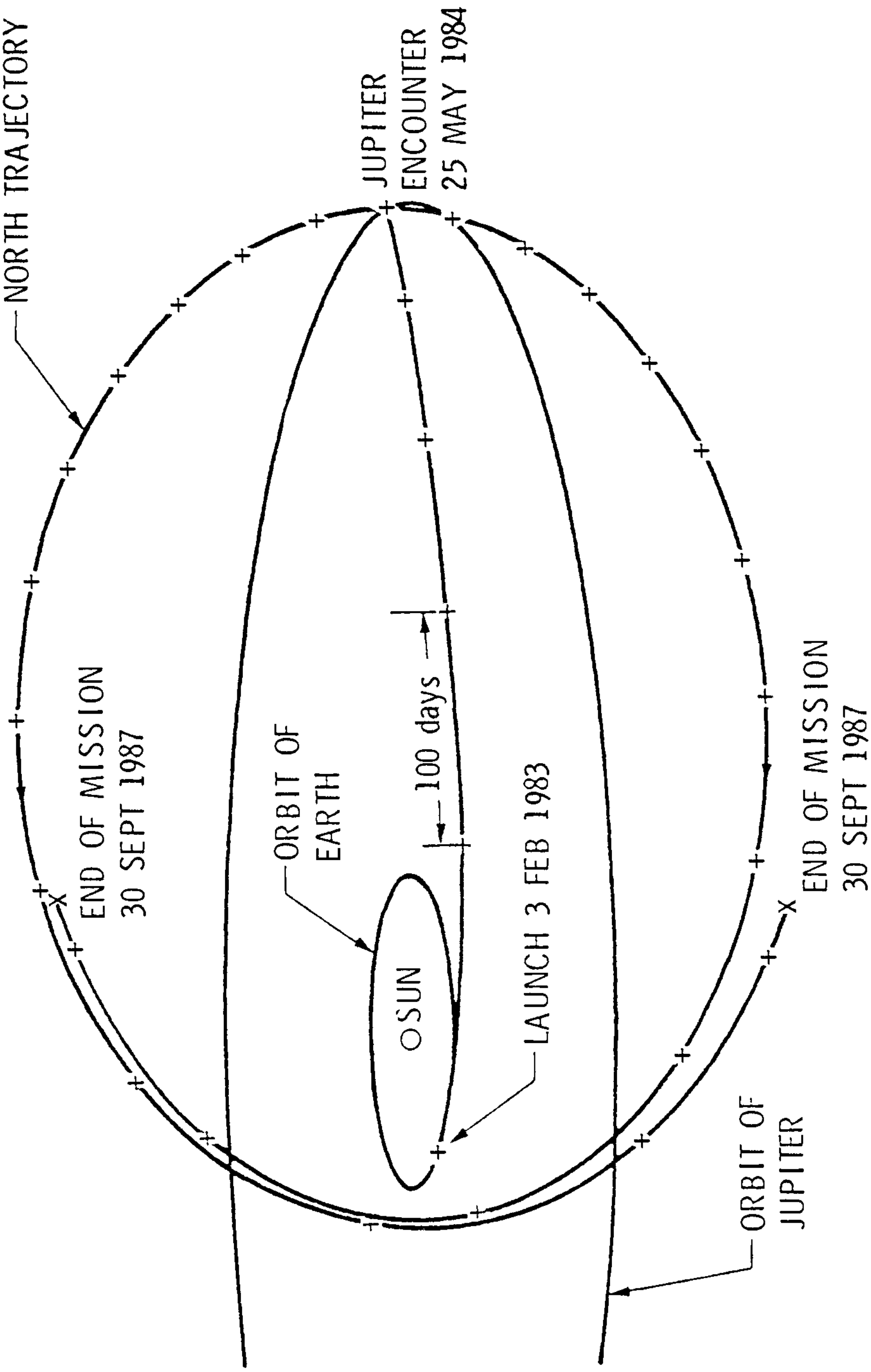


FIG 2 ISPM MISSION PROFILE

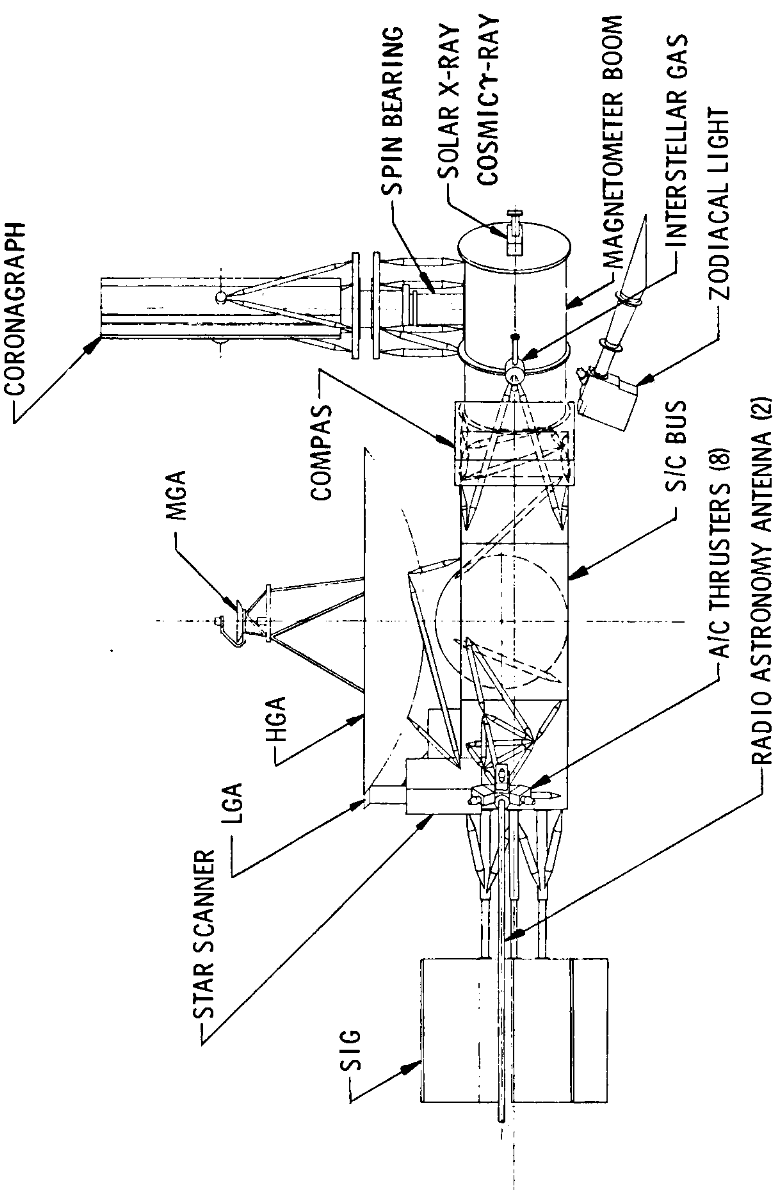


FIG 3 NASA SPACECRAFT OUTLINE

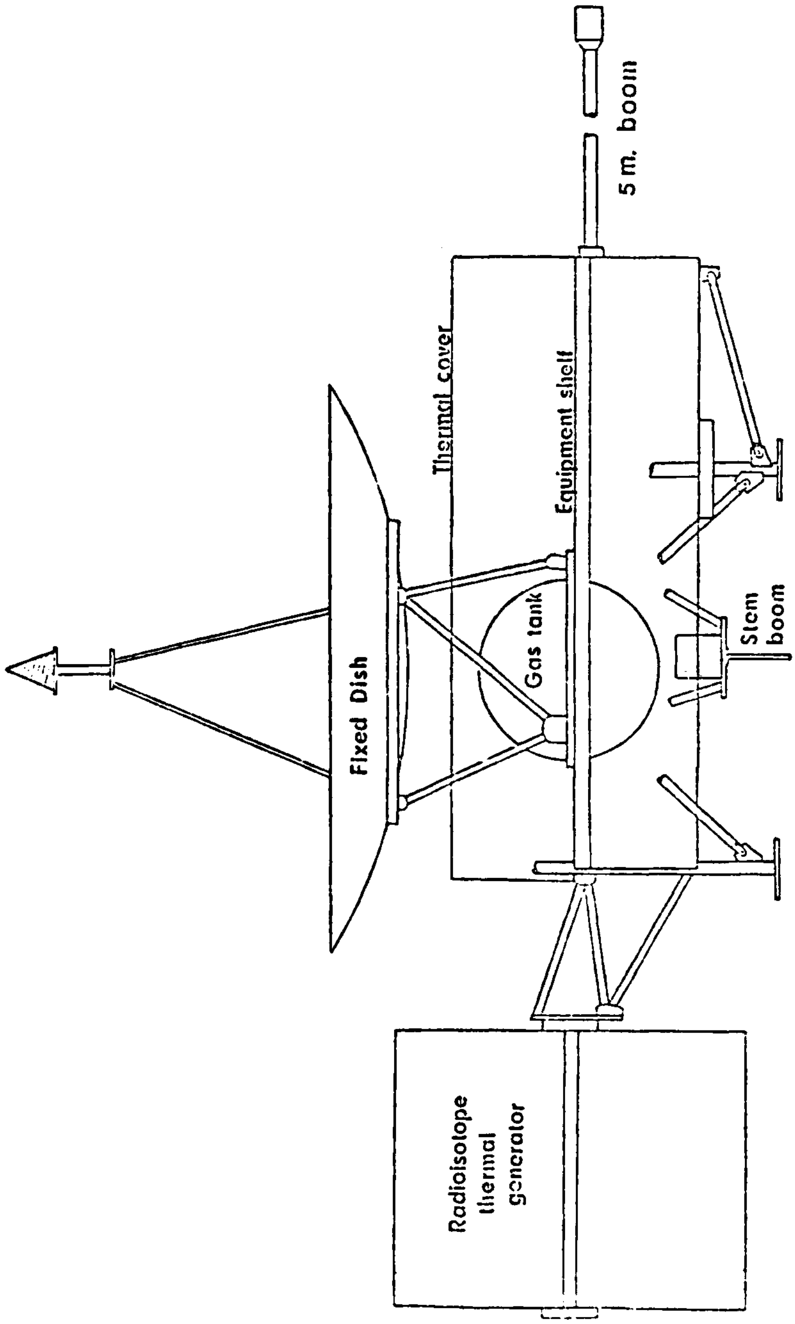


FIG 4 ESA SPACECRAFT OUTLINE

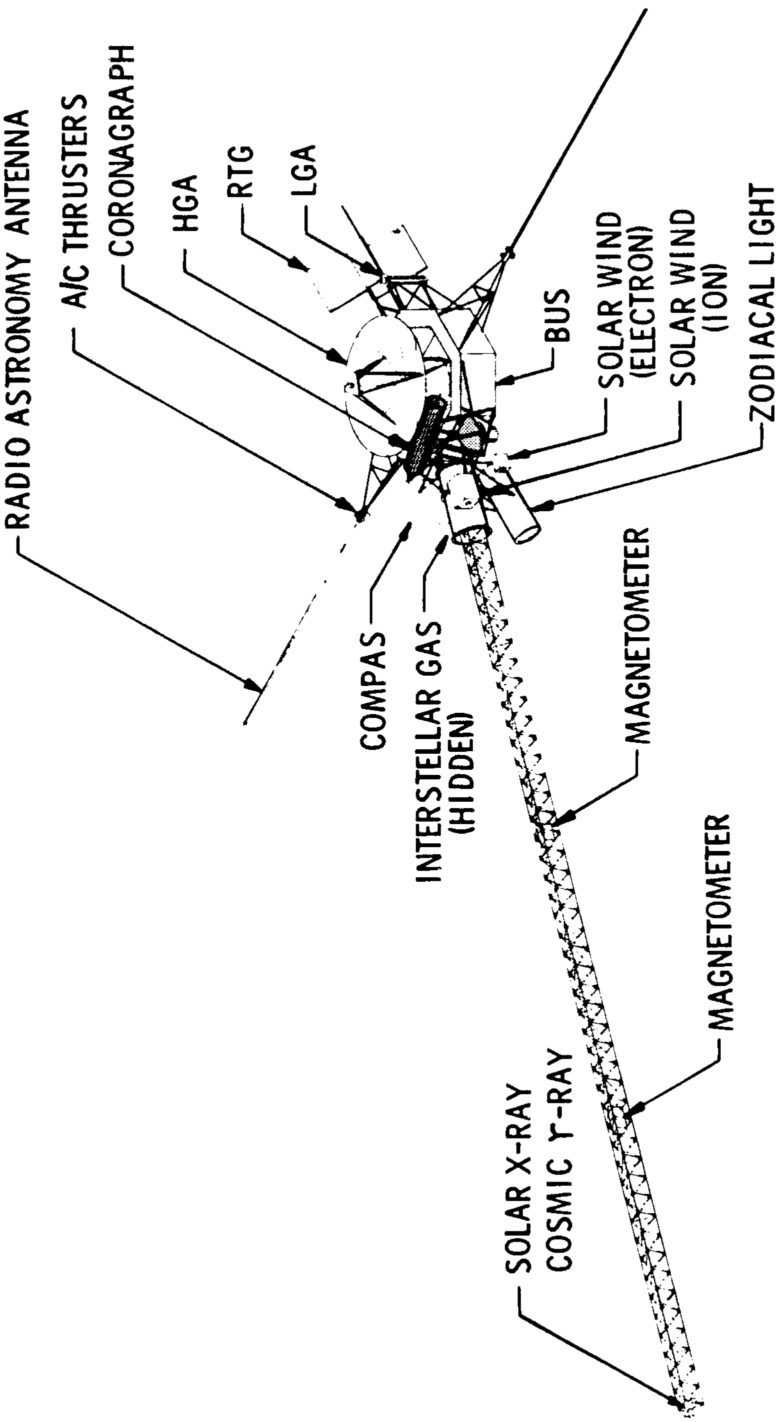


FIG 5 NASA SPACECRAFT EXPERIMENT LOCATIONS

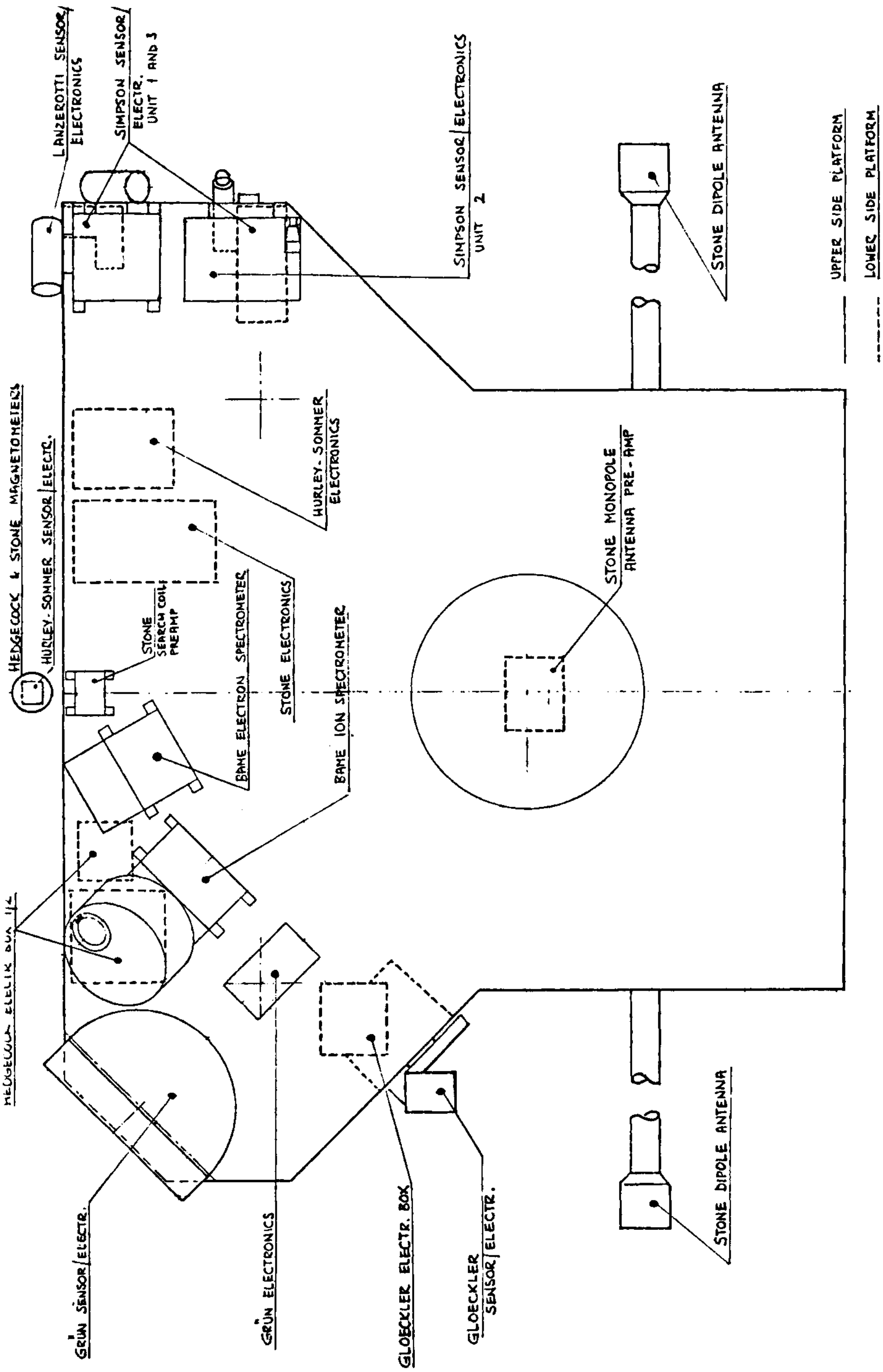


FIG 6 ESA SPACECRAFT EXPERIMENT LOCATIONS

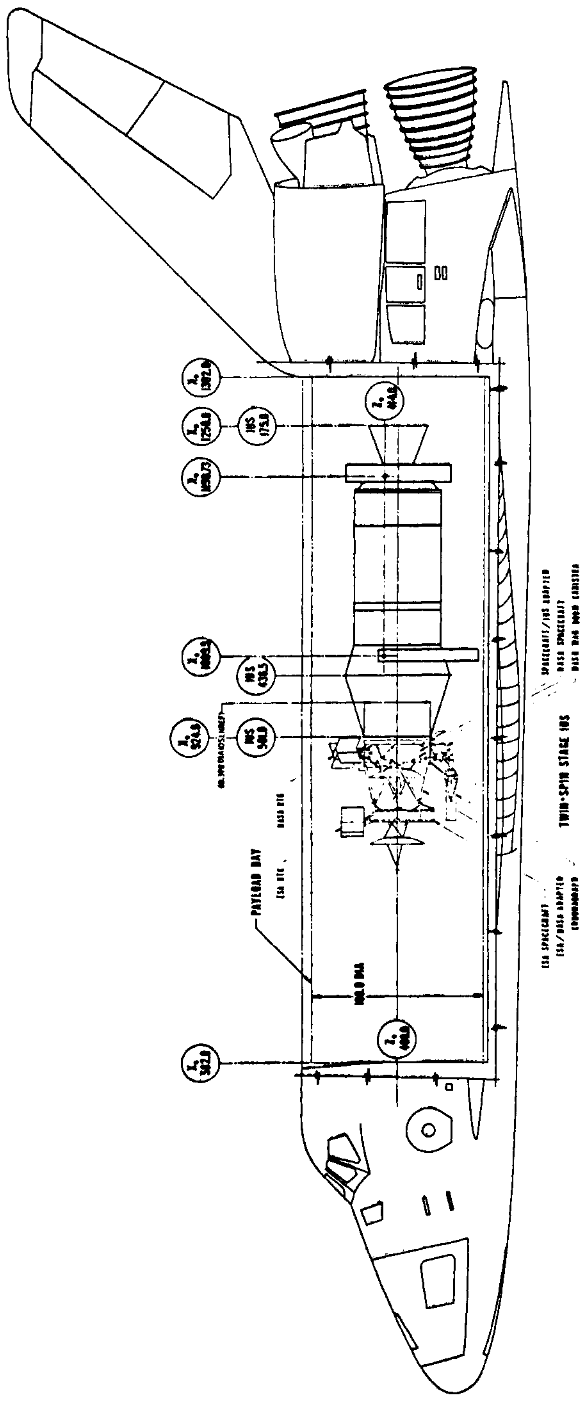


FIG 7 ISPM LAUNCH CONFIGURATION

SPACELAB UTILISATION IN EUROPE AFTER THE FIRST SPACELAB MISSION

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ABSTRACT

Four Spacelab missions following the first one are at present envisaged in the initial phase of Spacelab utilisation in Europe (1982-1984 time frame): two Demonstration Missions (micro-gravity and Earth-oriented) planned by the European Space Agency (ESA) in the framework of its Spacelab Utilisation Programme, and two additional national missions (micro-gravity and astronomy) planned by the Federal Republic of Germany and open to a complementary participation by other Europeans.

A call for experiment proposals was issued in April 1978 with the objective of identifying users' interest in order to provide a planning basis for all four missions and for the definition of their payloads.

On the basis of the proposals submitted in reply to the call, a missions analysis study has been undertaken to identify the optimum sequence, schedule and the preliminary compositions of the payloads of these missions, based on user requirements, on timely availability of experiments and facilities and on minimisation of costs associated with the missions.

This paper presents an outline of the main features of the Spacelab utilisation programme, an overview of the response to the call for experiment proposals and of the preliminary results of the missions analysis study, with emphasis on the main scientific and technical characteristics of the payloads envisaged for the four Spacelab missions.

INTRODUCTION

Manned space systems will be an important element in future space activities, calling, due to their complexity and to the amount of resources required, for broad international cooperation.

The interest of Europe in participating in the development of manned space systems was proved by the decision to undertake the development of Spacelab, one of the main elements of NASA's Space Transportation System.

Bearing in mind the coherence that has to be sought in a European context between the effort on the development of Spacelab and its subsequent utilisation, if Europe's presence in future manned space activities is to be pursued and confirmed, the

European Space Agency (ESA) has set up and is in the course of implementing a Spacelab Utilisation Programme, whose essential objective is to facilitate and to promote access to Spacelab by European users.

THE SPACELAB UTILISATION PROGRAMME (SLUP)

The main characteristics of ESA's Spacelab Utilisation Programme (SLUP) paraphrasing the declaration whereby the Member States unanimously approved it, may be summarised as follows:

- It is an optional programme. It may be defined as an "open" optional programme in that it is divided into successive parts, the missions being subject to separate decisions.

  The participating States, in fact, according to their interests, will decide for each proposed mission if and how they intend to participate. Participation in a particular mission does not commit the Member State to any further mission.

- It comprises two distinct aspects:

  (i) A Spacelab access service, responsible for the preparation and execution of missions at the request of users and of the missions financed by the Agency. This includes the necessary assistance to the experimenters for those tasks they cannot see to themselves and, in general, the provision of those services the users may wish to entrust to the Agency.

  This service, whose costs will be charged to the users, will be set up and managed by SPICE, an ESA operational group created for the purpose and located in Germany.

  (ii) Missions funded by the Agency, comprising more specifically the First Spacelab Payload (FSLP) and two demonstration missions, in which Member States may take part if they wish:

  The two demonstration missions are centred respectively on Earth-oriented disciplines and on micro-gravity experiments (material sciences, life sciences).

- After the first three missions, which constitute a demonstration phase, subsequent missions will be carried out in accordance with the modalities to be defined by the Council of ESA.

  Their essential purpose will be to meet requests from Spacelab users.

It is, as can be seen, a programme "à la carte" in the full sense of the expression, in which the level of participation by Member States will be strongly influenced by the demands of the users.

In addition to this European programme in the initial phase of which two missions are foreseen to follow the FSLP, the Federal Republic of Germany - the main contributor to the development of Spacelab - has planned two national missions: one in the field of micro-gravity, the other in the field of astronomy/astrophysics.

These missions are open to the participation of other European experimenters.

The set of four missions, all foreseen in the time frame 1982 - 1984 covers the three fundamental types of Spacelab missions:

- Micro gravity (*)
- Earth-oriented
- Deep-space-oriented.

The ensemble of the European and German plans, complementary and interdependent, constitutes a demonstration phase of Spacelab utilisation in Europe.

Particular emphasis is given to the new fields of research (life sciences and material sciences) opened by the advent of Spacelab with two dedicated micro-gravity missions. To these disciplines, as well as to all the others which are simultaneously represented in the FSLP, is given a new flight opportunity with dedicated missions, free from the constraints imposed in the first mission by the testing of the Spacelab/Shuttle system and with the possibility of grouping more compatible experiments.

In parallel with the planning of these missions, which will be dealt with in more detail in the following section, it is worthwhile mentioning two activities carried out by ESA in the frame of this programme.

One, intended to facilitate the access to Spacelab by European experimenters, consists in the setting up of a pool of instruments, flight and ground support equipment. The possibility of drawing from this common source should ensure the avoidance of duplication and save money for the user.

The other, intended to promote the utilisation of Spacelab by popularising space techniques and research, two kinds of experiments dedicated to young people will be carried out on Spacelab free of charge.

The first will take advantage of the Spacelab environment for carrying out single experiments demonstrating fundamental laws of physics in a way impossible on Earth. The film of these experiments would then be integrated in didactic films tailored to the different education systems in Europe.

The second will see young people as protagonists, since they will be given an opportunity to prepare and carry out by themselves, simple, small-scale experiments on Spacelab.

THE CALL FOR PROPOSALS

For the early phase of Spacelab utilisation in Europe outlined above ESA, in cooperation with the German authorities, has issued (in April 1978) a call for proposals addressing all the four missions at once in order to be in a position to optimise the mission sequence and the payload composition.

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* Although one may argue that micro-gravity is a standard condition in orbit, it is worth mentioning here that dedicated micro-gravity missions (gravity gradient stabilised) have to be foreseen since the low levels of gravity tolerated by many of the experiments (particularly in the field of material sciences) are incompatible with the Orbiter attitude manoeuvres.

These missions were proposed as follows:

Micro-gravity missions (one ESA, DM1 and one FRG, D1).

Spacelab configuration: Long module plus one pallet.

Mission duration: 7 - 10 days.

Orbit: $28.5° \leq i \leq 57°$, $250km \leq z \leq 400km$, gravity-gradient stabilised.

Objectives: Preference was given to those disciplines which take advantage of the micro-gravity environment, such as material sciences/space processing, life sciences and, to some extent, space technology.

The multi-user facilities proposed for material sciences investigations in the micro-gravity environment enable experiments to be carried out in fields such as:

- immiscible alloys and associated segregation phenomena
- unidirectional solidification to achieve special material properties
- diffusion phenomena
- particle/fibre reinforced composite materials
- diffusion controlled growth of large single crystals
- crystal growth using the floating zone method and other methods
- glass and ceramics investigations
- fluid physics/fluid dynamics/boundary layers research
- chemistry and physical chemistry
- separation techniques such as electrophoresis.

A cryostat facility, developed by ESA, cooled by superfluid helium (^4HeII) and providing a thermal environment lower than 2°K to on-board experiments was proposed for HeII fluid physics experiments on the micro-gravity mission, as well as astronomy experiments and atmospheric studies/Earth observations on the other types of mission.

In the field of life sciences the ESA-developed Sled facility was proposed as a research tool for investigations on the human and animal neuro-vestibular system. The equilibrium adaptation process in the micro-gravity environment and ways to alleviate the problems of space sickness could be studied.

Earth-oriented mission (ESA, DM2)

Spacelab configuration: Short module plus a 3-pallet train.

Mission duration: 7 - 10 days.

Orbit: $28.5° \leq i \leq 57°$, $250km \leq z \leq 400km$.

Objectives: Preference was given to Earth-oriented disciplines such as atmospheric sciences, Earth observation and geodesy.

A major mission objective of the atmospheric part of the payload could be a contribution to the international Middle Atmosphere Programme (MAP), comprising investigations in chemistry, composition, energetics, dynamics and thermodynamics of the Earth's atmosphere from the upper troposphere to the lower thermosphere.

The emphasis of the Earth observation portion of the payload (consisting at present of three facilities: a metric camera, a microwave remote sensing instrument and a synthetic aperture radar) was put on combined optical and microwave measurement cycles.

The geodesy/geodynamics portion of the payload could aim at investigations of the Earth's gravity parameters, rotational motion, accurate positioning, ocean and ice dynamics, etc.

Deep space-oriented mission (FRG, D4)

Spacelab configuration: Short module plus a 3-pallet train or pallet only.

Mission duration: 10 - 16 days.

Orbit: $28.5° \leq i \leq 57°$, $220km \leq z \leq 450km$.

Objectives: The mission objectives of the deep space-oriented mission were kept as broad as possible ranging from IR astronomy, via optical astronomy (e.g. wide field cameras), soft X-ray astronomy (e.g. imaging techniques, X-ray spectrometers, Wolter Telescopes), hard X-ray astronomy (e.g. detector arrays could be used for fast varying X-ray sources), to gamma astronomy.

In reply to the call 232 proposals (status as at August 1978) have been received by ESA largely over-subscribing, for all four missions, the resources available. Several of them are cooperative and include investigations from Norway and the U.S.A. Lately, 3 Japanese proposals have also been submitted.

This result is considered very successful and a noticeable improvement with respect to the reply to the call for proposals for the FSLP, bearing also in mind that the 54 German proposals included in the total number are already the result of a national screening.

Table 1 summarises the repartition of the replies per Member State and per discipline. In parenthesis are the corresponding figures for the FSLP. It may be noted that the number of proposals has increased for all Member States and for most of the disciplines.

In particular the new disciplines (material sciences and life sciences) represent almost half of the proposals.

Moreover it may be noted that, despite the short mission duration, which can be an important constraint for astronomy/astrophysics research, the proposals submitted in this field amount to a total mass of 16,000kg, enough for three complete payloads.

PRELIMINARY MISSION PLANNING

On the basis of these proposals, ESA, with the help of an industrial contractor, has undertaken a mission planning exercise for three of the four missions (DM1, DM2, D4), concentrated on technical evaluation (best suitable Spacelab configuration, technical incompatibilities between experiments, preliminary assessment of resources needed) together with an identification of complementary or duplicating scientific objectives. The fourth mission (D1, similar to DM1) is being studied by the German space authorities.

The results of this analysis are intended to help Member States in their decision-making process as to which experiments they intend to fund.

As a matter of fact the success of the call for proposals, generally beyond the present funding capabilities of Member States, has somewhat complicated the process of defining the payloads for the Spacelab missions in question.

Although every effort has been made to narrow the initially vast field of options, the whole early phase of Spacelab utilisation in Europe is not yet at a stage of definition where mission sequence and payload composition can be finalised.

Therefore the information about the envisaged payloads which follows has to be considered as preliminary and essentially as a planning tool.

As regards the micro-gravity mission (DM1), Table 2 summarises the basic payload core, upon which the mission analysis was based.

The major guidelines applied in establishing the payload composition were:

- Energy sharing between material sciences and life sciences experiments, around 50/50.

- Candidates for facilities and autonomous experiments to be chosen in function of a certain equilibrium amongst the different disciplines and of an anticipated realistic share between the Member States.

- Explore the possibility of adding astronomy experiments of a survey type (no attitude manoeuvres).

Table 3 presents the mission drivers resulting from the analysis and gives a proportional allocation of mission time for the various facilities.

The analysis has shown furthermore that, except for power, all experiment requirements can be satisfied. The energy margin could even permit a mission extension beyond the planned 7 days. The power criticality, on the other hand, results in an under-utilisation of the isothermal and gradient heating facilities.

Since the pallet is relatively under-loaded, the next phase of the analysis will consider a module-only option which should easen the power problem.

As regards the Earth-oriented mission (DM2), nine options were analysed. Table 4 presents the two options which, at present, appear to be the most viable. Their essential difference is represented by the alternative presence of the German IR helium-cooled telescope (GIRL) and of the Dutch sub-millimetre telescope (STAAR) (both used in an atmospheric research mode).

The orbit characteristics best suited to the payload requirements are: $z = 250$km, $i = 57$ degrees. The launch date to be foreseen is around the equinoxes (Autumn 1982 or Spring 1983) with a launch time optimised for suitable ground target illumination (Brasil and Europe coverage).

The major mission drivers are:

- The GIRL telescope which has a strong influence on the configuration of the payload and whose operation time has to be allocated from the start of the mission onwards, without interruption, because of cryogenics evaporation.

- The solar package, hindering nadir or limb pointing during its operation.

- The Earth-observation package, requiring very high data rates over specific ground targets.

In any case all Spacelab resources seem to cope with the requirements (careful scheduling can resolve the high data rate problems) and the operation time offered to the experiments only in a few cases is slightly below the required time and in some cases even above it.

However, since the short module is somewhat under-utilised, a pallet-only option will be analysed, in view of a more attractive mission cost repartition due to the higher payload carrying capability of this configuration.

The deep space-oriented mission (D4) is characterised by the presence of relatively few (with respect to the other missions) large candidate experiments from only six of the Member States. The major problem therefore appeared to be the definition of a payload entailing realistic sharing by the participants.

Table 5 gives an overview of the four options considered. Option C was studied in detail since it corresponds to the maximum use of existing equipment and allowed the allocation of separate pallets to participants with a high share.

The results of the analysis show that Spacelab resources can cope with all the requirements with the exception of a shortage of an experiment computer memory, entailing some operational difficulty since the payload specialists would be required to swap around the software in the memory.

CONCLUSIONS

The lack of decisions as to which experiments are finally funded leaves the question of the final payload composition and mission sequence of the early phase of Spacelab utilisation in Europe open. The model payloads analysed, however, can be considered realistic and have proven that Spacelab can, in general, cope with their requirements satisfactorily.

As to the mission sequecne, although no decision has been taken, the trend seems to be towards a schedule foreseeing D1 in mid-1982, DM2 in Spring 1983, DM1 in early 1984 and D4 in late 1984.

TABLE 1 SPACELAB UTILISATION AFTER FSLP
OVERVIEW OF THE REPLIES TO THE CALL FOR PROPOSALS

	TOTALS	A	B	CH	D	DK	E	F	I	NL	S	UK	ESA
Astronomy/ Astrophysics	40 (9)	1	1	-	6	-	-	5	9	7	1	10	-
Solar Physics/ Atmosphere	37(20)	3	2	1	12	-	-	10	1	2	1	4	1
Earth Observations/ Geodesy	11(22)	-	-	-	4	-	-	5	2	-	-	-	-
Space Technology	24(10)	-	-	1	1	-	-	17	3	1	-	1	-
Life Sciences	54(31)	2	2	4	20	1	-	18	2	1	-	3	1
Material Sciences	64(8✦)	-	5	1	11	1	1	23	7	4	5	6	-
Others	2 -	-	-	-	-	-	-	-	-	-	-	2	-
	232 (100)	6 (5)	10 (5)	7 (4)	54 (30)	2 (0)	1 (1)	78 (28)	24 (6)	15 (3)	7 (3)	26 (15)	2

Notes : In parenthesis are the equivalent data of the call for proposals for the FSLP

✦ A separate call for proposals in MS was issued for FSLP. The figure quoted concerns new proposals in response to the general call for FSLP.

TABLE 2 MICRO-GRAVITY MISSION DM1. PAYLOAD CORE

MATERIAL SCIENCES

Facilities:

- Material Sciences Double Rack (MSDR) — 43 candidate expts
  - Isothermal heating facility
  - Gradient heating facility
  - Mirror heating facility
  - Fluid Physics Module
- Process chamber — 3 expts
- Chemistry laboratory — 2 expts

Autonomous

9 experiments concerning cristallisation, fluid physics, friction, phase change

Space Technology

19 candidate experiments

LIFE SCIENCES

Facilities:

- Space vestibular SLED — 8 experiments
- Biorack — 16 candidate experiments
  - Plant incubator
  - Fish incubator
  - Frog unit
  - Cell and tissue incubator

Support

- 1 g centrifuge
- High speed centrifuge
- 4°C freezer
- Liquid nitrogen freezer.

Autonomous

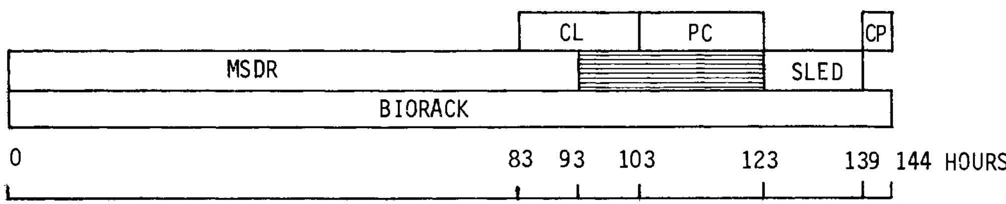
17 experiments concerning human physiology, zoo and fito biology.

Astrophysics

Cryogenic IR background experiment (CIRBS) + Cryostat

TABLE 3 MICRO-GRAVITY MISSION DM1 : MISSION "DRIVERS"

INSTRUMENT / FACILITY		EFFECT
CIRBS (ASTRONOMY)	:	SETS LAUNCH TIME FOR OPTIMUM SKY COVERAGE OPPORTUNITIES INERTIAL ATTITUDE FOR ORBITER WHEN CIRBS OPERATES IN POINTING MODE (DURING SLED AND CREW PHYSIOLOGY PERIODS)
SLED	:	INTERRUPTIONS 1 HR IN 24 HRS DURING MISSION. REQUIRES 2 MEN
MSDR	:	93 HOURS TOTAL OPERATION PERIOD
CHEMISTRY LAB (CL) & PROCESS CHAMBER (PC)	:	20 HOURS EACH, WITH CL OPS OVERLAP WITH MSDR
CREW PHYSIOLOGY (CP)	:	1 HOUR IN 24 HOURS; 2 CREWMEN
BIORACK	:	ON ALL MISSIONS (FOR ENVIRONMENTAL CONTROL)



PROPORTIONAL ALLOCATION OF MISSION (NOT A SCHEDULE)

BY ENERGY

LIFE SCIENCES ≃ 46%

MATERIAL SCIENCES ≃ 54%

TABLE 4 <u>EARTH-ORIENTED MISSION DM_2. PRELIMINARY PAYLOAD OPTIONS</u>

1 <u>Minor constituents' profiles</u>

(A) ◆ German IR Laboratory (GIRL)
- Ebert Fastie Spectrometer
- Michelson Interferometer
- Fabry Perot Interferometer

◆ Microwave Atmospheric Sounder

◆ Combined Airglow Telescope Spectrometer (CATS)

◆ Cooled Infrared Radiometer (CIR) + Cryostat

□ ◆ Grille Spectrometer

(B) ◆ Submillimeter Teles. for Astronomy and Atmospheric Research (STAAR)

2 <u>Airglow</u>

◆ Night Airglow Camera

◆ Wide-angle Broadband Spectrometer (WABS)

◆ Mesosphere optical measurements

□ ◆ Waves in OH emissive layers

3 <u>Wind</u>

□ ◆ Temperatures and Wind (Mesosphere, Thermosphere)

◆ Wind Experiment (Troposphere, Stratosphere)

4 <u>Radiation Budget</u>

◆ Polarimeter

◆ Scan Radiometer

◆ Stereo Line Scanner

◆ Microwave Pressure Sounder

5 <u>Solar Calibration</u>

◆ Solar calibration package (SCALP)

□ ◆ Medium UV Solar Irradiance Spectroscopy

◆ Solar Spectrum

□ ◆ Solar Constant 1

◆ Solar Constant 2

6 <u>Thermo/Iono/Exo-sphere</u>

□ ◆ H, D, Ly-alpha emissions

□ ◆ Phenomena induced by charged particle beams (PICPAB)

□ ◆ Low-energy Electrons Distribution Function

◆ Magnetic Field Vector

7 <u>Solar Physics</u>

◆ NA, D Line Profiles

◆ Solar Oblateness Measurements

TABLE 4 EARTH-ORIENTED MISSION DM_2. PRELIMINARY PAYLOAD OPTIONS (contd.)

8 Earth Observation

□ ✦ Metric Camera

□ ✦ Microwave Remote Sensing Instrument (MRSI)

✦ Synthetic Aperture Radar (SAR)

(B) 4 Modular Opto-electronic Multispectral Scanner (MOMS)

9 Material Sciences

□ ✦ Fluid Physics Module

Total mass of experiments and facilities :

Option A : 2415 kg

Option B : 2050 kg

Notes : □ denotes an FSLP instrument

(A) and (B) denote alternative options.

TABLE 5 DEEP SPACE ORIENTED MISSION D4. PRELIMINARY PAYLOAD OPTIONS

Experiment Title	Country	Options	Co-Investigator from other country
GIRL (IPS)	D	A B C D	-
80 cm Wolter Telescope (IPS)	D	A B C D	-
Spacelab UV Stellar Spectrograph (SSUS) - IPS	NL	A B C D	-
Submillimeter Telescope (STAAR) - SEM 1	NL	A B C -	F, UK, ESA
Cryogenic IR Background (CIRBS) - SEM 2	UK	A B C D	UK, I, F, ESA
High Resolution X-ray Background	I	A B C D	-
High Energy Imaging X-ray Telescope	UK	A B C D	-
Temporal-Spectral Study of Cosmic X-ray Sources	UK	A - - -	-
X-ray Spectroscopy Payload	F	A B C D	US
Large Area Proportional Counter	D	A B - D	-
Heavy Ion Package	D	A - - -	-
X-ray Spectroscopy with Gas Scintillation Prop. Counter	I	A B C D	-
Super Wide Angle Camera	D	A B C D	-
EUV Stellar Spectroscopy (SEM 2)	D	A B C D	-
Very Wide Field Camera	F	- B C D	-
Far UV Space Telescope	F	- B C D	-
Sky Surveyor	I	- B C D	-
Large Area X-Ray Experiment	I	- - C -	-
UV Telescope for Wide Fields and X-ray Stars (UTEX) (SEM 1)	I	- - - D	I, F, NL, DK

Total mass of options :
A : 4371 kg
B : 4711 kg
C : 4711 kg
D : 4401 kg

IPS : Instrument Pointing System
SEM : Small Experiment Mount

SPACELAB
THERMAL CONTROL SUBSYSTEM DEVELOPMENT
ANALYSIS — DESIGN — MANUFACTURING
TESTING

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ABSTRACT

SPACELAB the European Space Laboratory, whose first mission on board of the U.S. Space Shuttle is planned at the end of 1980, has completed the phase of development and has entered production and acceptance of the flight unit hardware.

The Analysis, Design, Manufacturing and Testing related to the development of Thermal Control of the Module and of the Pallet, of AERITALIA responsibility, are discussed with the purpose to illustrate the main problems and solutions found during the four years that have lead to the successful conclusion of the Development Phase.

A description of the basic features of the Active Thermal Control Section consisting of two fluid loops, and of the Passive Section relative to the covers of the Module and of the Pallet is presented; the basic design solutions adopted are illustrated and discussed.

Some relevant details of the design of the active thermal control components developed by MICROTECNICA are illustrated, as well as, the ones relative to the high performance insulation blankets developed by AERITALIA.

A review of the thermal analyses performed for the evaluation of the performances of the Thermal Control Sections is given; the mathematical models constructed to utilize the SINDA computer program are described and discussed.
Results of some typical environmental conditions such as the "hot and cold cases" are reported and discussed; in addition the main conclusion of a sensitivity analysis performed to explore the influence of the various parameters affecting the design are presented.

A brief description of the manufacturing process and techniques adopted in the realization of the development models is given to provide an insight in the solution adopted.

The large effort devoted during development to testing from small items, components and elements, up to full scale breadboard models is illustrated.
The more important results of the development tests are presented, compared with the analysis and discussed; in particular the ones concerning the module only mode of the breadboard test that fully simulates the entire active cooling loop behaviour.

INTRODUCTION

The European Space Laboratory, SPACELAB, to be used over the next decade for Scientific and Technological Space Researches, in conjunction with the SPACE SHUTTLE, is a cooperative programme between the European Space Agency (ESA) and the National Aeronautics and Space Administration (NASA).

The SPACELAB designed for the best utilization of the payload capabilities of the SPACE SHUTTLE, has been conceived with an extremely flexible design to allow the performance of a large variety of experiments in space. Brought into orbit by the ORBITER, for missions lasting from seven up to thirty days, SPACELAB will offer the international community of users an efficient and versatile general purpose mean to conduct the next generation of manned space research and space exploration activities (fig. 1).

Eleven outstanding Aerospace Companies belonging to ten European Countries joined at the level of Cocontractors in a Consortium lead by ERNO VFW-Fokker, together with about forty Subcontractor Companies, are performing the design, development, manufacturing and testing activities of the various SPACELAB Systems under a contract awarded by ESA.

The SPACELAB is formed by two basic elements, the "Pressurized Module" and the "Unpressurized Pallet" that, designed with a modular concept, can be used separately of in conjunction,giving rise to different configurations.
The "Module" is a cylindrical compartment that provides to the experimenters and to their equipments an environment equal, apart the absence of gravity, to the sea level earth conditions. Inside the Module standard elements for the experiments support such as floor racks, airlocks, heat exchanger, cold plates, as well as basic services such as power, environmental control and data management are provided.
The "Pallet" is a platform to support experiments directly exposed to the space environments.

The responsibilities of AERITALIA in the Program are the analysis, design, manufacturing and testing of the Module Structure and the Thermal Control Sub-Systems, subdivided in turn into two sections, the Active Thermal Control Section (ATCS) and the Passive Thermal Control Section (PTCS).

AERITALIA in the development of the Active Thermal Control Section has availed of Microtecnica as subcontractor for the development of some coolant loops components and has conducted the thermal control system level design and development activities in cooperation with ERNO that has integrated the Environmental Control and Life Support Subsystem (developed by Dornier) with the Thermal Control Subsystem.

A.T.C.S. FLUID LOOPS FUNCTIONS AND DESCRIPTION

The basic function of the Active Thermal Control System (ATCS) is the transfer of all the heat loads generated inside the Module and on the Pallet by SPACELAB subsystems, experiment equipments and by the metabolic processes associated with the crew, to the Orbiter heat rejection system that provides to radiate the heat into space.

The ATCS is limited in the amount of heat (8.5 kW) that continuously can be transferred to the Orbiter Payload Heat Exchanger (OPHX); for short periods (15 minutes every three hours) higher peak heat loads up to 12.4 kW can be accomodated by storage of heat via heat capacitors and rejected at a delayed time.

According to the SPACELAB flight configurations obtained by combinations of the Module and the Pallets, different ATCS configurations are foreseen.

The basic components used in all the configurations are identical and they have been designed to optimize their overall performance in the different conditions.

I) Module Only Mode

A main cooling loop inside the module, operated with water for safety reasons, with nominal mass flow 227 kg/hr, collects the heat from three auxiliary cooling loops and transfers the total heat to the Orbiter/Payload Heat Exchanger (O.P.H.X.)(fig.2)
- Cabin Air Loop that controls the Module atmosphere, it interfaces with the water main loop via the Condensing Heat Exchanger (C.H.X.)
A maximum continuous heat rejection capability of 1 kWatt, with a peak up to 3 kW can be accomodated in total by the Cabin Air Loop.
The forced air flow within the Module (5-12 m/min) provides an adjustment of the cabin air temperature in the range from 18°C to 27°C, selected by crew men with an automatic control to within $\pm$ 1°C.

- Avionic Air Loop that provides conditioning for the equipment located into the subsystem and experiment racks, it interfaces with the water loop via the Avionics Heat Exchanger (A.H.X.). This loop is separated from the habitable volume in the Module by sealing of the racks.
A nominal continuous heat rejection capability of 4,0 kWatt with a peak up to 10 kW can be accomodated in total by the Avionic Air Loop.
The avionics air loop flow enters the racks at a nominal temperature of 22°C and can reach up to 40°C at the outlet (for peak loads it can increase up to 50°C).

- Experiment Fluid Loop that interfaces with the main water loop via the Experiment Heat Exchanger (E.H.X.) that can be installed in the water loop either upstream of the avionic heat exchanger or downstream of the subsystems cold plates.
This loop provides thermal control of experiment equipments with up to 4 kWatt of power dissipation.

II) Module-Pallet Mode

The Water Loop is the same as in the Module Only Configuration; in addition to the three cooling loops inside the Module, a fourth is connected to the main loop to collect the heat from the Freon Loop via an Interloop Heat Exchanger (I.H.X.) located outside the Module in place of the Thermal Capacitor Assy.
- The Freon Loop collects heat from the experiment and subsystem equipments located on the Pallet by means of eight Standard Experiment Cold Plates; up to four Thermal Capacitors mounted on the Cold Plates to accomodate the peak heat loads.
The Freon Loop nominal mass flow is 1368 kg/hr., with a normal rejection capability of 4,5 kWatt.

III) Pallet Only Mode

In this configuration the Pallet Freon Loop interfaces directly with the Orbiter Payload Heat Exchanger.
Along the loop are located Experiment Standard Cold Plate (eight) and Thermal Capacitor (four), available for cooling the experiment and subsystem positioned on the Pallet, as in the case of the Module-Pallet configuration.
In addition, immediately downstream of the Orbiter/Payload Heat Exchanger, are located two Subsystem Cold Plates and nine Subsystem Cold Plates for cooling the equipment mounted inside the Igloo.
The maximum normal heat rejection capability is 8.5 kW with a normal mass flow of 910 kg/hr.

A.T.C.S. COMPONENTS FUNCTIONS AND DESCRIPTION

As outlined in the description of the A.T.C.S., several standard components have been utilized to form the Fluid Loops.

o Experiment and Interloop Heat Exchangers
The Experiment Heat Exchanger (E.H.X.) and the Interloop Heat Exchanger (I.H.X.) are phisically identical (fig. 3a), their capability is 8 kW.
The Heat Exchanger consists of a brazed assembly of stainless steel plates and closure tubes with nickel fins, with brackets and headings welded on the assembly.
It is a counter flow design, once folded, with fifteen fins layers per side; guiding blades at the inlet headings at both sizes are introduced to improve the heat transfer effectiveness.

- Cold Plates. The Cold Plate is an element designed to transfer heat, from the electronic equipments and/or thermal capacitors mounted on it, to the water or freon loops (fig. 3b).
The Cold Plate consists of a brazed assembly of stainless steel face sheets, bosses and closure tubes, and internal nickel fins.
The nominal heat rejection capability of the Standard Cold Plate is of 1 kW each.
A grid hole pattern 70x70 mm is provided for mounting Electrical Components and/or Thermal Capacitor elements.

- Thermal Capacitor. The Thermal Capacitor is an element designed to store heat loads resulting from transient overcharges in the Fluid Loops; the heat accumulated in the Capacitor, through a phase change process, is returned into the Loop at a later time when the heat transfer balance does allow it (fig. 3c).
The Capacitors consist of an aluminum structure containing a very large number of independent small square cavities partially filled with the phase change material (n-Heneicosane).
Thermal Capacitors are designed for a nominal heat storage capacity of 0.25 kWh each with an input of 1 kW and a phase change temperature range of 39-40.5°C.

- Water and Freon Pump Packages. Water and Freon Pump Packages (Hamilton Standard) have basically the same architecture and consist of two redundant flow paths made up of an inlet filter, an electrically powered centrifugal fluid pump, a manual bypass valve and a reserve-flow check valve (fig. 3d).
The pump inlet pressure is established by a nitrogen charged accumulator. Should the pressure rise across a flow path (filter/pump/check valve) drop below 0.28 kg/cm^2 (3.5 psi) the delta pressure switch contacts open, providing a signal of the low pressure and the operation of the mission.

- Plumbing. The plumbing is a combination of hard and flexible lines. Stainless steel lines are used with induction brazed fitting for unbreakable joints and quick disconnector or MC fittings for the breakable joints.

P.T.C.S. HIGH PERFORMANCE INSULATION COVERS FUNCTION AND DESCRIPTION

The SPACELAB Passive Thermal Control Section is designed to provide thermal insulation of the Module Structure, the external mounted Equipment, the Pallet Structure and mounted Equipments as well as the Utility Bridge linking the Pallet to the Module (fig. 4).

The entire Module surface is protected by a cover tailored to wrap the cylinders and the cones surfaces. The forward cone cover is supported by a special structure that allows the creation of a compartment thermically protected, in which different components as the gas storage tanks and ATCS pump package can be located. Special "collars" are designed to ensure the overlapping of the covers at the major interfaces between cylinders, cylinder-cones and airlocks.

The design approach for the Thermal Covers is quite advanced, Multilayer High Performance Insulation blankets are used, with double goldized kapton sheets and dacron net separators, protected externally by a teflon coated fiberglass cloth and by a double goldized kapton sheet reinforced with nomex inside.
The multilayer insulation provides an efficient barrier to heat transfer by radiation through the multi-reflection path created between the layers of the cover.

Some of the major details of the Module thermal cover design are reported (fig.5) among which the retention system with buttoms that allows an easy remotion of the cover.

The entire system has provisions for the venting, being the sheet perforated and being provided a venting system to allow air exit during ascent into orbit.

DEVELOPMENT APPROACH

The development of the SPACELAB Thermal Control Subsystem has been based on two foundations: Analysis and Test.

- The Analysis Activities have allowed the evaluation of the response of the A.T.C.S. Components and Fluid Loops to the applied environmental and thermal loads. Steady state and transient analyses have been performed during the development phases and have been reiterated upon results of the development tests, to account for more correct inputs on components performances.
The High Performance Insulation Cover sizing has been done on the basis of extensive analyses supported by development tests, that have allowed the determination of the number of sheets to be used to prevent excessive temperature fluctuations of the Module shell walls and Pallet panels under the applied environmental and thermal loads.
For the analysis, general purpose and specific computer programs have been utilized, like SINDA and LOHARP, that require the extensive use of large computer facilities available at AERITALIA.

- The Testing Activities have constituted the support of the design and have provided the validation and verification of the approaches selected.
Development Tests have been performed at component level first, and later at assembly and system levels. The results of Develpment Tests have provided the necessary inputs to modify the design of the Development Units, and later on, of the Qualifications Unit whenever necessary.

THERMAL ANALYSIS

The development of the SPACELAB Thermal Control System has required extensive computational and design activities in order to define the various components of the fluid loops and to evaluate the behaviour of the thermal cover elements under the environmental conditions resulting from the flight within the Cargo Bay of the ORBITER.

The Active Thermal Control Analysis of the three basic SPACELAB configurations has required a relevant effort due to the optimization process needed by the requirement of commonality of all the components for the three configurations.

The A.T.C. System Thermal Analysis

The Thermal Analysis of a complex A.T.C. System as the SPACELAB, consisting of different fluid cooling loops, internal and external heat sources, needs to be treated with a sofisticated Thermal Analyzer Program, such as SINDA, capable of defining, under the different thermal loads conditions occurring during the mission, the temperature histories of the various components of the system.

The difficulties in establishing the Thermal Model lie in the definition of the thermal properties of the nodes in which the system is subdivided, and of the thermal resistances and capacitances associated.

The basic objective of the A.T.C. System thermal analysis have been:

I) To show that for all SPACELAB configurations (Module Only Mode, Pallet Only Mode; Module/pallet Mode) the Water and Freon Loops satisfy the following functions:

a) Collection of heat dissipated in the Module. b) Collection of heat dissipated by a Pallet Cold Plate mounted Equipments. c) Heat transport. d) Rejection of heat to the Orbiter Payload Heat Exchanger. e) Accomodation of peak heat loads which are temporaly stored by Thermal Capacitor elements.

II) To establish the temperature distribution (inlet and outlet values) at the main subsystem components.

III) To verify that the following system requirements are satisfied:

a) ATCS shall accomodate a continuous heat loads of 8.5 kW. b) ATCS heat transfer loops shall accomodate a 3 hour peak heat load cycle with 12.4 kW max. for 15 min. followed by 7.4 kW for 165 min. c) ATCS fluid elements shall not exceed the specified temperatures.

For each of the three basic configuration of the SPACELAB Active Thermal Control Loop, a mathematical model has been developed (ref. 2, 3, 4).

The Module/Pallet model mathematical model (fig. 6a) is discussed being the more completed and comprehensive of the other two modes; the system nodal diagram (fig. 6b) shows 100 nodes having capacitances interconnected by resistances.

- The various components have been schematized according to simplified mathematical models that have been proven to give results comparable with the ones obtained previously from the more complex models that for each components had to be constructed to investigate its behaviour and to assist in the design.

- The fluid model of the water loop is decoupled from the module structure being the plumbing mounted with teflon coated clamps and the temperature of the water estimated approximately equal to the ambient and/or structure temperature.

- The interface with the Orbiter is represented by the inlet Orbiter Payload Heat Exchanger temperature range (1.7÷4.4 °C).

- The fluid model of the freon loop is coupled with the Pallet Structure only through the Standards Cold Plates, and relative underlying panel.

The thermal analysis provides:
a) the steady state and transient temperatures of each node
b) the thermal flow at each component
c) the total energy balance
d) the thermal power transferred to the Orbiter Payload H/X

Two thermal load cases were investigated. In the first case the heat peak is imposed on the water loop (Module) through the Avionics Heat Exchanger, reaching a peak of 9.5 kWatt, while the Condensing Heat Load is constant at 3 kWatt. The heat must, in this case, the transferred across the Interloop Heat Exchanger to the Freon Loop and then to the Capacitors. In the second case the peak is imposed directly in the Freon Loop (Pallet) throught the Cold Plates, each one with a load of 0,5 kWatt (total 4 kWatt).

The temperatures of the key nodes as a function of time, have been computed and some of them (Water Loop, Freon Loop and Interloop Heat Exchanger nodes (fig. 7a), Cold Plate/Wax, Bolt Pad and Electronic Equipment nodes (fig. 7b) are reported.

The heat load profiles at the Orbiter Payload Heat Exchanger for the three configurations analyzed are reported (fig. 8a). The transient temperatures levels of the fluid delivered to the Orbiter Payload Heat Exchanger during peak/recovery condition for the three configurations are as well reported (fig. 8b).

A detailed "Sensitivity Analysis" has been performed (Ref. 5) for the three basic fluid loop configurations by varying the main system parameters; flow rates (water: nominal 227 kg/hr, minimum -5%, maximum +5%; freon: nominal 906 kg/hr, minimum -10%, maximum +10%), wax melting temperature ranges (nominal 39-40,Δ°C, minimum 38-39, Δ °C, maximum 40-41, Δ °C) and Orbiter Payload Heat Exchanger inlet temperatures (nominal 4.4°C, minimum 1,7°C).

Also heat load distribution has been changed, defining a minimum value, a maximum continuous value, and a peak and recovery value, as specified by interface documents.

The major aim of the study has been to investigate the influence of these main parameters on the interface with the Orbiter, namely on the outlet temperature and on the max heat rejection during peak conditions. In addition for all the components, the inlet and outlet minimum, maximum continuous, peak and recovery temperatures, in each case have been investigated.

The ATCS sensitivity analysis has confirmed that if each configuration is separately analyzed it is possible to further optimize the system by proper selection of some parameters. The commonality requirement for all the S/L components prevents the optimization of each individual ATCS configuration; the various components selection has been confirmed, from an over all point of view, to have been properly made.

The P.T.C. System Thermal Analysis

The thermal analysis of the high performance insulation blankets includes the effects of the multilayer radiation exchange, the rarified gaseous heat transfer, and the conduction in the spacers between the multilayers.
An equivalent conductance normal to the multilayer sheet is computed, as a function of the temperature for the different number of sheet in the blanket, through the use of a mathematical model.

The thermal analysis has been performed assuming a mission composed by an ascent trajectory a cold case (tail to sun bottom to earth) and an hot case (top to sun, starboard to earth) as orbital mission cases, and a descent trajectory.

The thermal analysis has been performed, utilizing the SINDA program, with environmental data and radiation factors provided by the LOHARP program; the model of the SPACELAB includes (fig. 9) the relevant parts of the Orbiter that exchange heat by radiation with the SPACELAB. A 167 nodes model with 2582 elements has been used for the general analysis, while more detailed model have been developed for specific localized areas.

A mathematical model of the SPACELAB Module structure has been developed to deal with the long Module configuration (two module segments), including the high performance insulation cover and is comprehensive of the tunnel, the top and aft airlocks, the simplified floor, racks, overhead, ceiling, stowage container modelling and the detailed modeeling of the attachment fittings.

The model comprising 192 nodes and 668 resistors is compatible with the Orbiter model and can be used for the foreseen integrated analysis to be conducted by NASA/ ESA.

The results relative to the on orbit cold and hot cases are shown (fig. 10) evidentiating the extreme temperatures obtained in the steady state conditions representing the more severe environmental conditions.

A mathematical model of the SPACELAB Pallet Structure has been developed for the analysis of the different Pallet configurations within the Orbiter Cargo Bay. The model comprises 170 nodes and 665 thermal resistors.

The two orbital worst cases have been considered in the analysis: Cold case: tail to sun,and hot case: top to sun; the steady temperatures have been computed in such extreme conditions for all the nodes of the mathematical model.

In the worst Cold Case orientation,the whole pallet reaches a mean temperature of about -180°C, while minimum and maximum temperatures of 185°C and -176°C are reached on the floor and skin center section panels respectively.
The four lateral attachments reach the same temperature level as the pallet structure, the keel attachment however, is slightly warmer, at -152°C, being connected to the orbiter structure, which is heated by earth infrared and albedo radiation.

In the Hot Case the highest temperature (77°C) is found on the skin center section panel while the floor center section panels reach a slightly lower temperature, in spite of being directly hit by the sun rays.

MANUFACTURING

The Active Thermal Control Subsystem consists as previously said of several components thatare utilized to form the basic Fluid Loops; the manufacturing of the components has been accomplished by Microtecnica that has utilized different techniques for each of them.

The A.T.C.S. components are successively connected by plumbings to form the standard circuits of the Water and Freon Loops; the activity of brazing the lines has been accomplished by AERITALIA that has utilized the Aeroquippe process. Pipe ends are butted or brought together at an angle and overlapped with special fittings incorporating the gold filler. Brazing is accomplished under special cleanliness conditions of the area and equipment used and under strict control for acceptance of the elements.

The Passive Thermal Control Subsystem consisting of the high performance thermal covers the manufacturing of which has requested extensive development at AERITALIA. Thebasic material double goldized kapton layers are contoured and cut, one by one utilizing for each piece a template; the extremities are in turn sew with an stainless steel wire. A grid of stainless steel wires is as well provided on the external teflon-fiberglass layer for grounding the static electricity.

TESTING

Development tests are performed at component level first, and later on at system level; the results of development tests provide the necessary inputs to modify the design of the development units and later on of the qualification unit if necessary.

Qualification tests are performed to evidentiate and to verify the adequacy of the hardware, in the flight unit configuration, to meet the flight requirements.

All the ATCS Components have been extensively tested by the manufacturer during the development phases of the program; thermal vacuum, vibration, shock, pressure thermal leak, physic properties and functional performance tests have been performed.

On the A.T.C.S., at system level two major tests have been planned and performed by AERITALIA.

- Thermal Vacuum on a Cold Plate, Thermal Capacitor, Filler, Electronics (simulated), Cold Plate Support Structure and Pallet Panel Assembly envisaged to verify the behaviour of different interface fillers and the cooling capability of the assembly under different heat cycles under vacuum.
The assembly was insulated by means of the standard thermal covers made of double goldized sheets with interposed dacron nets and two protective external layers.
The test article has been successfully tested in the AERITALIA Vacuum Chamber containing two cryogenic shrouds and contact heaters to simulate the environment conditions; a fluid circuit providing freon 21 at controlled temperature and flow rates has been used to feed the Cold Plate. Each element of the assembly has been extensively instrumented with thermocouples and also with heat flow transducers.
Eight test configuration were tested verying test article (type of filler), heat profile and mechanical interface (bolts and support pads). Test results are satisfactory (6) and have confirmed the design solution adequacy.

- Bread-Board Test on Water and Freon Loops, to assess the functional and operational performances of the Active Thermal Control Fluid Loops as a System (7).
The schematic diagram is shown for the Module Only configuration that has been tested as first (fig. 11).

The test article consists of all the ATCS components mounted on a test rig reproducing the flight location of each component; real development units are used except for OPHX, CHX, AHX and Payloads which are simulated (fig. 12).
The ATCS Ground Support Equipment consisting of Water Servicer, Freon Servicer, Signal Conditioning and Display Unit, Freon Leak Detection Unit (all designed and manufactured by Microtecnica), are considered integral part of the test article.
The three basic design configurations (Module only, Module Pallet, Pallet only) are separately tested for the nominal design conditions as well as for the extreme operational conditions to check the fluid flow rates, the pressure drop and the temperature levels as well as the other major design parameters.
The main objectives of the test are:
a) to establish the capability of the GSE to properly service, check-out, support, purge and dry the flight loop of ATCS.

b) To demonstrate the capability of the ATFS Fluid Loop to accomodate expected ground and flight thermal loads.

c) To verify equipment efficiency.

d) To determine the extreme capabilities of the ATCS design, under off design conditions.

e) To assess the fluid lines leakage expecially at breackable joints.

f) To evaluate the ATCS response to simulate hardware failures and to verify the capability of flight hardware instrumentation to detect these failures.

In addition to the flight instrumentation a special extensive test instrumentation is provided to monitor and record pressures, temperatures, flow rates and power conditions of the different components.

The first set of results are relative to the hydraulic behaviour of the system, for the module only mode (the first one so far tested) the overall pressure drop of the water loop has been measured and is reported as a function of the mass flow rate. Theoretical predictions have been confirmed by test results.

A second set of results is relative to the steady state thermal conditions existing in the fluid loop with maximum continuum and minimum heat loads and nominal, 227 kg/hr, flow rate. The results (fig. 13) in terms of fluid temperatures, ambient temperature and equipment temperatures agree within $\pm 0.5^{\circ}C$ with the predicted ones.

Investigations on the transient behaviour have been made, imposing an heat load with a specified peak of 12.5 kWatt for 15 minutes, the thermal response of the system has been investigated. Temperatures histories at the inlet and outlet of the Orbiter Payload Heat Exchanger are recorded (fig. 14) for the nominal flow rate condition; maximum value outlet reaches about $40^{\circ}C$ within the specified requirements of the interface.

The efficiency of the thermal capacitors included in the fluid loop is demonstrated by the difference in temperature level noticeable between the module output and S/L loop output curves.

CONCLUSIONS

The development of the SPACELAB Thermal Control System has required an extensive activity of design,analysis and testing that has been performed by AERITALIA, with the involvement of Microtecnica, Hamilton Standard and other qualified companies for the ATCS components; these activities have been completed with the successful Critical Design Review that has taken place in September 77 at AERITALIA.

No major change in the system design approach and in the components design has been needed, being the system requirements met; the majority of the actions resulting from the NASA/ESA/ERNO comments and instructions have been fulfilled and the remaining are being completed.

The interface activities are presently as well at their conclusion; mechanical and functional interfaces have been defined among the various subsystems and the final verification of the design has been reached during the System Critical Design Review successfully held at the end of February 78 at ERNO.

The qualification and flight hardware drawing release has been accomplished and the AERITALIA and MICROTECNICA manufacturing department have initiated production; the qualification and acceptance test are planned to be completed within October 1978.

The SPACELAB even if conceived to accomodate a large varieties of payloads, thus offering a large flexibility in design, has some inherent limitations that, in the light of the evolution of the space activities based on the utilization of the SPACE SHUTTLE-SPACELAB system, will require improvements, modifications, extensions.

Already to day, from the result of the discussions on the increasing payloads requirements held between NASA and ESA, is evident, even if not firm, that a mission duration extension is highly desirable. The evolution of the SPACELAB foresees as well progressive increasing degree of authonomy from the Orbiter that will be leading to the Free Flyer concept, a further step towards the SPACE STATIONS.

The role of the Thermal Control in this evolution is fundamental and the expertize gained so far with the SPACELAB baseline design will be extremely useful for any future involvement of AERITALIA in the area of advanced manned Spacecraft design, development and production.

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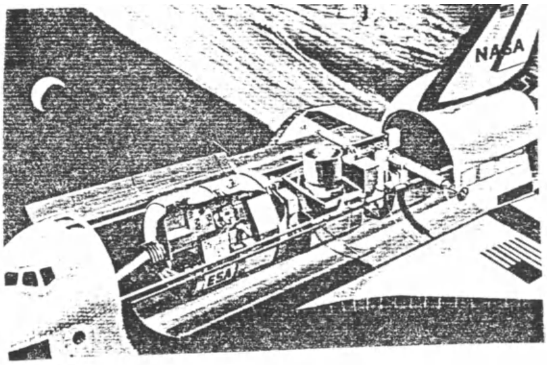

Fig. 1 - SPACE SHUTTLE

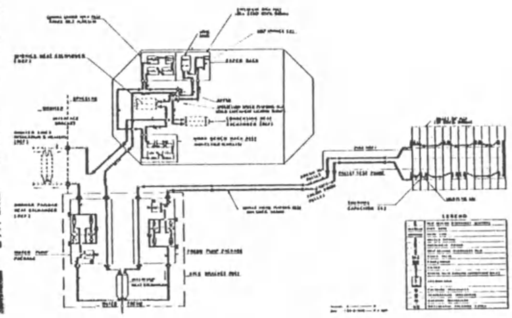

Fig. 2 - ATCS SCHEMATIC (MODULE/PALLET MODE)

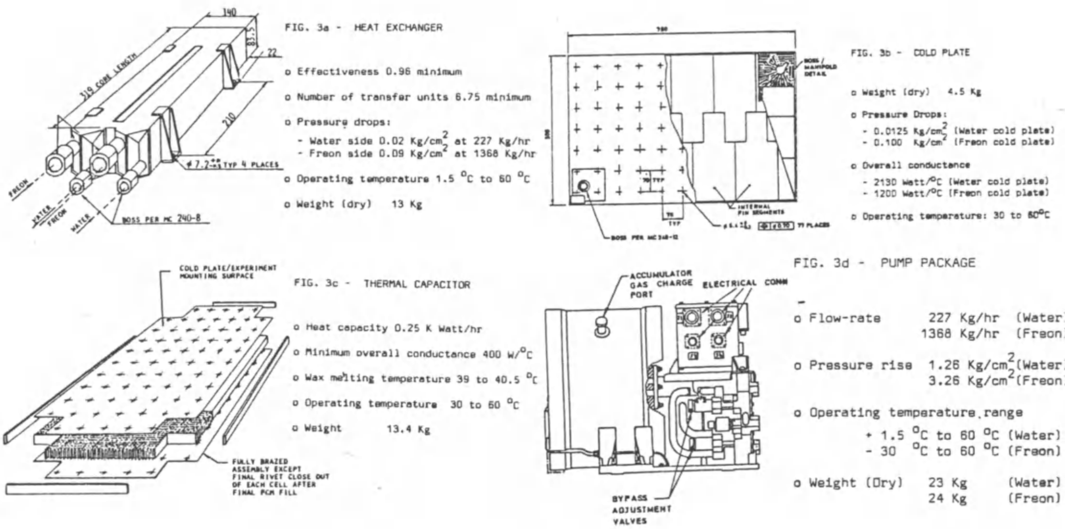

Fig. 3 - ATCS COMPONENTS

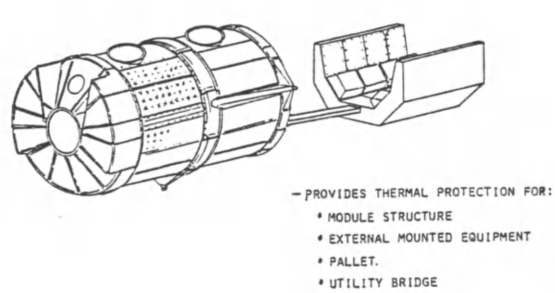

Fig. 4 - PTCS MODULE AND PALLET

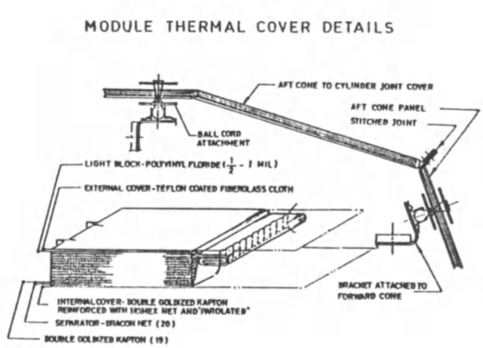

Fig. 5 - THERMAL COVER DETAILS

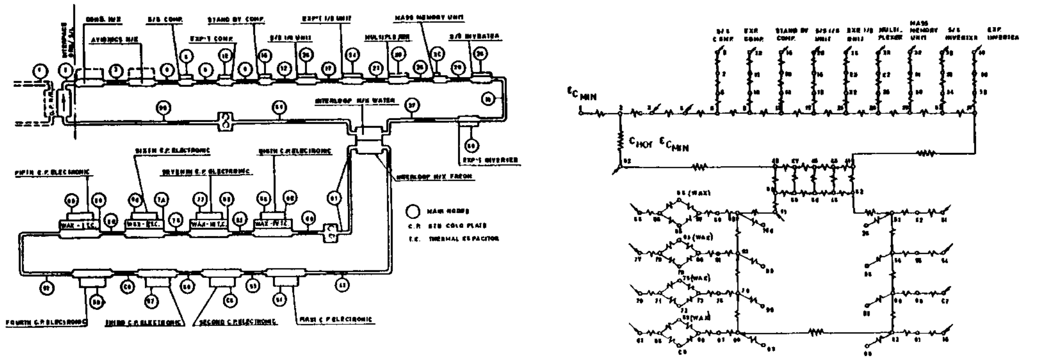

Fig. 6 - MODULE/PALLET MATH. MODEL AND NODAL DIAGRAM

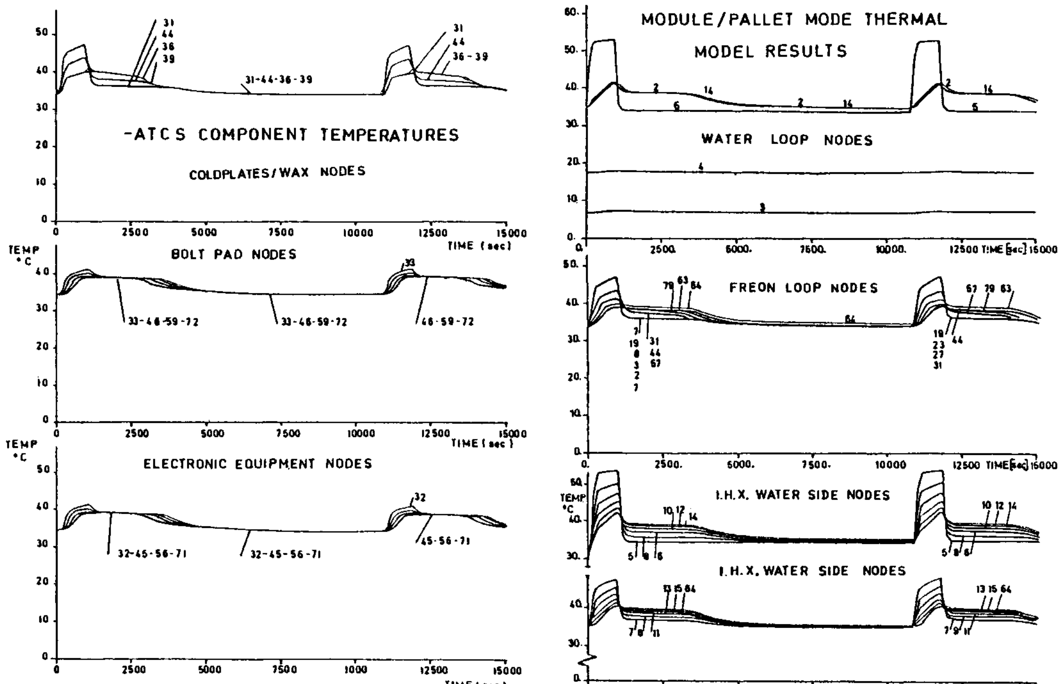

Fig. 7 - TEMPERATURES OF KEY NODES

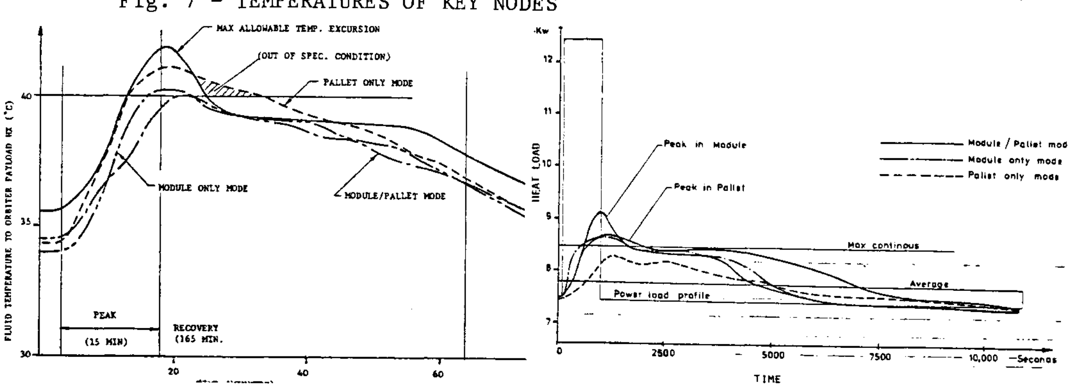

Fig. 8 - HEAT LOAD PROFILES AND TRANSIENT TEMPERATURES

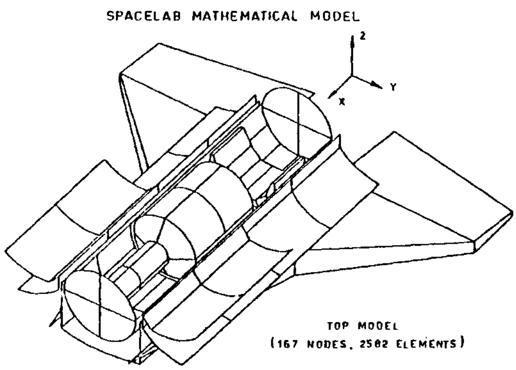

Fig. 9 - PTCS MATH. MODEL

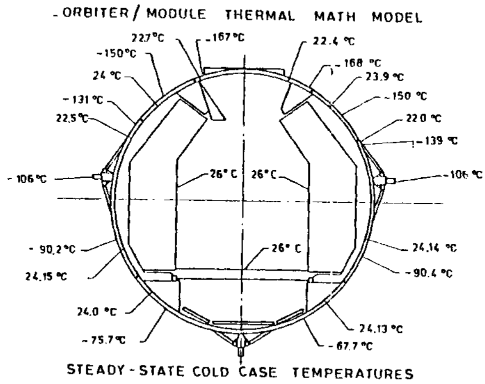

Fig. 10 - STEADY STATE COLD CASE

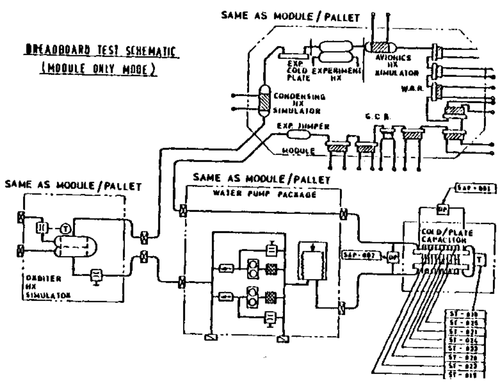

Fig. 11 - BREADBOARD TEST SCHEMATIC DIAGRAM

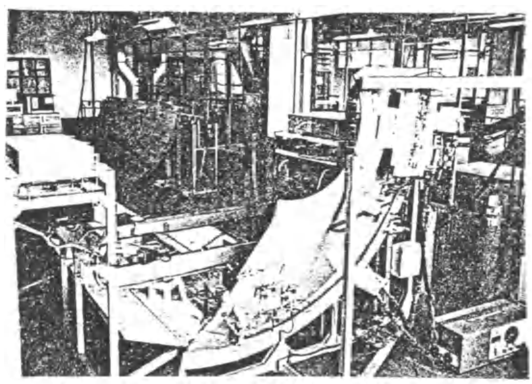

Fig. 12 - BREADBOARD TEST ARTICLE

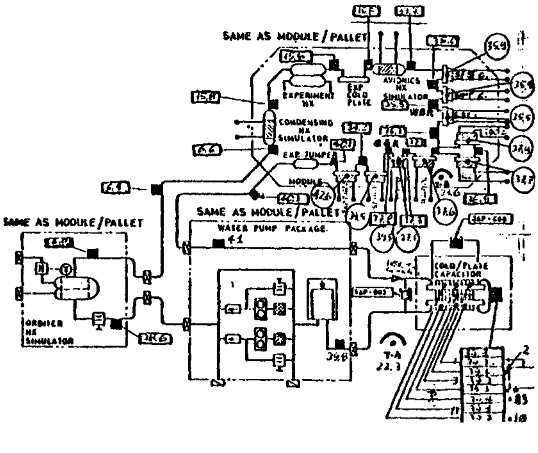

Fig. 13 - STEADY STATE RESULTS

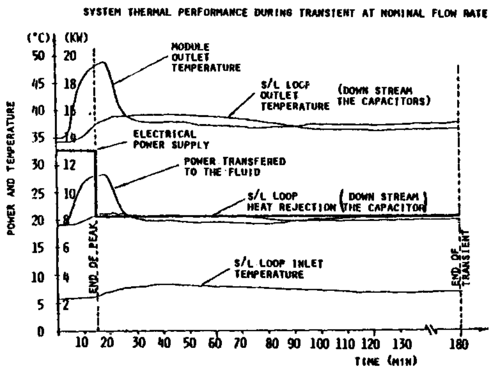

Fig. 14 - TRANSIENT STATE RESULTS

SPACELAB ENVIRONMENTAL CONTROL/LIFE SUPPORT SYSTEM (ECLS) FOR LIFE SCIENCE EXPERIMENTS

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ABSTRACT

Spacelab is the first spacecraft which offers the users earthlike conditions in zero gravity. An Environmental Control and Life Support System (ECLS) provides the appropriate functional hardware groups to control the Spaclab atmosphere. Oxygen/nitrogen composition, humidity, temperature, carbon dioxide, trace gas and odour are controlled for the crew as well as for the payload. Temperature control will also be provided for the subsystems and for open or compartmentized experiments located in standard racks.

This paper describes the ECLS in general with special emphasis on support of Life Sciences Experiments. Highlights of specific Life Sciences Experiments located in special racks are separately described. These space loboratories require their own environmental control circuits which interface with, and are supported by the Spacelab ECLS.

PART 1: ECLS-SUBSYSTEM DESCRIPTION

INTRODUCTION

A manned spacecraft is in principle, a huge thermal bottle which has theoretically no energy or material exchange with its surroundings. In order to provide a habitable compartment for human beings, the spacelab must not only condition the atmosphere but must also control the distribution and rejection of all heat generated in the vehicle. Electrical, mechanical and metabolic energy will be transformed into heat which must be removed from the cabin by being transported to and rejected by the Orbiter via radiators into deep space. There is however, an influence from the space environment. A sun oriented Spacelab mission heats up the vehicle, while a shadow position cools Spacelab. Further, atmospheric leakage occurs through all the structural seals. The ECLS controls those positive and negative heatleaks and compensates the oxygen and nitrogen loss.

Spacelab is the first spacecraft which provides the crew and the users a shirtsleeve atmosphere under earthlike conditions. The cabin temperature is selectable between 18° and 27° C; and the humidity levels meets crew comfort criteria. The 1 atmosphere (760 mm Hg) internal environment has a 21%/79% oxygen/nitrogen composition.

FUNCTIONAL DESCRIPTION

The Spacelab Environmental Control/Life Support Subsystem (ECLS) is comprised of two major portions, the Atmosphere Storage and Control Section (ASCS), and the Atmosphere Revitalization Section (ARS).

The ASCS furnishes a two-gas atmosphere in the Spacelab cabin compatible with the atmosphere of the Orbiter crew compartment. Primary functions provided by the ASCS are: (1) storage and supply of gaseous nitrogen required for leakage make-up and experiment airlock operations, (2) supply of gaseous oxygen transferred from the Orbiter and required for metabolic consumption and leakage make-up and (3) control of the Spacelab cabin total pressure and oxygen partial pressure for an earthlike atmosphere.

The ARS maintains a shirtsleeve conditioned environment for the crew and a temperature controlled atmosphere for avionics equipment and experiments inside the module. Major functions provided by the ARS are: (1) control of cabin temperature and humidity, (2) air ventilation and distribution, (3) carbon dioxide, odour and trace contaminant removal, (4) storage of condensate, and (5) avionics and experiment cooling.

Hardware to accommodate the ASCS functional requirements include a two-gas control system with pressure regulators, control units, valves, sensors, and logic units. For the ARS, the hardware includes two airloops with fans, heat exchangers, lithium hydroxide (LiOH) cartridges and filters, a water separator with a storage tank and dump devices, and a complete ducting system for air circulation and ventilation.

DESIGN REQUIREMENTS

The ECLS is designed to support 50 normal Spacelab missions of 7 days duration over a time period of 10 years. With minor changes missions up to 30 days can be supported. The ECLS operates similiarly for both the long Spacelab module with 77 m^3 free volume and the one-segment Spacelab with 38 m^3 free volume. Table 1 lists the major design criteria while table 2 shows the performance requirements.

Crew Size	0 - 4 men
nominal	1 - 3 men
	52 manhrs/d
Atmosphere Total Pressure	1.013 +/- 0.013 bar
Oxygen Partial Pressure	0.220 +/- 0.017 bar
Oxygen Consumption, nom.	0.84 kg/manday
Carbondioxid Generation, nom	0.99 kg/manday
Humidity Level	$6^{o}C$ to $15^{o}C$ Dewpoint
Module Atmosphere Leakage	1,35 kg/d max.

Table 1: ECLS Design Criteria

Cabin Air Velocities	5 to 12 m/min
Temperature	
Cabin, selectable	$18^{o}C$ to $27^{o}C$
Rack Inlet (nom. Cabin Load)	$35^{o}C$ max.
Heat Loads	
Cabin Loop Total	2782 W (Design Point)
Avionics Loop, Total	4510 W
Payload Accommodation	
Cabin	1000 W
Avionics Loop	4000 W
Single Rack	1600 W
Double Rack	3130 W
Air Filtration	300 micron
CO_2 Partial Pressure, nom.	0 to 6.7 mbar
Noise Control	NC 50 - 3 dB
Fire/Smoke Detection	for on-orbit and ascent/descent
Fire Suppression	for racks and underfloor

Table 2: Performance Requirements

SYSTEM DESCRIPTION

Atmosphere Storage and Control

A schematic of the ASCS is presented in Fig. 2. High pressure gaseous nitrogen is stored in a lightweight composite tank located outside the module at the forward endcone. The necessary oxygen is provided by the Orbiter at a pressure of 100 psig. The oxygen and high pressure nitrogen lines deliver the gases to a N_2/O_2 Control Panel which is located inside the module. Oxygen partial pressure sensors assure a normal O_2/N_2 mixture within Spacelab.

The ASCS also supports the experiment airlock with dry nitrogen for refill purposes. The oxygen system allows manual override of the automatic control to overcome possible pressure interactions between Spacelab and Orbiter.

Valves, located on the upper feedthrough plate, control Spacelab total pressure and allow, if required, partial or total dump of the Spacelab atmosphere in the event of contingencies.

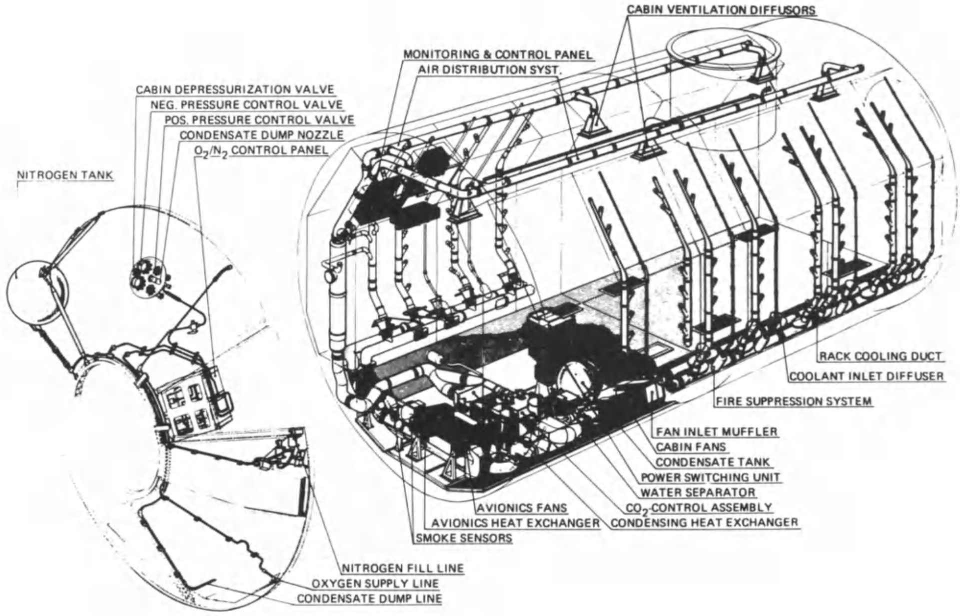

Fig. 1: ECLS Hardware Arrangement

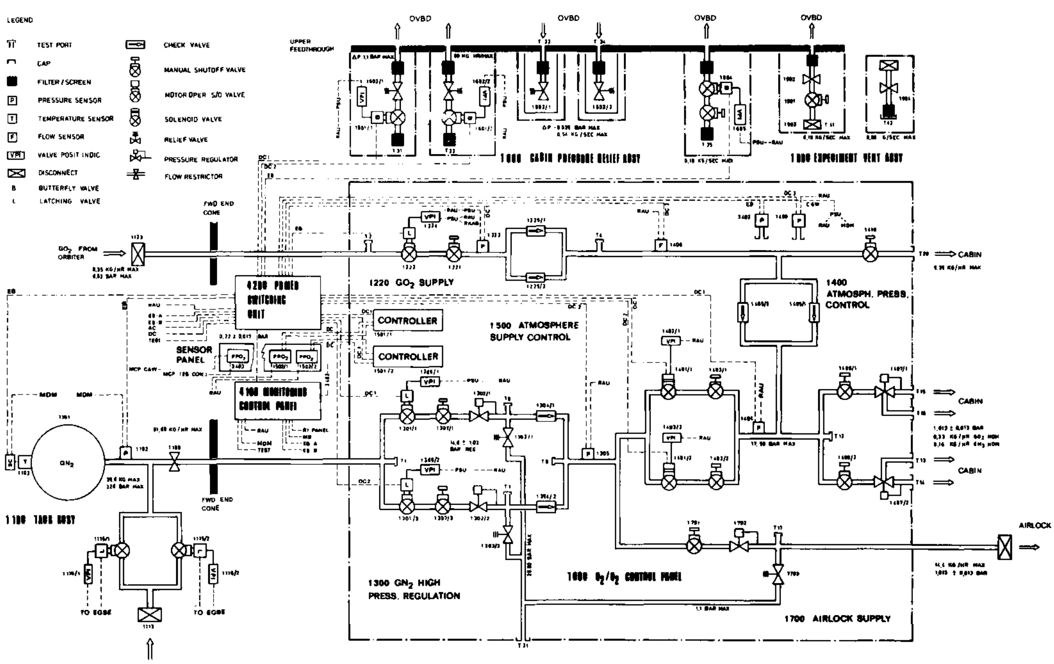

Fig. 2: ASCS Schematic

Atmosphere Revitalization

The Atmosphere Revitalization Section is illustrated in Fig. 3. This section is, for thermal reasons, divided into two airloops. A cabin loop provides a shirtsleeve environment for the crew as well as for thermal control of experiments in the open cabin. An avionics loop cools most of the subsystem and payload equipment located in the cabin racks.

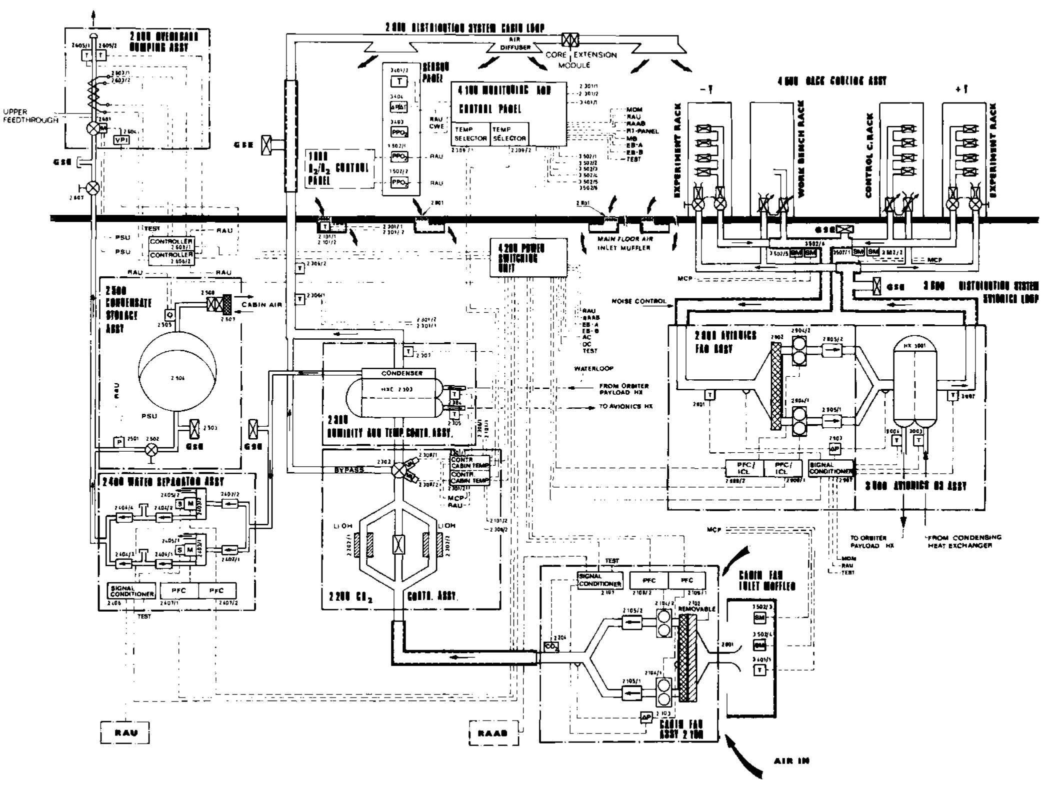

Fig. 3: ARS Schematic

ARS-Cabin Loop

An open cabin loop provides air ventilation, distribution, and heat collection within the module.

A cabin fan sucks the cabin air through grills in the main floor into the subfloor area, cooling subsystem equipment before entering the duct system through a muffler. The muffler, in conjunction with other devices, attenuates noise in the Spacelab cabin.

Lithium hydroxide cartridges control CO_2, trace gases, and odors, while a condensing heat exchanger controls both temperature and humidity. The heat sink for the condensing and avionics heat exchangers is a water loop connected to the Orbiter payload heat exchanger.

Conditioned air is ducted to a distribution system which is located in the Spacelab ceiling. The air is blown into the cabin, through diffusers providing good ventilation without any stagnation. In the open cabin area, the airflow picks up heat from crew, payloads, walls, and equipment rack radiated heat. The ventilation system also provides for an adequate interaction with the tunnel ventilation system.

ARS - Avionics Loop

An avionics fan provides airflow through the Spacelab subsystem racks and experiment racks. Since many of the assemblies in the subsystem racks are coldplate cooled, the flow is defined by the requirements of non-cold-plated assemblies and experiments. For the purpose of power conservation and smoke detection, the avionics fan is designed for two operational speeds. During ascent/descent, when only a few experiments are operating and power is limited, the fan is operated at low speed (normal operation: 670 W, 872 kg/hr; reduced speed: 120 W, 290 kg/hr).

By connecting the avionics loop to the cabin loop during ascent and descent through openings in the avionics ducting, smoke detection in all areas, which must normally be supplied by both loops is, assured with only the avionics fan running.

Avionics Loop Payload Support

The long module allows for a maximum accommodation of ten experiment racks and the short module for four racks.

Spacelab provides two rack configurations, single racks containing a maximum heat load of 1600 W and double racks containing up to 3130 W. Fig. 4 shows the worst case heat load allocation for experiments and the appropriate coolant support.

Each rack is connected to the avionics loop supply and return lines. To allow adaptation to different missions or to different experiment requirements during a mission, rack shut-off valves are installed in the inlets and outlets.

Air is blown into the rack via a diffuser at the rack bottom. A return duct with branch lines is installed inside the rack. For flow control, each branch is equipped with a trim orifice adjusting the airflow rate and the air distribution inside the rack. Internally cooled equipment is connected directly to these branches (Fig. 5).

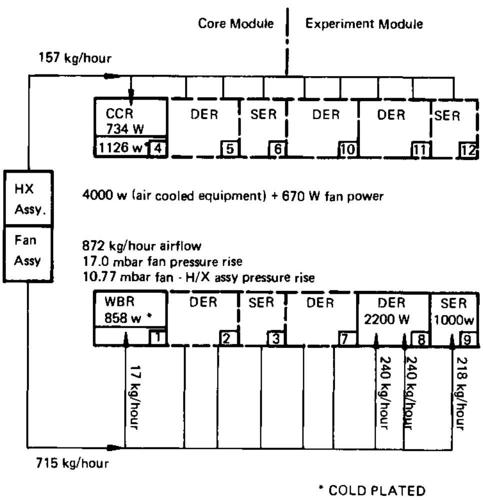

Fig. 4 Avionics Loop Cooling

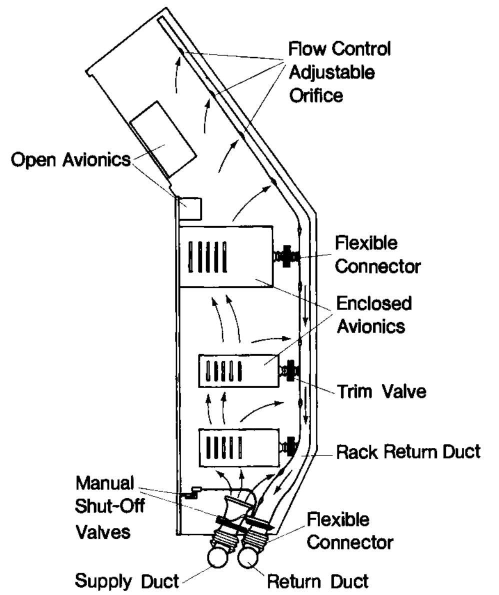

Fig. 5 Equipment Rack Cooling

Cooling Flow Adjustment

A procedure has been established to balance the flow distribution according to the power consumption of the installed equipment. After experiment integration, the fully equipped rack will be internally balanced according to the flow versus power requirements, using the trim orifices of the branch lines.

Since the pressure difference between avionics loop supply and return lines will vary along the loop, each rack's total airflow must be adjusted by its inlet/outlet shut-off valves according to the rack position in the loop. This will be done at the experiment train level when all experiment racks are installed in the module.

On a rack integration level, the entire avionics loop, including experiment racks and subsystem racks, will be finally balanced, to provide air cooling according to the overall heat loads, internal power distribution, location, and internal shape of contained equipment.

SYSTEM PERFORMANCE

Fig. 6 shows the achievable cabin temperatures at the design point for the max. continuous heat load and the worst case coolant inlet temperature. At these conditions the system can supply $19,6\,^{\circ}C$ as the low temperature. It should be pointed out that the nominal water supply temperature results in cabin temperatures even below $18\,^{\circ}C$. These temperatures are measured at the bottom of the habitable area.

There is between the top of the crew compartment and the main floor a temperature gradient of less than 2°C, which is achieved by an optimized cabin air flow pattern.

Fig. 6 shows how much heat load could be introduced in addition to the design heatload (which includes 1 kw for experiments) into the habitable area while still achieving temperature control.

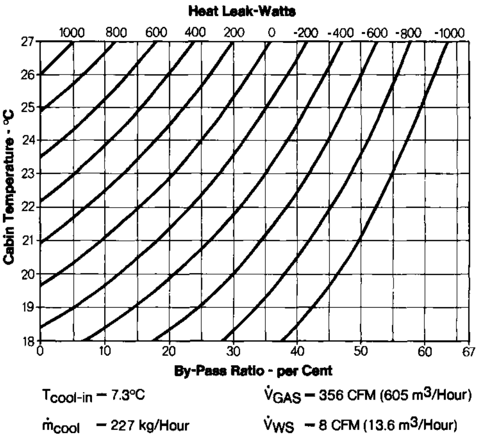

Fig. 6 Cabin Temperatures

Fig. 7 shows the measured air velocity profiles in the habitable Spacelab cabin.

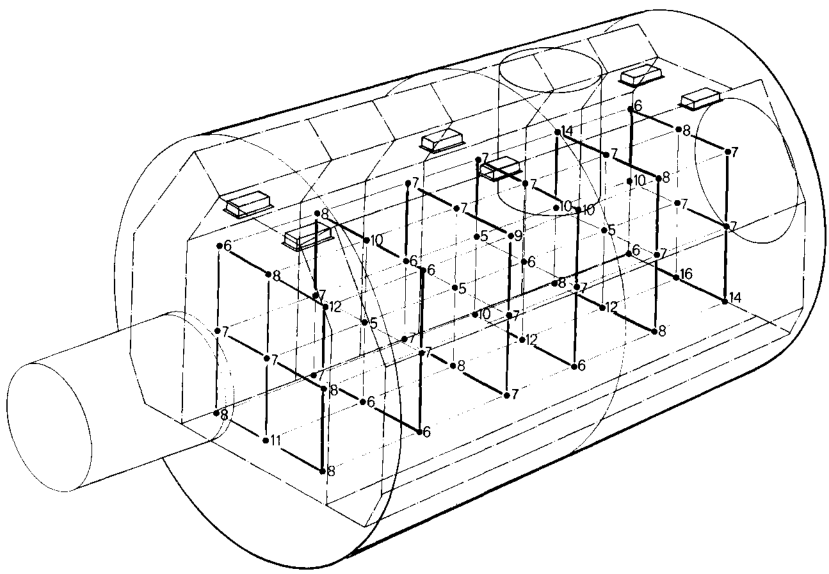

Fig. 7: Cabin Air Velocities (in m/min)

Fig. 8 shows the crew comfort envelope with the cabin dew point resulting from the sensible and latent heat loads of experiments, subsystem and the crew, plus an additional 250 W latent load for experiments which is equal to another 3 men or can be used for life sciences experiments.

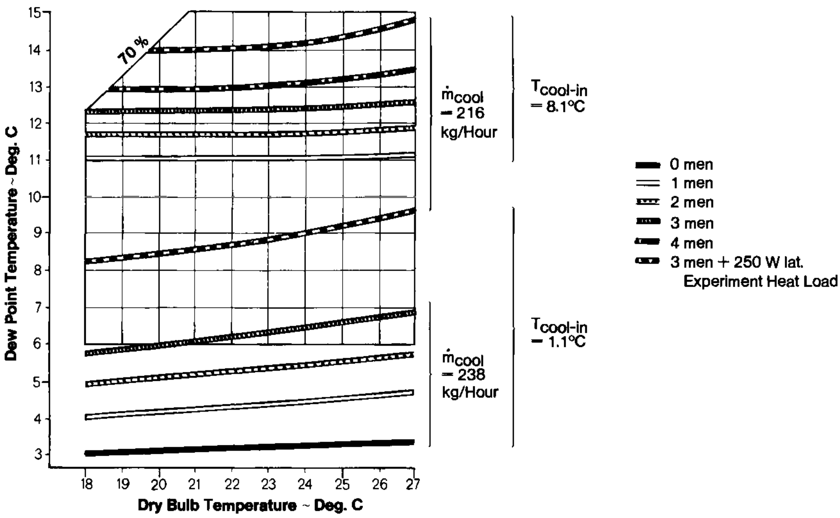

Fig. 8: Cabin Dew Point

The removed latent load, the moisture of the air, will be separated from the atmosphere by means of a condensing heat exchanger and a water separator and collected in a tank. The capacity of the tank allows an additional 20 % (10 liters) to the normal load for experiments, if required. A dump device is also installed to allow overboard dumping of condensate as often as required to support longer mission durations and to control enexpected moisture generation.

Fig. 9 shows the noise level induced by the ECLS without noise attenuation and the analytical prediction for the ECLS noise level after implementation of selected noise attenuation devices. The final noise level will be in the range of the Orbiter noise criteria 45 contour.

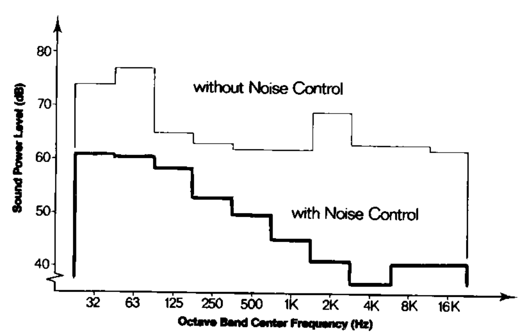

Fig. 9: ECLS Noise Attenuation

Fig. 10 shows the oxygen partial pressure variation over a 7 day mission. It is based on the given crew duty cycle which is a 12 hr. shift by 3 men following a 12 hr. shift of 1 man (both shift overlap one hour). The oxygen is supplied by the Orbiter with sufficient margins either for payloads or for longer missions. The Orbiter baseline includes double the necessary amount of oxygen for Spacelab. Also the Spacelab nitrogen tank is, for a nominal mission, not fully loaded, leaving a margin for payload support.

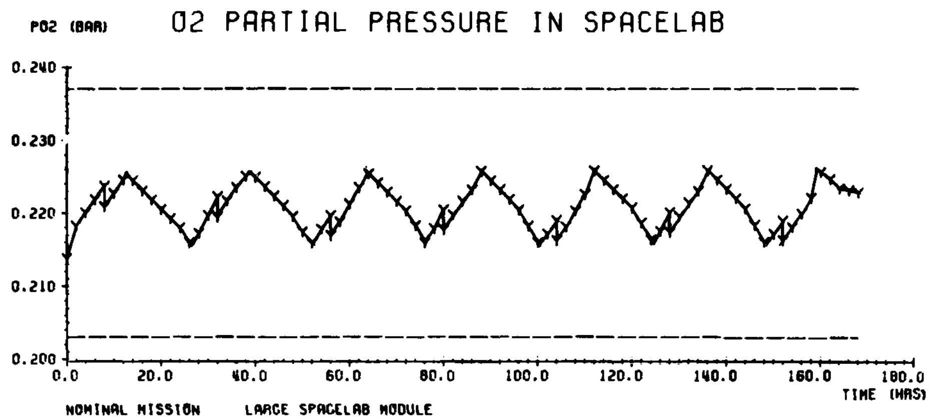

Fig. 10: Oxygen Partial Pressure Profile

The CO_2-level profile in Fig. 11 shows that during a change sequence of 21.6 hrs 5 mm Hg never will be exceeded. Here it should be noted that the Spacelab and Orbiter LiOH-Cartridges (with activated charcoal) are identical and therefore interchangeable. If there is a higher production rate of CO_2 or trace gases/odours, one must only change the cartridges more often in order to keep the allowable concentration level in the atmosphere. It should also be mentioned, particularly for life science payloads, that the condensing heat exchanger removes most of the water soluble trace gases, such as methane or ammonia, from the cabin air.

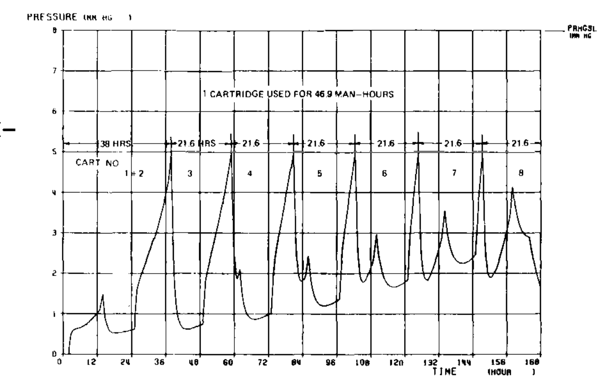

Fig. 11: CO_2 Partial Pressure Profile

CONCLUSION

This description points out that the ECLS is not only designed for the basic Spacelab but also to support a wide range of payloads. There are, in most areas, sufficient margins which experiments can readily utilize.

The design in its present configurations can be used as is for life sciences experiments located in their own racks (such as Biorack). Minor modifications would allow flying experiments with apes, rats, mice, etc.. Some of such experiments might require a caged location with its own air conditioning. However, the ECLS would be the interface for environmental control.

PART 2: LIFE SCIENCES RESEARCH ONBOARD SPACELAB

ADVANTAGES OF SPACELAB FOR LIFE SCIENCES RESEARCH

Spacelab offers the opportunity to perform life sciences investigations within a large scope. High complexity of experimental procedures combined with an increased precision of experimental techniques are required to investigate the aetiology, the nature and mechanisms of physiological and biochemical processes. Therefore an appropriate laboratory environment is needed offering the possibility of handling experimental equipment directly and of altering procedures if this is required by unforeseen events (Fig. 12). On the other side a certain degree of automation or a limitation of the number of experiments is necessary because of restricted crew time.

Additional advantages of life sciences research by Spacelab are:

- Environmental conditions can be controlled very similarly to those of terrestrial laboratories.
- Scientific planning can take place in a similar way as in ground laboratories.
- Possibility of follow-on experiments. New findings and results may be examined on following flights either within the planned life sciences missions or by carry-on experiments.
- Study of long-term effects of weightlessness and other parameters on organisms.

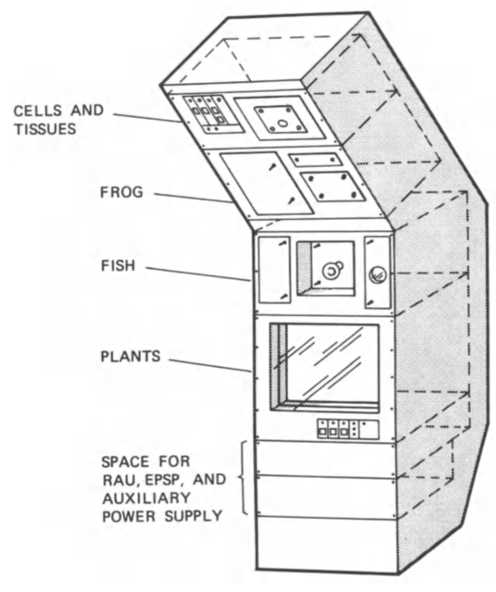

Fig. 12: Biorack Incubators and Holding Units for Cells and Tissues, Plants and Low Vertebrates

Life sciences laboratories with the capability of controlling environmental conditions include incubators and holding units for cells and tissues, plants and animals, equipped with the requisite instrumentation to record and monitor the various experimental parameters. They include, moreover, equipment for medical examinations of the crewmembers themselves for diagnostic purposes and clinical surveillance.

RESEARCH EQUIPMENT

Three types of life sciences laboratories may be taken into consideration. The research equipment may be laid out as:

- Single drawers
- A compact life sciences laboratory within one or more single or double racks, which could be called "BIORACK" or "Mini-Lab"
- A laboratory covering the whole Spacelab.

The single drawers, which are used to conduct a single experiment or a few closely related ones, may fly as carry-on experiments located in the Orbiter, the Spacelab module or on the pallet. An example could be the fish incubator (Fig. 13, SL module version), which is used for vestibular research.

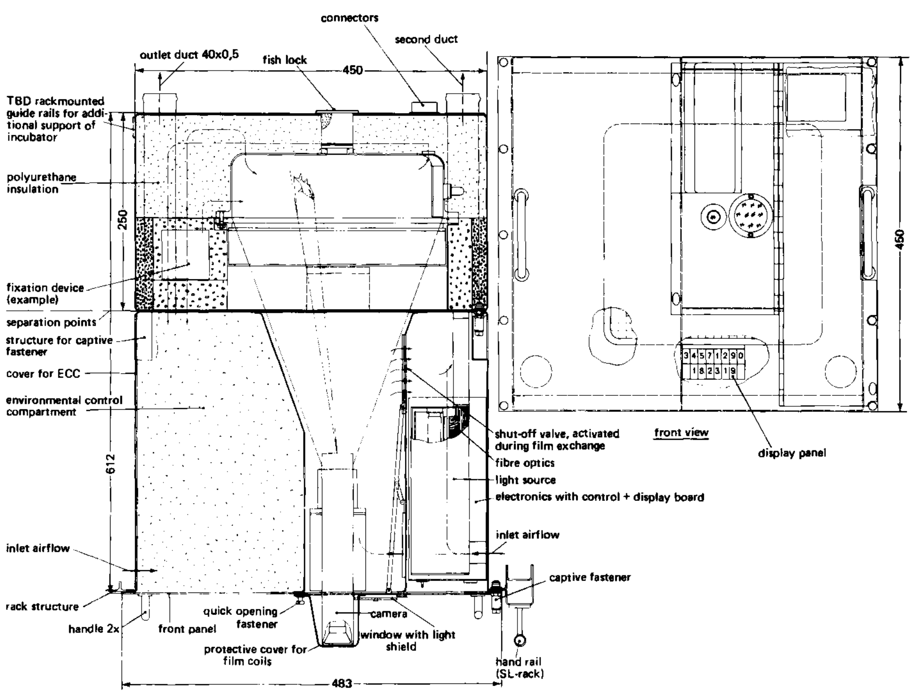

Fig. 13: Fish Incubator (as carry-on experiment)

The next larger type, the single or double rack laboratory ("BIO-RACK"), is capable of supporting a number of experiments (see Fig. 12). It will be flown during multidisciplinary Spacelab missions. That are missions with additional other disciplines outside of the life sciences.

The largest type requires the whole Spacelab module as laboratory, utilizing all available resources of Spacelab for life sciences experiments. This type of laboratory is associated with dedicated life sciences missions for biological and medical research. Crew time shall be regarded as a critcal resource.

BIORACK - AN EXAMPLE FOR THE LABORATORY CONFIGURATION

To give an example for one type of a life sciences laboratory, the "Incubators and Holding Units for Cells and Tissues, Plants and Low Vertebrates" may be mentioned here. A study on this BIORACK was awarded by ESA to Dornier System with the design goal of satisfying the different needs of the following life sciences programme:

- Effects of space environment on cells and tissues with regard to e.g.: growth, development and metabolism
- Effects of weightlessness on germination, growth and bioloical rhythms of plants
- Effects of weightlessness and hard radiation on animals, in this study on low vertebrates, especially concerning the vestibular function and the impact of HZE-particles on the retina.

The study was related to the design of four chambers with closely controlled environmental conditions like temperature, humidity, light and the composition of the atmosphere, additionally filled with water or a nutrient medium if necessary. These "incubators" are filling a Spacelab standard rack. The incubators for low vertebrates were in charge of Dornier System (Germany) as prime contractor. The incubators for cells, tissues and plants were in charge of the STEEL company (France), which acted as subcontractor.

Any such incubator, which must function under zero-gravity conditions as well as under presence of gravity, was equipped with the requisite instrumentation to record and monitor the various experimental parameters. Such control and monitoring systems must be compatible with the basic Spacelab subsystems and environment during ground operations, launch, mission and landing. The accommodation of the incubators to Spacelab has therefore been studied taking in particular into consideration all parameters related to biological specimens.

It is important to know that the incubators have been projected as a "Facility", i.e. not dependenton one experiment or two, but usuable for a lot of experiments according to the different wishes of the experimentators. That is why a system with easy exchangeable modules, a "modularized system", has been designed.

Incubators for Low Vertebrates

As low vertebrates there are used fishes and frogs. The fish incubator with an aquarium inside, equipped with a camera, is used for filming the fish behaviour under the influence of weightlessness, supplemented by acceleration and optical stimuli. That belongs to the investigation of the vestibular system of vertebrates. In addition, research on the development of fertilized fish eggs and young fishes can be carried out. The incubator design must allow for the use of salt water, and stringent requirements had to be fulfilled concerning water oxygenation, temperature regulation and lighting (Fig. 14 to 16). The interface to the Spacelab Environmental Control System is also shown on the figures.

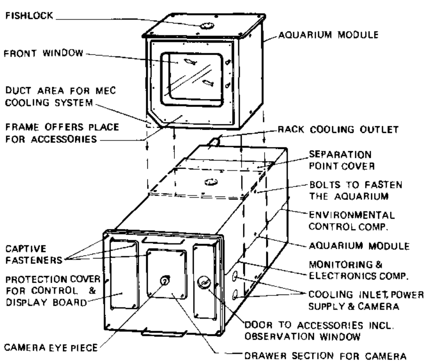

Fig. 14: Fish Incubator General View

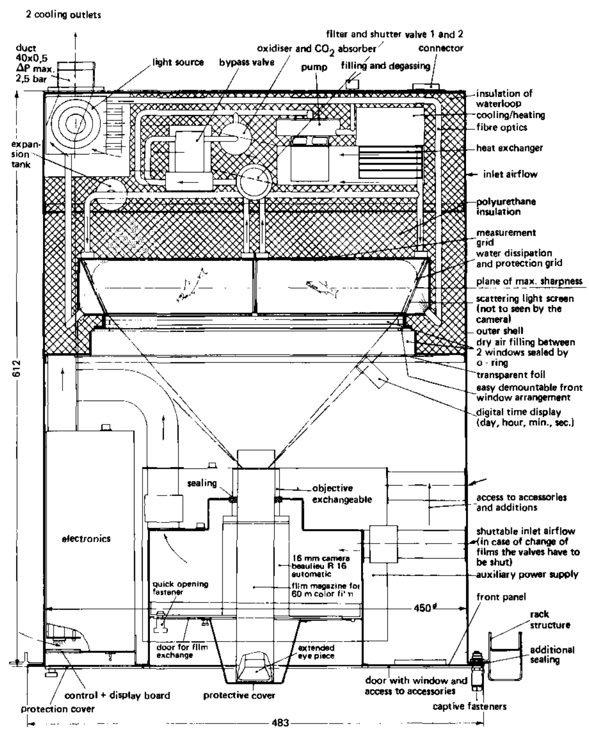

Fig. 15: Fish Incubator

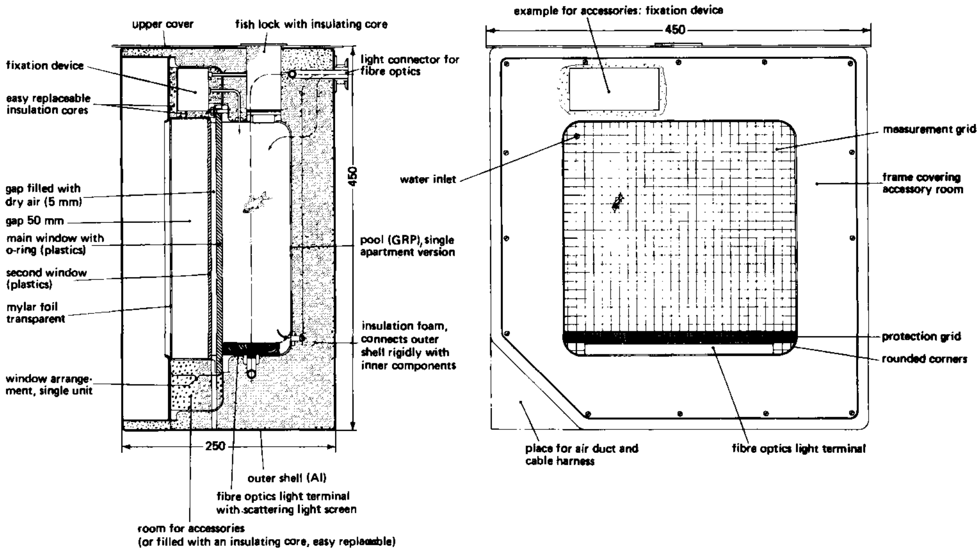

Fig. 16: Fish Incubator Aquarium Module

The frog incubator serves for the determination of the effects of hard radiation (HZE-particles) on low vertebrates. Therefore an amplifying and recording system for an electroretinogram is provided for, which is activated by signals from either a flash or a high energy particle. The frog is kept in semihibernation lying in a foam bed with a controlled system for the humidification of its skin and for temperature and atmosphere regulation (Fig. 17, which also shows the interface to the Spacelab Avionics Loop).

The reason of this experiment is that luminous trails or whitish flashes have been experienced during manned spaceflight. These light phenomena are probably related to the cosmic radiation which can induce a fluorescence of the vitreus (Cerenkov's effect) or directly stimulate and possibly damage the retina.

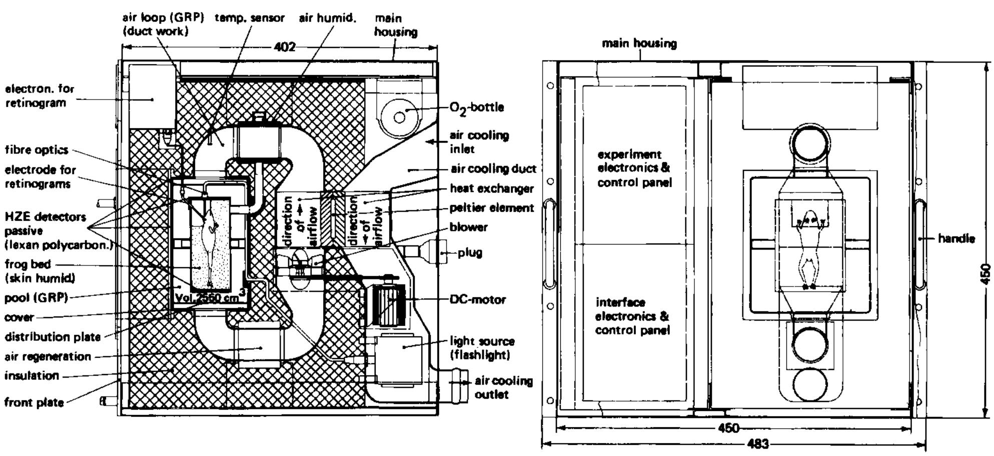

Fig. 17: Frog Incubator

Incubator for Cells and Tissues

This incubator enables the evaluation of the specific effects of space environment on cells and tissues with regard to e.g. growth and metabolism. Living cells and the metabolisms deriving from them are in all cases extremely sensitive to temperature. Therefore a very accurate thermal regulation is required. Furthermore, some experiments require observation of the cells using a microscope linked with a camera (outside of the incubator). The accessibility and ease of handling the culture media must be ensured, as well as proper lighting and fixation devices. (Installation within the BIORACK see Fig. 12).

Incubator for Plants

The study of the influence of the space environment, especially of weightlessness, on plants is essentially oriented towards investigations of geotropism, i.e. modification of plants as a function of their orientation with respect to the gravity vector or their orientation at zero gravity. These studies are conducted in general by photographic recording of the behaviour of plants, followed by cytological studies of the cells after the flight, necessary for the overall understanding of the phenomena observed. (Installation within the BIORACK see Fig. 12).

CONCLUSION

Life sciences laboratories will help us to study the specific effects of exposure to space to ensure the safety, health and efficiency of the crewmembers and to re-evalute various biological systems with an impact not only to space biology and medicine, but also to fundamental biology and clinical medicine on earth. The Spacelab resources, especially the Environmental Control and Life Support System, enable these scientific investigations.

EVOLUTION OF SPACE POWER SYSTEMS

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ABSTRACT

NASA planning for large power systems (tens to hundreds of kilowatts) in space for the next decade is summarized. Applications requiring large amounts of power, the selection of solar photovoltaic as the primary power conversion approach, and the power technology base are explained. Large power systems, beginning with a Space Shuttle/Spacelab power augmentation kit and an orbitally stored Power Module, are described.

INTRODUCTION

It is particularly timely to review the course of future space power systems. After almost a decade of development, the Space Shuttle is rapidly approaching the date of its first orbital flight. This event will be closely followed by a buildup of operational flights bringing a new era of space achievements.

The early Shuttle capabilities will represent a giant step forward in man's conquest of space. Yet, in another sense, the present Shuttle is only an early baseline for even greater capabilities. We foresee the rapid evolution of new capabilities for doing useful work in space. We foresee extending the Shuttle virtues of reusability, low cost, and manned operations to higher altitudes and to more routine operations including permanent occupancy of space.

SPACE OPERATIONS EVOLUTION

With this evolution of space transportation and orbital systems, we will see a similar evolution of space power needs. Before delving into space power requirements growth, technology, and systems descriptions, we would like to lay out our vision of the milieu in which future space power systems will evolve.

The first two decades of space operations have, of necessity, been based upon one basic principle. This has been the concept of keeping the spacecraft as simple, uncomplicated and reliable as possible. A corollary to this point is the policy of keeping the complexity on the ground and relieving the satellite of as many functions as possible. With the achievement of easy access to space and ultimately permanent occupancy of space, the opportunity presents itself to reverse this process and to develop much larger, complex satellites and greatly simplified ground stations. This reversal is possible because of continued access to the satellite for maintenance and updating, because of the opportunity to erect, deploy and checkout large structures such as high-gain antennas, space platforms, and other mechanisms and because of the dramatic increase in electronic capacity which allows on-orbit functions that could not be risked with current unattended satellites. It follows that such systems create a greatly increased demand for spacecraft power on orbit.

Such a concept allows broad proliferation of ground stations bringing practical utilization of space systems on an everyday basis to the man-in-the street. Applications of this technique are manifold.

Space power systems will be but one of several new enabling systems which will be available in the 1980's to initiate this trend. By enabling systems, we mean systems which offer the capability to perform missions which heretofore were not possible. Foremost among these systems, of course, is the Space Shuttle (Fig. 1). Not only will the Shuttle provide the transportation to low earth orbit that formerly was provided by expendable boosters, but the Shuttle will open the door to routine pre-deployment checkout, retrieval and return, on-orbit servicing, construction and assembly, and, until a permanent space station is available, sortie missions. The keys to these capabilities are the Shuttle's reusability and man.

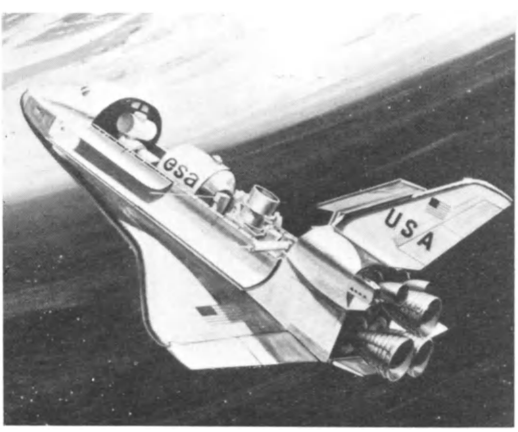

Fig. 1. Space Shuttle

Quickly following Shuttle will be a host of other new systems which will expand upon and build from Shuttle capabilities. Transportation with low thrust and manned high performance Orbit Transfer Vehicles will extend many of the Shuttle capabilities to geosynchronous orbit and other high energy orbits. In orbital regimes in which it is not technically or economically possible to transport man, his sensory and manipulative capabilities can be extended through remotely operated telemechanisms such as Teleoperator Retrieval System now under development by NASA. Beam fabrication machines (Fig. 2) will form the heart of space construction and assembly facilities (Fig. 3) which will permit the fabrication of very large antennas and structures in space. Through Spacelab follow-on development or Skylab reboost and rehabilitation may come permanent habitation by man, our first true space station (Fig. 4).

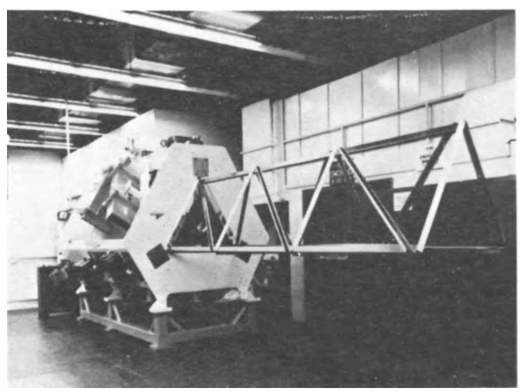

Fig. 2. Beam Fabrication Machine

These systems, together with space power systems, permit an orderly progression toward ever increasing capability to support missions in space (Fig. 5). Power equals duration in this evolution; the availability of an augmentary power source will extend the duration of Shuttle/Spacelab sortie missions. The same power system will support free-flight payloads between Shuttle flights, and, with habitability modules, form the core of a space station. If Skylab is successfully reboosted, it and the power system could form an early Shuttle-tended station. These stations, with suitable construction facilities and transportation, will be stepping stones to high power operations and to geosynchronous orbit operations.

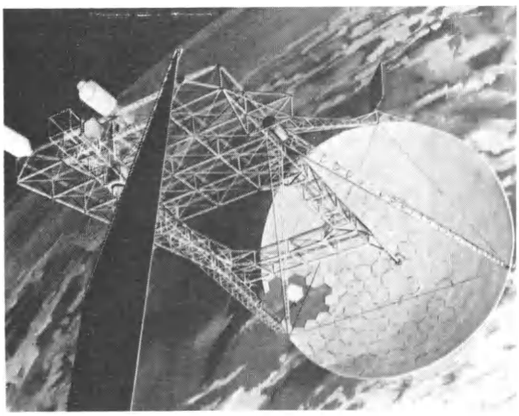

Fig. 3. Space Construction Platform

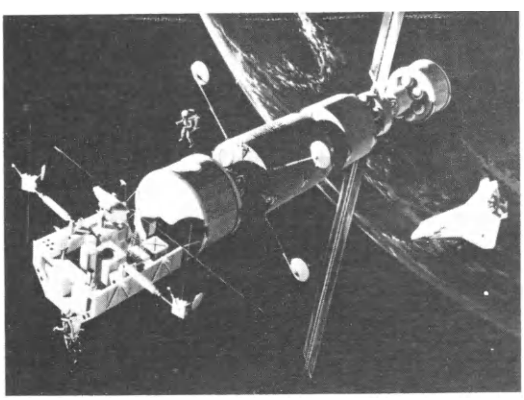

Fig. 4. Manned Space Platform

SPACE POWER APPLICATIONS AND REQUIREMENTS

We will find that through these enabling systems our capabilities for performing materials and pharmaceuticals research, development, demonstration, and, finally, production will quickly expand. These will be accomplished on Spacelab, on Materials Experiments Modules (Fig. 6) and similar facilities and, finally, on production platforms. Increased demand for improved communications at low cost will be met with large Public Service Platforms (Fig.7) constructed, transported, and maintained with our enabling systems, Transportation of such large platforms and of certain interplanetary spacecraft will be accomplished with large electric propulsion systems. All our enabling systems would be put to task in support of Satellite Power System (SPS) experiments (Fig. 8), demonstration, and construction. The enabling systems, then, are the foundation for what has been termed Space Industrialization, the use of space for the social and economic benefit of mankind.

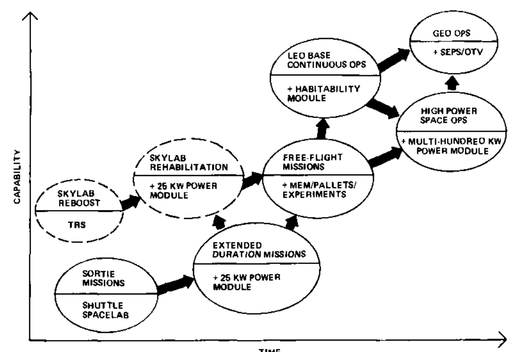

Fig. 5. Space Operations Evolution

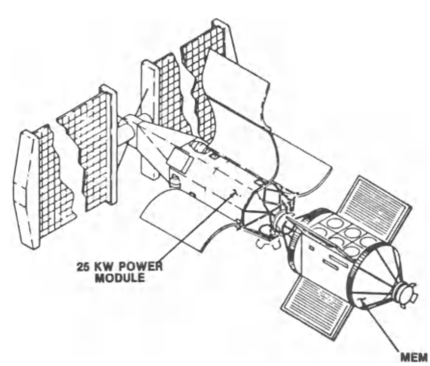

Fig. 6. Materials Experiment Module

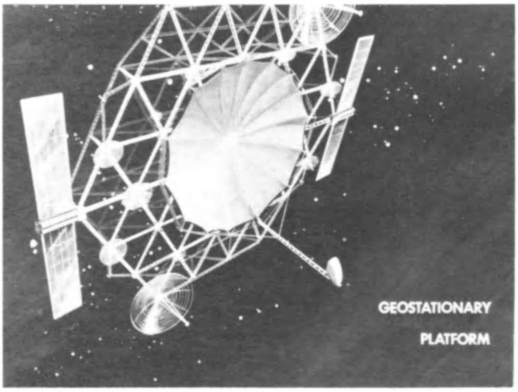

Fig. 7. Public Service Platform

Such is our future. In it, we see a requirement for ever increasing power in space (Fig. 9). Our enabling systems permit the transportation, construction, and support of missions which will require, at first, tens of kilowatts of electrical power, then, hundreds of kilowatts, and, finally, megawatts to gigawatts. The trend begins with the 21 kilowatts delivered by the Shuttle, of which users are already asking for growth, and follows the natural growth curve inevitable in any synergistic environment. While the precise power levels and timing may be in question in the mid and far term, our concern is with general trends and order of magnitude power levels.

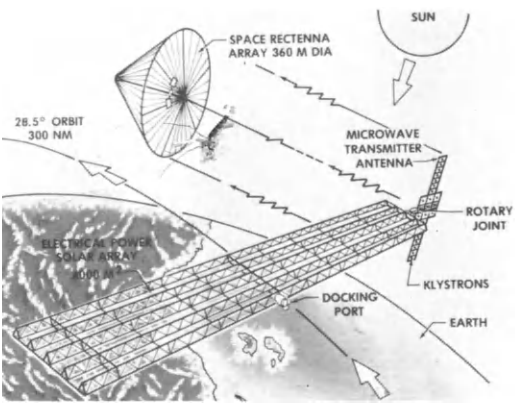

Fig. 8. Satellite Power System Test Article

We also find the same systems will enable improved and more effective accomplishment of established space missions. Science and technology can now be accomplished with many of their prior technical constraints removed. Abundant power, large structures and apertures, long mission duration, and man's presence offer new mission freedom. Compatible missions such as solar and earth observations or communications can be grouped into platforms to offer users reduced support costs and improved services while reducing orbit crowding, especially important at geosynchronous altitude.

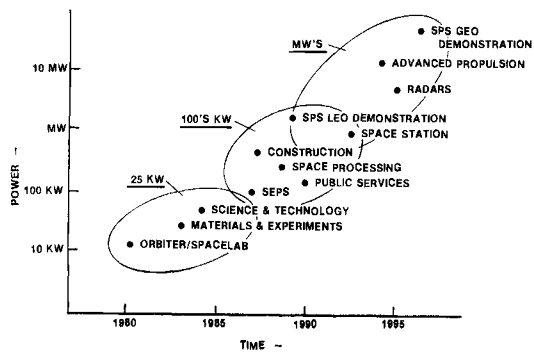

Fig. 9. Power Requirements in Space

The one uncertainty in this trend is the SPS. While the press for SPS could possibly drive technology and permit earlier large systems, the converse seems more likely. We anticipate that the above space applications will drive power development on a time scale comparable with the requirements generated by a development program leading to an operational SPS. We anticipate that the tremendous commitments to SPS will await demonstrations made possible by systems developed to meet these other and earlier space needs. We will touch on this in the latter part of the paper.

Before discussing the nature and characteristics of evolving power systems, we wish to note a more immediate power requirement in space. The Shuttle, as configured today, can support the Spacelab on-orbit for approximately seven days. This limit is determined by the quantity of fuel cell cyrogens carried by the Shuttle. Even during this period, the power available to Spacelab experiments is very limited after subtracting housekeeping power for the Shuttle and Spacelab from that available from Shuttle fuel cells. In addition, even if additional power were available, its use would quickly tax the Shuttle's heat rejection capability. We have, then, limits to duration, peak power, and heat rejection. We will return to a potential solution when addressing initial steps in power system development.

Our subject is evolution of space power systems, but we have noted, and we hope have made apparent in describing enabled systems above, that power is but a part of a power system. While the term platforms may be somewhat ambiguous, it does imply the notion of providing a certain level of housekeeping; perhaps our term should be service platforms. Indeed, the power systems we have studied at NASA share the ability to provide not only power, but also heat rejection, attitude control, communications and data handling, and, in certain cases, drag makeup. For our purposes, space power systems include most or all of these functions.

POWER CONVERSION SYSTEM SELECTION

In addition to studies which projected future power requirements, NASA has recently reexamined alternate power sources which could meet large scale power requirements, primarily in low earth orbit. Similar studies have been performed by the Department of Defense for their future systems, and by the Department of Energy, in conjunction with NASA, for SPS application. These studies examined alternate power conversion approaches, including solar photovoltaic (Fig. 10), solar Brayton-cycle (Fig. 11), and nuclear Brayton-cycle (Fig. 12) power generation systems. Other conversion techniques such as thermionic and Rankine-cycle were also analyzed, but determined non-competitive for the power levels studied or for the projected state of technology which would be available in the time period postulated.

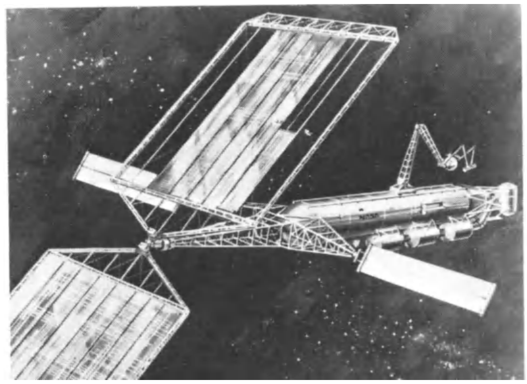

Fig. 10. Solar Photovoltaic Power System

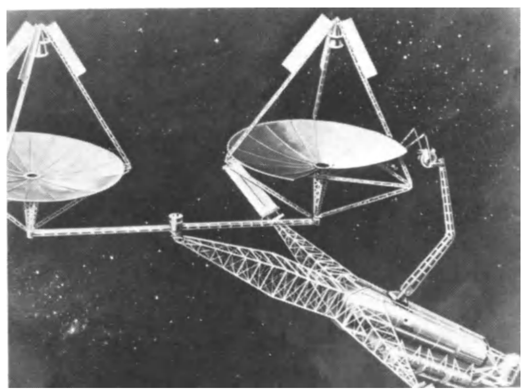

Fig. 11. Solar Brayton-cycle Power System

Of the first three approaches, our studies indicated that, while each was technically acceptable, solar photovoltaic systems were preferred in the tens to hundreds of kilowatts range in low earth orbit. The problems of adequate safeguards notwithstanding, the nuclear system showed less promise primarily because of the high development cost and the development risk of its advanced heat pipe, high temperature, fast reactor. The solar Brayton-cycle system carried the technical risks associated with its thermal receiver/heat storage unit and with control of its large parabolic reflectors. The solar Brayton-cycle was also the heaviest system, affecting transportation cost. Both Brayton-cycle concepts required the development and maintenance of large, long life, space qualified turbo-machinery, again a technical risk.

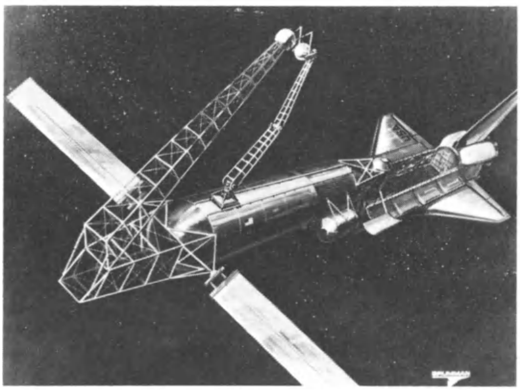

Fig. 12 Nuclear Brayton-cycle Power System

We do not wish to leave the impression that there is no place in space for these other systems. For systems of hundreds of kilowatts and larger capacity, the optimum approach is still an open question. Payloads which require constant or rapid reorientation or manuevering or for which view angle is important may desire the more compact thermal conversion systems. A high radiation environment, such as occurs with the slow transportation of very large photovoltaic systems through the radiation belts to geosynchronous orbit, may cause unacceptable solar cell degradation. The transportation cost of heavy systems will also be more important for large geosynchronous power systems. For outer solar system exploration, there may be no alternative to nuclear systems for power and propulsion. But for the immediate future, solar photovoltaic will dominate.

<u>NASA POWER TECHNOLOGY PROGRAM</u>

Based on the above studies and other factors, NASA is committing itself to solar photovoltaic systems for its early large space power systems. Indeed, the thrust of our power technology program is aimed almost entirely toward such solar systems. Low cost, light weight solar cells and blankets high structural efficiency arrays, high voltage power conditioning equipment, and advanced energy storage subsystems are goals in our five-year technology plan. Technology development for other approaches is minimal, and, for large nuclear systems, limited to liaison and studies. For example, NASA is supporting life tests of a 10 KW Brayton Isotope Power System (Fig. 13) sponsored by the Department of Energy. The Jet Propulsion Laboratory is studying high performance conversion devices aimed at nuclear electric propulsion. Solar photovoltaic efforts overshadow these exceptions, however.

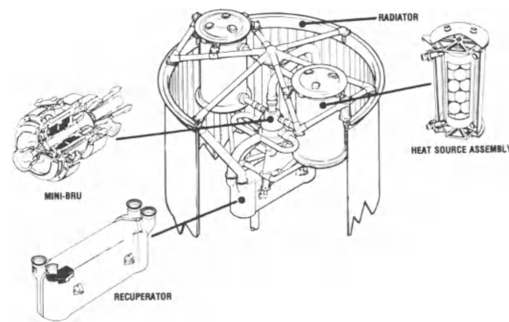

Fig. 13. Brayton Isotope Power System

One contributing factor to the Solar photovoltaic selection was the progress within NASA in developing large solar arrays. As early as 1971, we demonstrated the feasibility of a deployable 100 kilowatt solar array intended for use on a space station (Fig. 14). More recently, development of a 12.5 kilowatt light weight deployable/retractable array measuring 4 meters by 32 meters has been pursued for use on a Solar Electric Propulsion Stage (SEPS) (Fig. 15). The SEPS array is particularly suited to our uses because it is approximately the right power level for early power systems, because of its advanced state of development, and because it can be retracted for manuevers or return to earth and subsequently redeployed. The deployment/retraction capability of the blanket has already been demonstrated at zero-g on a C-135 aircraft flight (Fig. 16). The mechanism which extends the array blankets is a truss structure mast, built of stiff yet flexible composites, which is spiraled into and out of a motorized cannister. Simple tailoring and resizing of these demonstrated elements gives us arrays perfectly suited for space power systems in the tens of kilowatts range. Space test of the SEPS array aboard the Shuttle is planned for 1980.

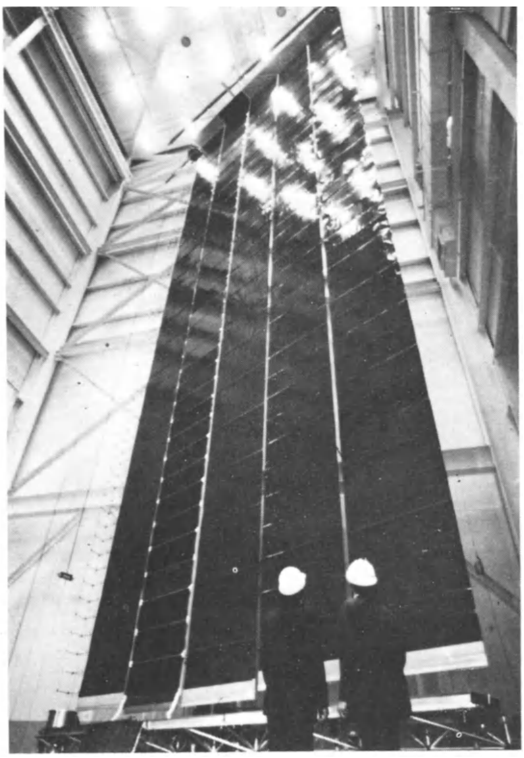

Fig. 14. Space Station Array Deployment Test

EARLY SPACE POWER SYSTEMS

The above technology will soon be put to use. NASA is just completing studies of systems in the tens of kilowatts range, nominally 25 kilowatts average power. What has emerged from these studies are Power Module concepts with the features of a platform we discussed earlier. The Power Module would have not only power generation, processing and storage capability, but would also provide compatible heat rejection capability, attitude control, and communications and data handling, Two such concepts were developed (Figs. 17 and 18), but for our purposes, their similarities are more important than their differences.

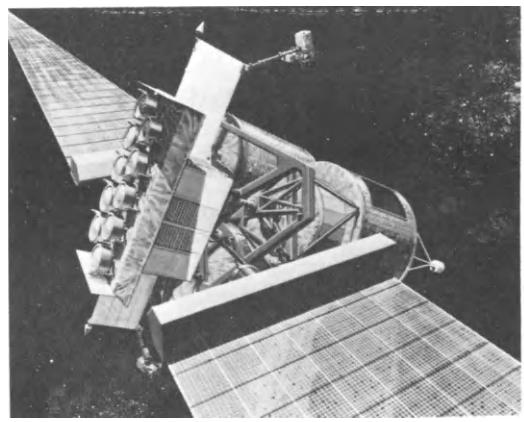

Fig. 15. Solar Electric Propulsion Stage

Fig. 16. Solar Blanket Zero-g Deployment Test

Both use derivatives of the SEPS solar arrays mounted on solar tracking gimbals. Voltage from the solar arrays is in the order of 200 volts, rather than the nominal 28 volts used on the Shuttle and earlier U.S. systems, to reduce wiring and power processing equipment weight. Regulators would step down the voltage to 28 volts for use on the Shuttle. Both Power Module concepts use nickle-cadmium batteries for dark side energy storage. These batteries account for nearly half the weight of the Power Module. Rejection for both internally generated heat and payload heat would be through a freon loop to either modified orbiter radiators or meteoroid resistant heat pipe radiators.

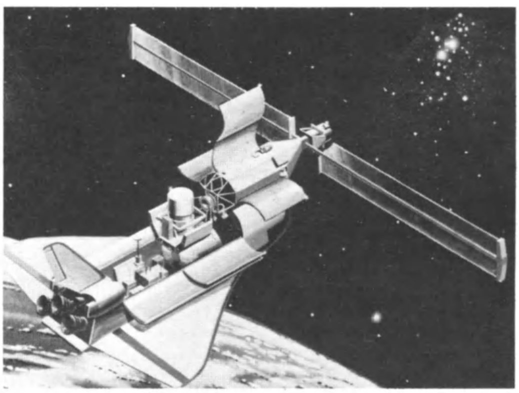

Fig. 17. 25 KW Power Module

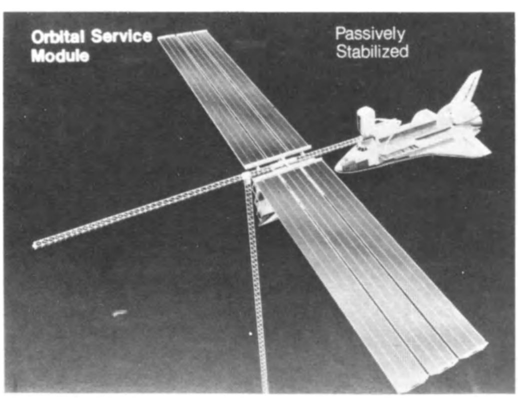

Fig. 18. Orbit Service Module

As far as other housekeeping functions, attitude control could be provided by gravity gradiant stabilization or a reaction control system. However, control movement gyros seem preferable for attitude flexibility, precise pointing, and negligible contamination. Communication and data handling capabilities will depend on user requirements. Both concepts have multiple docking ports for simultaneous docking of the Shuttle and other payloads. For the time being, drag makeup would be accomplished while the Shuttle was docked, with its Orbital Manuevering Subsystem engines. A self-contained propulsion system for orbital maintenance is certainly possible.

The Power Module will be transported to its operating orbit on a single Shuttle flight and left in this orbit. Once in this orbit, it can operate in any of three modes. First, it would support the Shuttle with a Spacelab for up to 60 days, limited only by the Shuttle's life support system capability and cryogen storage capability for the return flight. A tended mode is possible, wherein the Shuttle would tend a payload docked to the Power Module, and either return the payload to the Shuttle payload bay or leave it, inactive, with the Power Module for a later visit. The advantage of this mode is that more power could be delivered directly to the payload than could be delivered via the Shuttle and Spacelab electrical distribution system. The third mode involves leaving automated or even manned payloads on orbit with the Power Module to perform their mission independent of the Shuttle (Fig. 19). Compatible payloads could be grouped onto a single Power Module to further reduce support costs. A Power Module may be required to support Skylab rehabilitation in either a tended or free-flight mode (Fig. 20).

The Power Module offers users extended Shuttle flight duration and free-flight capability. Life science, solar-terrestrial observation and other missions seeking orbit stay times of months or even years would now have that opportunity. Material processing experiments and demonstrations could be accomplished with abundant power and without having to transport the entire processing facility to orbit and back on every mission. With Spacelab follow on development imminent, a host of possibilities open with intermittent or permanent manned habitation.

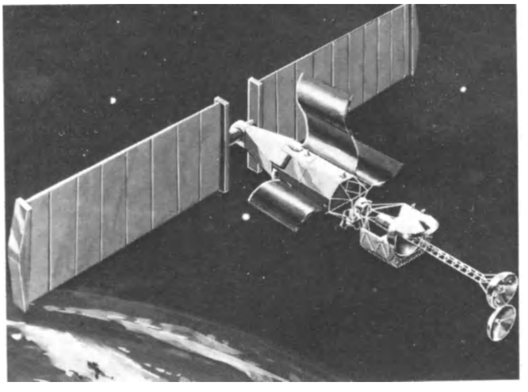

Fig. 19. Power Module Supporting a Free-flying Payload

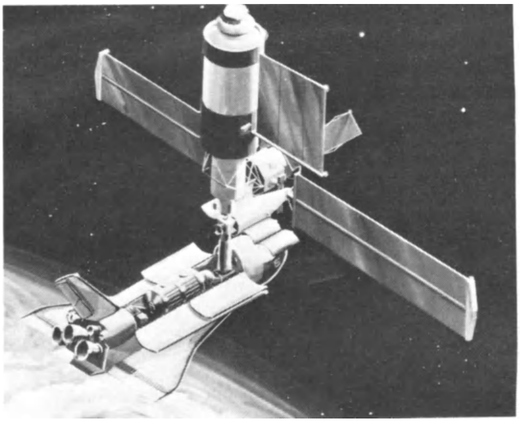

Fig. 20. Power Module Supporting Skylab

We are anticipating initiating development of the Power Module in 1980 with operational capability in 1983. In 1979 the specific configuration to be developed will be determined in definition studies.

The Power Module has a limitation in that it operates in orbits fixed in inclination. For long duration missions on the Shuttle at inclinations in which a Power Module is not operating, some other means of extending the basic fuel cell cryogen duration is desired. Originally, this was to be accomplished with additional cryogen tank set kits to be installed beneath and in the after end of the Shuttle payload bay. The weight of the kits and the cryogens would subtract from that allotted to the payload, a particularly serious problem to certain already return weight limited Spacelab payloads. Furthermore, installation and removal of tank set kits with their brazed fittings would impose a substantial impact on ground operations.

NASA engineering personnel have proposed a concept, which uses the same solar arrays as the Power Module, to overcome these problems. The arrays, mounted on a solar tracking gimbal system, are grappled by the Shuttle Remote Manipulator System (RMS) and deployed while on-orbit (Fig. 21). Prior to return, the arrays are retracted and returned to the payload bay. As the arrays are compact and light, they can be stored at almost any point along the bay with minimal impact to the primary payload. While on the sun side of an orbit, power from the arrays is fed through an umbilical cable mounted on the RMS, to regulators mounted in the bay, and into the orbiter distribution system. During this time, the fuel cells operate in an idle mode, ready to pick up the full load in the dark side. The approach is a hybrid, with the solar array conserving fuel cell cryogens on the sun side. The seven day duration of the presently configured Shuttle is extended appreciably, depending on orbit inclination and season of launch. For a solstice launch at 55^{o} inclination, the duration triples to approximately 22 days.

The array can also provide greater than the nominal 21 kilowatt average power available from the fuel cells, with some reduction in duration, for payloads presently power limited.

The principal constraint on the Shuttle when augmented by the RMS deployed array is heat rejection. Improvements are possible by adjusting the Shuttle radiator angles to permit back-side radiation and by pointing the Shuttle payload bay off-axis when flying sun-looking or earth-looking missions.

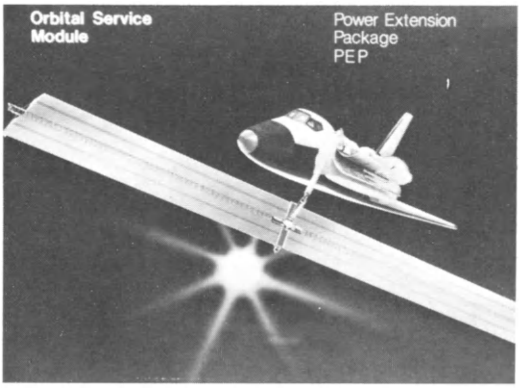

Fig. 21. RMS Deployed Array

Both impose some view angle limitations on instruments mounted in the payload bay, although these should be acceptable for most applications. Offsetting these attitude constraints is the outstanding attitude flexibility of the RMS mounted array.

The RMS deployed array is a flexible, low cost complement to the Power Module. It shares the array and power processing components with the Power Module, and it permits extended duration Shuttle missions at orbit inclinations in which a Power Module is not available. Development on this system will begin in parallel with the Power Module and should lead to operations in 1982.

EVOLUTION OF LARGER SYSTEMS

Beyond the Power Module and RMS deployed array, description of systems becomes more speculative. User requirements have not been explicitly defined beyond the 25 to 50 kilowatt range of the Power Module; only the general demand earlier has been projected. We do see several classes of power systems in the mid to late 1980's.

The Power Module could perhaps double its power level by ganging components or entire modules. But as we move to 100 kilowatts and above, development of a new system becomes more effective. At that time, basic power source trades would certainly be re-accomplished. However, given the heavy investment in solar photovoltaic systems and technology, contrasted to the limited support for other approaches, it is difficult to project a change in technologies at that point. We will address most of our comments toward solar photovoltaic systems.

In the hundreds of kilowatts range, our solar power system and, indeed, any of the systems, may become too large for a single Shuttle flight. Space assembly or construction of the power system would then be required, as it would most likely be for the payload being supported. With these large, assembled structures, attitude control becomes more difficult because of low frequency dynamic reactions. While not the problem it would be for antennas, surface control to compensate for misalignment, assembly tolerances, and thermal distortion would be required.

We would find several new power technologies, the products of our technology program, on the platform. Low cost solar cells, which would have been assembled onto arrays in an automated production facility, could be at least four times the area of current cells. Perhaps the cells would be gallium-arsenide rather than silicon to permit high solar concentration ratios. Array voltages could now jump to thousands of volts to continue the weight reduction trend in wiring and power conditioning equipment. Rather than nickle-cadmium batteries for energy storage, water electrolysis units and fuel cells, reversible fuel cell units, or advanced batteries may provide the storage and reconversion functions.

This large platform could support a large materials processing facility, a space construction base, extensive research and test facilities, or a fuel processing depot for advanced cryogenic Orbit Transfer Vehicles. Whatever its primary application, though, it would be large enough to perform early SPS experiments and tests. Demonstration of the basic power components, structures, and space flight operations for SPS is inherent with the power platform. By addition of a microwave antenna, issues associated with energy transmission could also be explored. The power levels would not be adequate for power transmission to earth or to measure power beam/ionospheric thermal interactions, but beam mapping/phase control, command/reference beam ionospheric effects, magnetosphere interactions, klystron operations, and power density tests are all plausible. So, the large power platform would not only provide support to other missions, but could also function as an early SPS demonstration article.

By the late eighties, we can anticipate large power users at geosynchronous altitudes, most likely requiring tens of kilowatts. Because of the high transportation costs, we can expect a direct evolution from the light-weight SEPS system. Low cell cost will be important, but the needs for reliability and, if transported by a SEPS through the Van Allen belts, radiation resistance will tend to override the quest for low cost components that will prevail in low earth orbit. Due to the short occultation times, energy storage requirements will not be as large as in low earth orbit. Housekeeping functions (attitude control and communications and data handling) would be similar to those in low earth orbit. A typical application for a geosynchronous power system would be to support a Public Service Platform. In this application, the power and housekeeping platform may function as the mounting structure for communications equipment and antennas; construction and assembly would be required even though the arrays themselves could simply be deployed.

Another power application would be for advanced SEP. For planetary exploration, the trend would be toward evolution of SEPS. A step function increase in capability would not be required until manned missions were contemplated. Even for automated planetary spacecraft, though, we would expect application of the then operational on-orbit construction capability, so planetary spacecraft in the late 1980's may appear quite different from those using SEPS as currently conceived. Solar electric propulsion will also be desirable to move large structures, such as the Public Service Platform, to geosynchronous orbit. In such applications, the electric thrusters would probably use the platform's power system rather than require a separate stage and power system.

We have not discussed multi-megawatt or gigawatt systems leading to SPS. As we see them today, the required technologies for a solar photovoltaic SPS would be straight-forward extrapolations of those for the hundreds of kilowatt systems. Again, though, the photovoltaic versus thermal conversion and solar versus nuclear issues will be readdressed. It is most likely that we have not yet seen the real SPS approach.

SUMMARY

In our early steps in the evolution of large space power systems, we seem to be committed to solar photovoltaic conversion. This commitment is based on economic and technical risk trades and on strong development experience with large solar arrays. Other approaches remain viable, however, for larger systems and for outer solar system applications.

We can expect advancements in all our solar power technologies: cells, arrays, power conditioning equipment, energy storage systems, and heat rejection components. Both the large array sizes and the desire to provide a platform for the payloads being supported will eventually drive us to structures constructed and assembled in space.

The earliest power systems will be a RMS deployed array to augment the Shuttle/Spacelab and an orbitally stored Power Module for sortie, tended, and free-flight missions. Both systems are in the tens of kilowatts range. Larger power systems, in the hundreds of kilowatts range, will incorporate power technology advances and may be constructed on orbit.

Large power systems will be important as one of several enabling systems. With their abundant power and permanent on-orbit support, materials processing, multi-purpose platforms, mass communications, SPS demonstration, and continuous manned habitation all come a step closer to reality.

The concepts set forth in this paper represent early planning associated with future space power systems and their development in the decade of the 1980's. Much analysis, --- technical, economic, and operational, needs to be evolved as the Shuttle era of spaceflight unfolds. However, we do firmly believe that the groundwork for routine operations in space that will be achieved by the Shuttle and Spacelab will rapidly evolve to enterprises of greater scope and value.

We can expect severe challenges to be in the forefront with our power technologies. Power is, and will continue to be, a critical element to rapid progress. However, with an abundance of power and with the permanent presence of man, we will be well on our way towards achieving the promise of space applications for the benefit of all mankind.

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LATEST RESULTS OBTAINED BY LANDSAT IMAGERY IN JAPAN

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ABSTRACT

Application of LANDSAT MSS data are made in the monitoring of environmental problems around Japan. It is found that LANDSAT MSS data are extremely useful for the monitoring of water pollution such as river effluent, red tide and industrial effluent in coastal area. On river effluent, the Band-4 and Band-5 can be effectively applicable for the detection of it in Kii strait and Osaka Bay. In case of red tide which consisted by abnormal growth of plankton NOCTILKA in Osaka Bay, the Band-6 is recognized as the most effective wavelength for the detection of it. In case of industrial effluent, the Band-4 and Band-5 are also recognized as the most effective wavelength for the monitoring of it in Harimanada, Seto Inland Sea and the expanding pattern of industrial effluent is very similar with the distribution pattern of COD load by hydraulic model investigation.

Due to the rapid increasing of polluted water from surrounding area, the environmental condition of Lake Suwa, located in the middle area of Japan became seriously bad. The abundant growth of water bloom, the water color of Lake Suwa changes to green in warm season and the distribution pattern of water bloom is well recognized in contrast stretched imagery and color sliced imagery by digital analysis. As a new environmental problem, the detection of the distribution pattern of falling ash from active volcano has become the center of interest in various fields of Japan. In case of falling ash from Mt. Usu, located in southern part of Hokkaido, the most effective wavelength for the detection of it is investigated as Band-6. But color composite imagery by Band-4, Band-5 and Band-6 is also well recognized as very applicable for the detection of falling ash. Compared with two imageries processed by digital analysis, a color sliced imagery after the arithmetic operation is more effective for the detection of the distribution pattern of falling ash around Mt. Usu.

INTRODUCTION

The main purpose of this LANDSAT study is to investigate the environmental problems around Japan. So, the author set up the test site in many places around Seto Inland Sea, Lake Suwa and Mt. Usu showed in Fig. 1. Besides these test site, the author set up many test sites around Japan such as Ariake Sea, Ise Bay and Tokyo Bay where various coastal features were experienced in recent year. In case of lake environment, Lake Biwa and Lake Kasumigaura are also selected as the test site. For the monitoring of the active volcano, Mt. Sakurajima and Mt. Tarumae are also investigated as the test site. In this report, the author pointed out few topics.

The first topic is the detection and monitoring of water pollution such as river effluent, red tide and industrial effluent around Osaka Bay, Kii Strait and Harima-nada, around Seto Inland Sea. The Second topic is the detection of distribution pattern of water bloom consisted by the plankton MICROCYSTIS AERUGINOSA in Lake Suwa located in Nagano Prefecture, center area of Japan. The third topic is the detection of the distribution pattern of falling ash from active volcano, Mt. Usu, located in southern part of Hokkaido and comparison of the distribution pattern with airborne data.
Through this investigation, the author recognized that it is very important to have a airborne remote sensing data and ground truth data around the test site es-pecilly in digital analysis. As the airborne remote sensing data, the author used multispectral scanner data obtained by JSCAN-AT-12M, JSCAN-AT-XM and DEADALUS-1250. 70 mm aerial photograph obtained by HASSELBLADS CAMERA is also used for analysis.* As the ground truth data, sea surface data collected by vessel and bouy are used for analysis in marine environmental problems and lake environmental problems. In case of falling ash, around Mt. Usu, the data collected by Hokkaido Prefecture and author are used for analysis.

DATA ANALYSIS

As shown in Fig. 2, the author tried digital analysis of LANDSAT MSS data using IMAGE-100 and FACOM PIA analyzing systems. IMAGE-100 has many function as follows:
(1) Signature acquisition
(2) Contrast stretch
(3) Grey level slicer
(4) Theme synthesizer
In signature acquisition analysis, the spectral signature of each spectral band in whole area or limited boundary could be calculated and lower limit, upper limit and mean value of grey level would be carried out. Divergence and histgram of each spectral band are also carried out. In contrast stretch analysis, the contra-st of limited band would be enhanced. In this case, we could enlarge the limited boundary of grey level showed in grey level histgram.
In grey level slicer analysis, the grey level of limited spectral band would be sliced at regular intervals and each sliced level would be displayed by limited color. So we could found out the density distribution pattern as the color sliced imagery. In theme synthesizer analysis, the theme extraction would be carried out after the calculation of signature acquisition as the limited theme of whole pixel between the lower limit and upper limit of density level of each spectral band.
The digital analysis by FACOM PIA is mainly used for airborne remote sensing data around Seto Inland Sea and Mt. Usu.

WATER POLLUTION AROUND SETO INLAND SEA

Seto Inland Sea

Seto Inland Sea, the biggest inlet in Japan is located in western part of Japan and its water dimension is more than 22,000km . As noted as 'Seto Inland Sea National Park', the scenery was very beautiful and the sea water was also clean about 20 years ago. But, due to the increasing of water pollution from the coastal zone, its environmental condition is seriously bad now. We can see so many big cities such as Osaka, Kobe, Himeji, Okayama, Hiroshima, Moji, Matsuyama, Tokushima and Wakayama, and newly-developed 'Kombinat' such as Shikama, Mizushima, Fukuyama, Iwa-kuni, Tokuyama, Ooita, Sakaide and Sakai around Seto Inland Sea. By the effect of rapid developing the big cities and big scale 'Konbinat' the beautiful cenery of Seto Inland Sea is destroyed in many places and the sea water of almost area of it is polluted seriously. Now, Seto Inland Sea is noted as one of the most polluted inlet in Japan.
For the purpose of prevention of the water pollution around Seto Inland Sea, a new rule named as 'Special Rule for Observation of the Environment of Seto Inland Sea

*For economy these photographs have been reproduced in black and white.

was enforced in 1973 as a time-limited rule and it was extended two years in 1976. But the environmental condition of Seto Inland Sea has not become good in these period. In 1974, a big scale oil pollution was occured in Hiuchinada, Harimanada and Kii Strait. Due to the accident of oil tank in oil refinery in Mizushima, more than 9,000Kl of heavy oil was leaked from the oil tank and almost of it spreaded over eastern half of Seto Inland Sea in few days. From the occurrence day of oil leakage, the oil pollution in eastern half of Seto Inland Sea continued more than two months and todal damage of fishing industry is estimated as 200 million dollars.
Although, the environmental conditon of Seto Inland Sea has not become good now, the utilization of it is very important for the fishing industry especially fishing industry especially fishing nursery industry around coastal area of Harimanada, Hiuchinada and Bingonada. Seto Inland Sea is noted as a one of the most important area for fishing industry in coastal area in Japan and the protection of it is urgent need for not only fishing industry aspect but also administrative aspect too. So, Environmental Agency decided the extention of 'Special rule for Observation of the Environment of Seto Inland Sea' as a non-time-limited rule this year.

River Effluent

The total number of river which flows into Seto Inland Sea is more than 60 and the biggest one is Yodo River which flows into Osaka Bay. The total amount of river flow for a year is $9{,}351.5\times10^6\ m^3/sec$ and the catchment area of Yodo River is nearly $7{,}300 km^2$. Recently, the river effluent from Yodo River is considered as one of the origin of water pollution in Osaka Bay. For example, the rapid increase of population around the catchment area of Yodo River influences the reduce of water quality of Osaka Bay and it bring on the occurrence of red tide in Osaka Bay.
Yoshino River which flows into Kii Strait is also one of the big river which flows into Seto Inland Sea. The expanding pattern of river water after the raining is well recognized in LANDSAT MSS data. The total amount of river flow for a year is nearly $5{,}000\times10^6 m^3/sec$ and it is the second ranking of total amount of river flow for a year around Seto Inland Sea. So, it affects the environmental condition of Kii Strait, Osaka Bay and southern part of Harimanada. Through the Kitan Strait located between Honshu and Awaji Island, the river water from Yoshino River invade into Osaka Bay influenced by tidal current.
Although the total amount of river flow is not so large quantity, Kako River and Ichi River which flows into northern part of Harimanada affects the environmental condition of Harimanada along the Shikama Industrial Zone.

Red Tide

Red tide named after its apparent color is caused by the abnormal growth of plankton in polluted water around coastal zone. By the report issued from Seto Inland Sea Fishing Control Office of Fishery Agency in Kobe, the total occurrence of red tide in 1950 was only 4 cases as shown in TABLE 1. The period of occurrence was limited in warm season and we never experienced in cold season. But, the occurrence case of red tide is increased year by year and the total occurrence of red tide around Seto Inland Sea was exceeded 300 cases in 1975. Through the year we experienced the occurrence of red tide recent year. In 1950, about a quarter century ago, the occurrence area of red tide in Seto Inland Sea was limited in a portion of Osaka Bay as shown in Fig. 3. But, the occurrence area in 1970 was expanded to almost area of Seto Inland Sea.
In mid August of 1972, we experienced a severe red tide in Harimanada and more than 14,280,000 yellowtails in fishing nursery were seriously damaged. The total damage of fishing industry around Harimanada was estimated as 40 million dollars. In this case, abnormal growth of plankton HORNELLIA was investigated as the ground truth data. From late July to early August of 1976, we experienced a severe red tide in Osaka Bay. By the report of patrol helicopter of Maritime Safety Board, almost area of Osaka Bay was considered as polluted by red tide which color is red.

During the existance of red tide around Osaka Bay, a good information is carried out from the LANDSAT-2 MSS data on August 1, 1976. By the report announced by Seto Inland Sea Fishing Control Office, the plankton which caused the occurrence of red tide was investigated as NOCTILUCA, red colored plankton.
In late August of 1977, a severe red tide prevailed around Harimanada and more than 1,300,000 young yelowtails in fishing nursery were killed. The total damage of fishing industry is estimated as 150 million dollars in this case. By the ground truth data, more than 2,000 HORNELLIA is detected in 1 cc sea water and it is about 200 times of volume content comparing with normal condition.
Red tide is normally red color just the same its name. But based on the plankton, the sea water changes its color to pink, dark brown, brown, light brown, yellow and green. In case of green color, it is called as 'Green water'.
Although the reason of abnormal growth of the plankton is not well investigated, the detection and monitoring are very important for fishing industry, especially fishing nursery which is rapidly promoted in coastal area of Seto Inland Sea.
Now, daily report of red tide collected by fishing vessels and monitoring stations is announced by Seto Inland Sea Fishing Control Office to fishing industry and administrative office around Seto Inland Sea.

Industrial Effluent

From the industrial zone located in big cities and Kombinats, a large amount of industrial effluent is discharged into Seto Inland Sea. In previous report(1),the author descrived the industrial effluent detected by LANDSAT MSS data around Seto Inland Sea and appealed the monitoring of industrial effluent by satellite.
In Mizushimanada one of the portion of Bingonada, fish coated by unfragrant smell by industrial effluent such as oil were collected by fishing net many times and it become a big social problem around Mizushima city. Along the southern coast of Hiuchinada, we experienced water pollution caused by industrial effluent from the pulp industry and it is considered as one of the reason of occurrence of red tide around Hiuchinada.

RESULTS OF ANALYSIS

In previous report(2), the author tried digital analysis of water pollution around Harimanada, Seto Inland Sea using IMAGE-100 analytical system and good results were carried out. In this report, the author tried the detection of river effluent from Yoshino River by contrast stretching and color slicing analysis.
As shown in Fig. 4, a pattern considered as turbid water from Yoshino River which flows into Kii Strait is well recognized in Band-4 and Band-5 imageries. Through the narrow channel between Honshu and Awaji Island, the turbid water from Yoshino River invades into Osaka Bay influenced by tidal current towards north direction.
In case of the detection of turbid water from river, the contrast stretching imageries is more effective than color slicing imageries and the Band 4 is recognized as the most effective wavelength for the detection of river effluenct.
A clockwise pattern detected in Osaka Bay has the same characteristic with river effluent at the mouth of Yoshino River in reflectance level of CCT. Depend on the authors experience, the pattern detected in Osaka Bay is considered as the specific phenomenon which occures after the rainning and we experienced anti-clockwise pattern in the same area by airborne remote sensing.
For the purpose of the detection of distribution pattern of red tide around Osaka Bay, the author tried contrast stretching and color slicing analysis on the data obtained by LANDSAT-2 as shown in Fig.5. In both analysis, we can found out the different pattern in Band-4, Band-5 and Band-6 imageries. In Band-4, Band-5 and Band-6 imageries a round circle pattern are well recognized in center area of Osaka Bay and another pattern faced to eastern coast of Awaji Island is well detected in Band-6 imageries. Compared with Band-4 and Band-6 imageries, the difference of the distritution pattern of red tide in Osaka Bay is considered as it is caused by the

two different kind of plankton. In case of the detection of the distribution pattern of red tide which consisted by two different kind of plankton, the Theme synthsizer analysis is very useful and good result is expected(3). For the same purpose, the color composit imagery after the contrast stretching is also would be carried out. Due to the effect of the tidal current, a round circle pattern of red tide is experienced in Hiuchinada on December 30, 1975 by LANDSAT-2 and it is also recognized as a typical pattern of red tide through the monitoring of Seto Inland Sea. As the typical patterns of industrial effluent, the author tried color slicing analysis around the northern part of Harimanada as shown in Fig. 6. Along the coast of Shikama Kombinat, industrial effluent are well recognized in color slicing imageries. Compared with airborne data showed in Fig. 7, the distribution pattern of industrial effluent around Shikama Kombinat are not so different. Although the airborne data are compressed to progressive direction in this case, the distribution pattern of industrial effluent is well recognized in CH. 4 imagery and the pattern of turbid water is expanding towards southern direction. By the effect of tidal current around Akashi Strait and northern part of Harimanada, the industrial effluent influenced its expanding direction. Along the northern coast of Harimanada, a clockwise current is exsisting. So, the distribution pattern of industrial effluent detected in color slicing imageries is formed to clockwise pattern.
In CH. 11 imagery of airborne data, the distribution pattern of sea surface temperature is well recognized around Akashi Strait and northern part of Harimanada and hot efflux from Shikama Kombinat is expanded towards southern direction.
In Akashi Strait, the sea surface temperature is recognized as low compared with Osaka Bay and northern part of Harimanada and it is considered as the effect of tidal current in Akashi Strait. In Akashi Strait, the mixing of sea water is promoted by the fast tidal current which flows from Osaka Bay to Harimanada in normal condition. If could I have a chance to get a thermal imagery obtained by LANDSAT-MSS data, we could carried out more useful information comparing both data.

WATER POLLUTION IN LAKE SUWA

Lake Suwa

Lake Suwa, located in southern part of Nagano Prefecture, middle part of Honshu is noted as a resort area in central Japan. In this district we can enjoy various kinds of hot spring through the year. The water dimension is about 15km^2 and it is well known as the origin of Tenryu River which flows into Enshunada, Pacific Ocean. Due to the rapid increasing of industrial effluent from the coastal zone, the environmental condition of Lake Suwa is seriously bad and it has become one of the most polluted lake in Japan. Compared with another lake located in Nagano Prefecture, the depth is very shallow. It has only 6.8m of depth in center area and the transparency is also not so good as shown in TABLE 2.

Water Pollution in Lake Suwa

During the cold season, the water color of Lake Suwa become brown on mild day and it is estimated as the effect of water depth. The quality of almost area of lake bottom is consisted by mud. So, the water color changes to black on the day when strong wind prevails around the Suwa District. In this point of view, the stage of Lake Suwa is considered as reaching on old age already.
During the warm season, the water color of Lake Suwa is changes to green by the abnormal growth of water bloom MICROCYSTIS AERUGINOSA as shown in Fig. 8. Between April or May water bloom starts its growth and disappear in October or November every year. Depend on the authors experience, the water bloom prevails in highest condition between August and September in normal condition. But in case of 1969, the water bloom disappeared in July and it is considered as the effect of reduce of water temperature. In 1969, we experienced so many rainy days around Lake Suwa and the water temperature does not rises to 18^{0}c in July and 20^{0}c in August.

The growth of the water bloom in Lake Suwa is influenced by the water temperature and it starts the growth when the water temperature exceed 18^{0}c. The period of the occurrence of water bloom is limited as the water temperature rises to 18^{0}c. Before 1928, the density of COD in Lake Suwa is beyond 2.0ppm as shown in TABLE 3 and we never experienced water bloom in Lake Suwa. But due to the increasing of COD, NH_4-N and PO_4-P, we experienced water bloom in Lake Suwa about 20 years ago. The increase of BOD load is also considered as the reason of the occurrence of water bloom in Lake Suwa as shown in TABLE 4.

Results of Analysis

In digital analysis, the author tried comparison of color slicing imageries which obtained on March 15, 1975 and September 11, 1975. In case of March 15, 1975, we could not found out any pattern in Lake Suwa. But in case of September 11, 1975, we could found recognized 5 level color sliced pattern in Lake Suwa as shown in Fig. 10. In contrast stretching analysis, we could enhanced the distribution pattern of water bloom in Lake Suwa as shown in Fig. 11. So, in this point of view, the monitoring of water bloom is considered as capable using the LANDSAT MSS data.

DETECTION OF FALLING ASH FROM ACTIVE VOLCANO MT. USU

Eruption of Mt. Usu

Mt. Usu one of the active volcano in Hokkaido suddenly eruped on August 7, 1977 and 4 big eruptions are recorded as follows:

09:12 August 7, 1977 15:40 August 8, 1977 11:50 August 9, 1977
23:30 August 8, 1977

The total energy which caused the eruption is estimated as 10^{24} erg and it was considered as the middle scale eruption in the stage of eruption. But more than 200 million m of falling ash affects seriously damage to forest, field and range land. The total damage by falling ash is estimated as more than 2,000 million dollars in Hokkaido.

Results of Analysis

For the purpose of detection of the falling ash around Mt. Usu, the author tried several special observation by airborne remote sensing using multispectral scanner and good information are carried out. As shown in Fig. 12, the boundary of the falling ash is well recognized in color composit imageries. In digital analysis of airborne remote sensing data using FACOM PIA, good results are carried out by arithmetic analysis and similarity analysis. The similarity analysis is more effctive than the arithmetic analysis for the detection of falling ash in this case. As shown in Fig. 14, the author tried to collect the ground truth data around Mt. Usu on August 30, 1977 and the ground truth data are used for the digital analysis. Although we could not get the LANDSAT-2 MSS data on August 30, 1977, we get a LANDSAT MSS data on September 17, 1977 as shown in Fig. 15. In digital analysis using IMAGE-100 system, the boundary of falling ash and its density are well recognized by color composit analysis, classification by single cell and arithmetic analysis. Compared with airborne data, the LANDSAT MSS data is not so different for the detection of falling ash.

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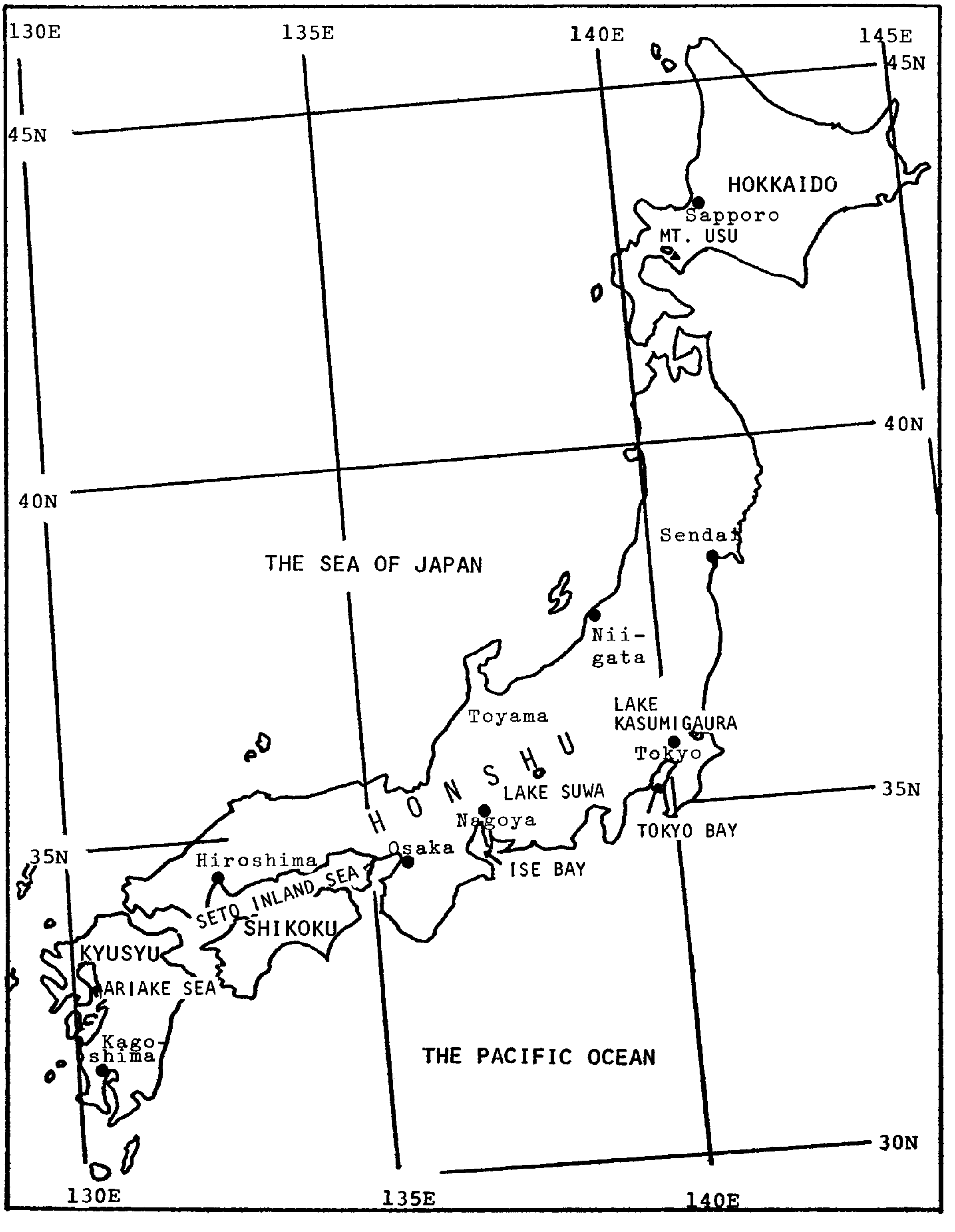

Fig. 1 Location of test sites in Japan.

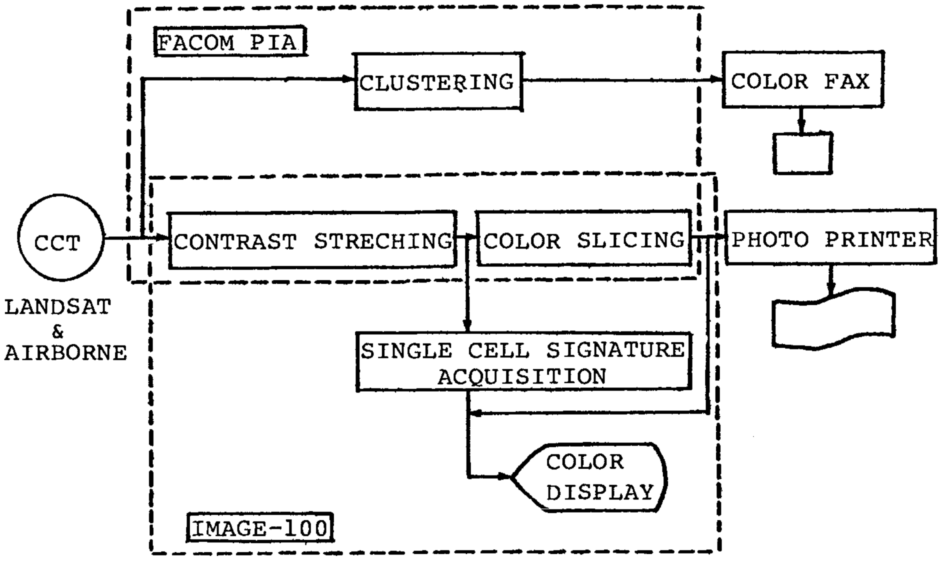

Fig. 2 Flow of data analysis.

TABLE 1 Annual occurrence of red tide around Seto Inland Sea.

Year	Number of occurrence cases	Number of damaged case
1950	4	
1960	18	
1967	48	8
1968	61	12
1969	67	18
1970	79	35
1971	136	39
1972	164	23
1973	210	18
1974	298	17
1975	300	29
1976	326	18
1977	236	27

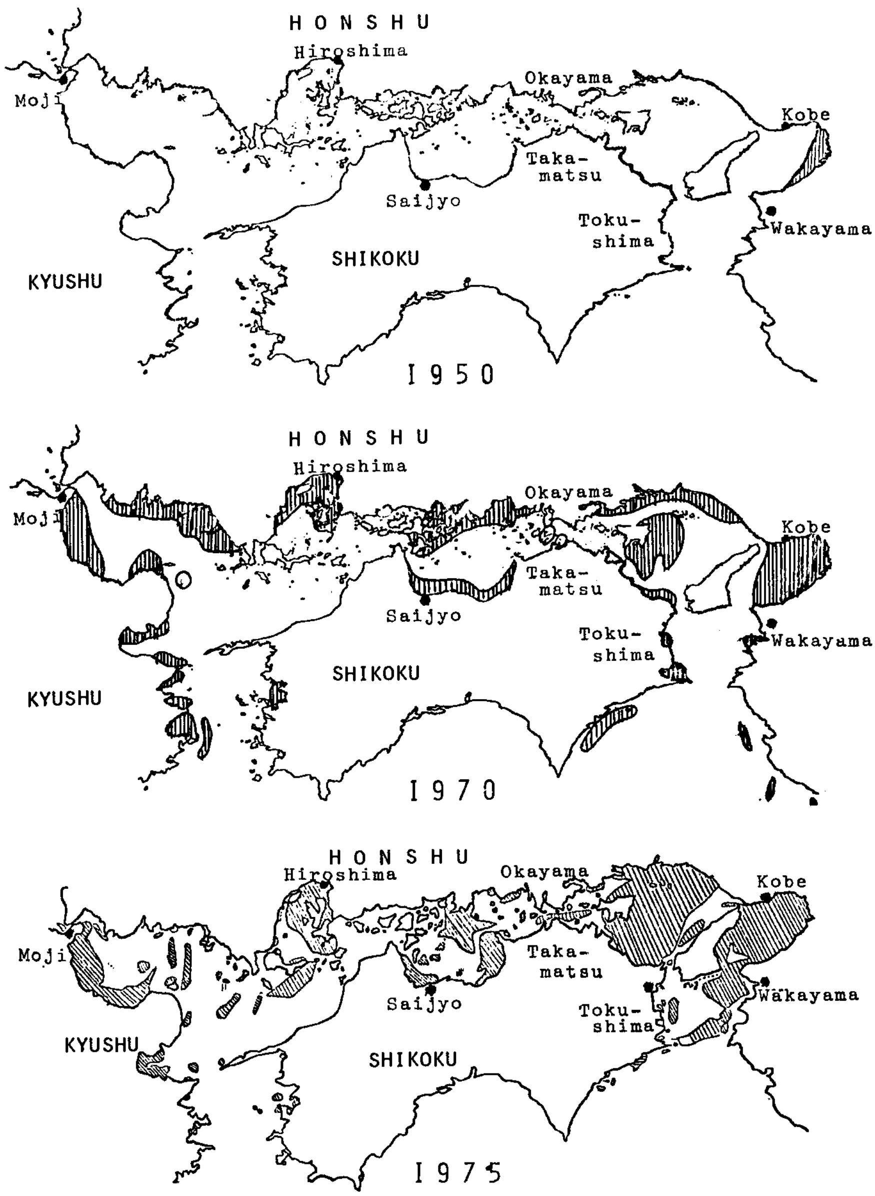

Fig. 3 Comparison of occurrence area of red tide (shaded area) around Seto Inland Sea.

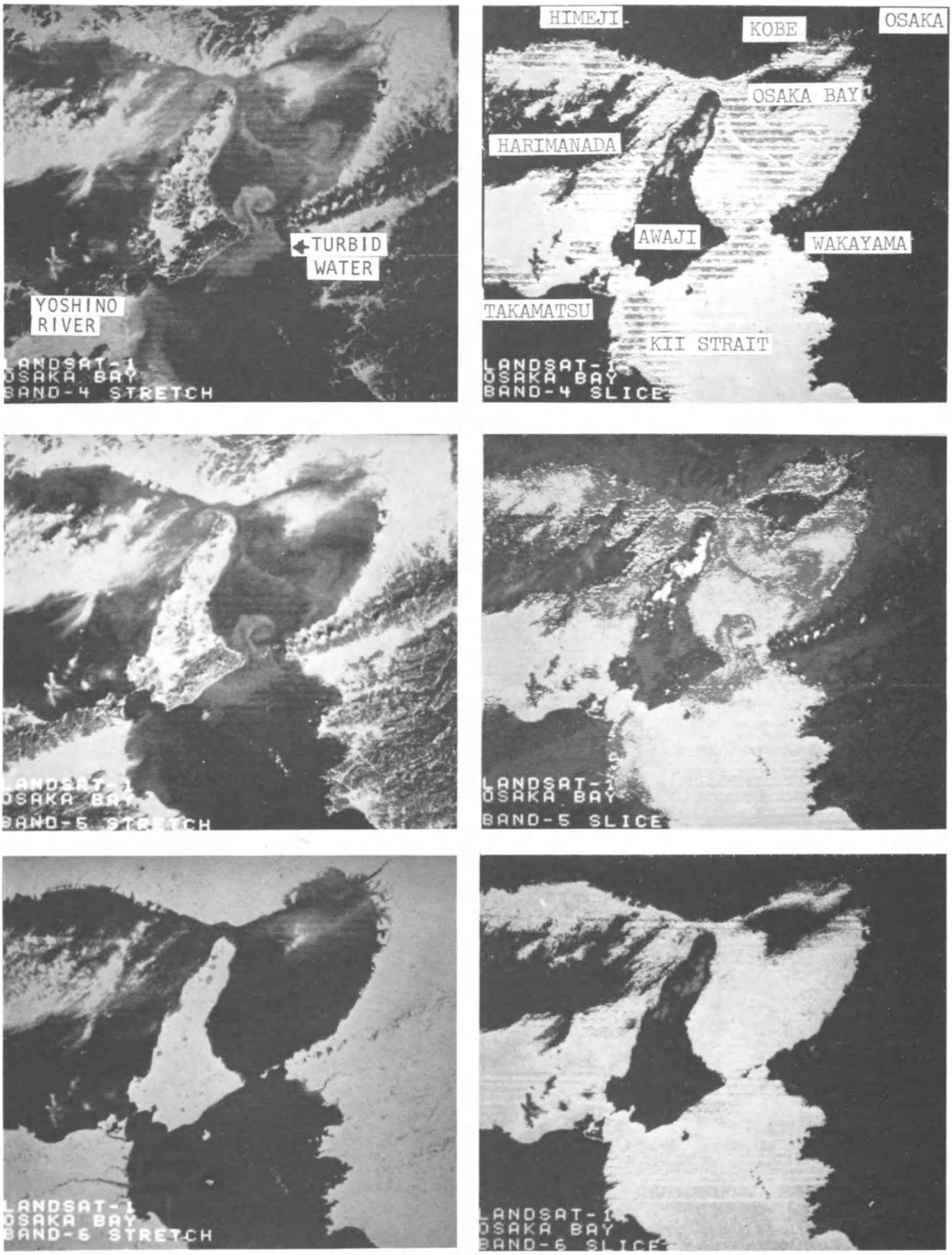

Fig. 4 Contrast stretching and color slicing imageries which detect the distribution pattern of turbid water around Osaka Bay. Oct. 24, 1972

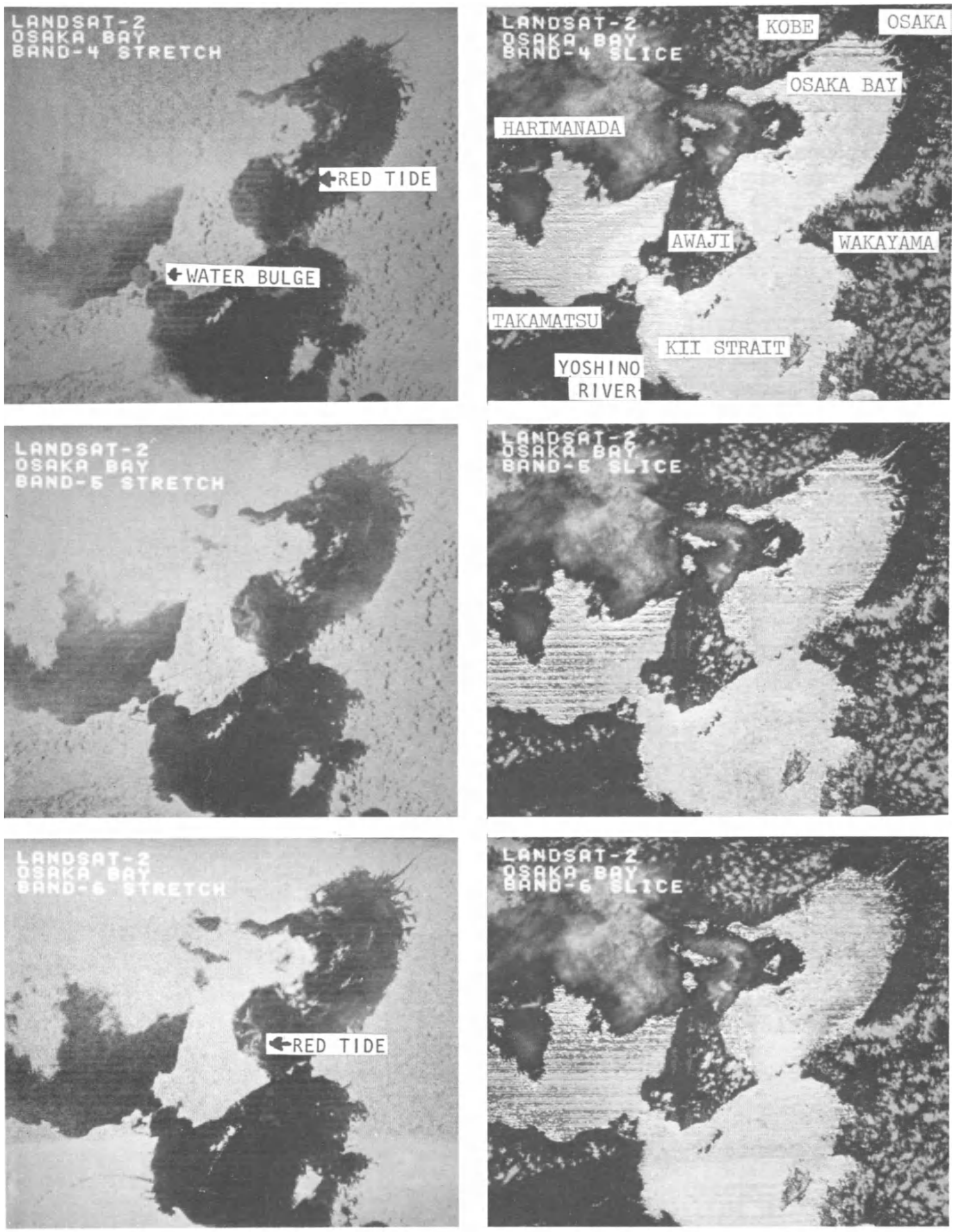

Fig. 5 Contrast stretching and color slicing imageries which detect the distribution pattern of red tide around Osaka Bay. Aug. 1, 1976

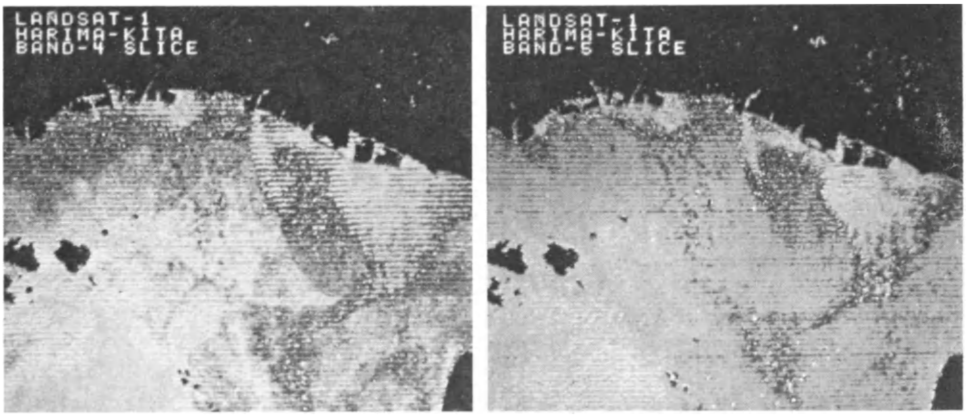

Fig. 6 Enlarged color slicing LANDSAT imageries around northern part of Harimanada, Seto Inland Sea. Nov. 12, 1972

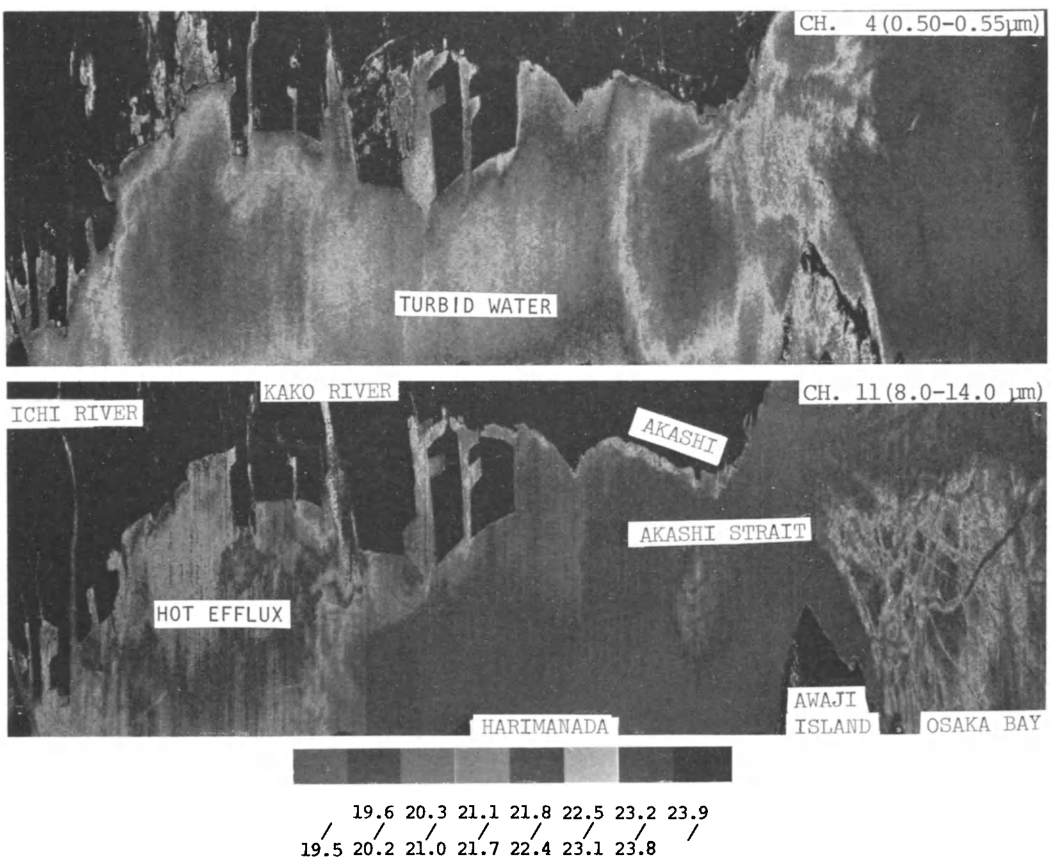

Fig. 7 Density slicing airborne MSS imageries around the same area showed in Figure 8. June 4,1977(Altitude 12,300ft)

TABLE 2 Comparison of maximum tranceparency between the lake located in Nagano prefecture.

Name	Elevation from sea level	Maximum depth	Maximum trance-parency
Lake Aoki	822 m	58 m	14 m
Lake Kisaki	764	29.5	8
Lake Suwa	759	6.8	2
Lake Nojiri	654	37.5	11

TABLE 3 Volume content of COD, NH_4-N, PO_4-P at lake surface in center area(ppm).

Year	COD	NH_4-N	PO_4-P
1909	1.12	0	
1928	1.99	0	
1931	2.53		
1947	1.61	0.3 0.5	0.004
1949		0.073	
1963		0.16 0.29	0.004 0.007
1966	4.15	0.03	0.003
1969	3.7	0.07	0.003 0.01
1970	3.5	0.14	0.008
1971	4.3	0.28	0.008
Rate of increase	About 4 times in 60 years	About 3 times in 60 years	Twice in 25 years

TABLE 4 BOD load from the river which flows into Lake Suwa.

Description	kg/Day	%
Social effluent	3,030	34.0
Industrial effluent	5,600	63.0
Hot efflux from hot spring zone	100	1.0
Others	200	2.0
Total	8,930	100.0

Fig. 8 Aerial photograph of water bloom in Lake Suwa.

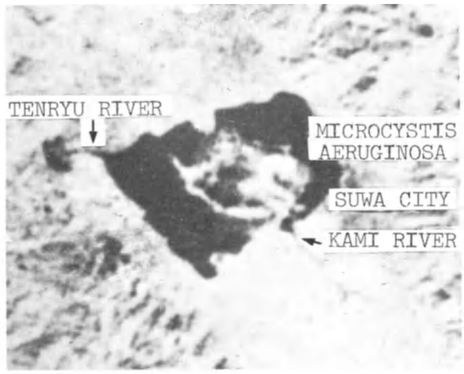

Fig. 9 Analog processed imagery. Oct. 5, 1972

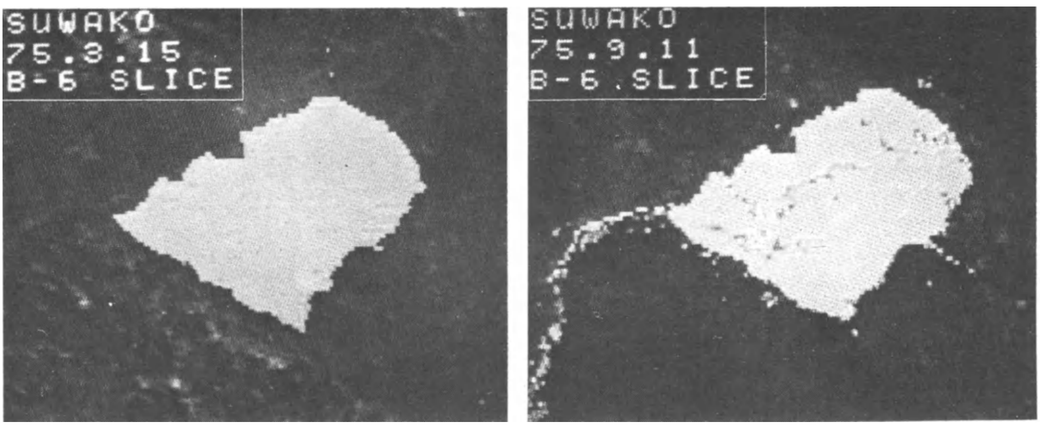

Fig. 10 Comparison of color slicing imageries obtained by LANDSAT-1 and LANDSAT-2.

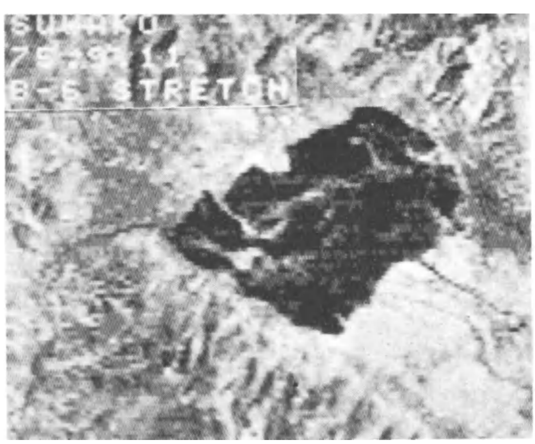

Fig. 11 Contrast stretching imagery obtained by LANDSAT-2.

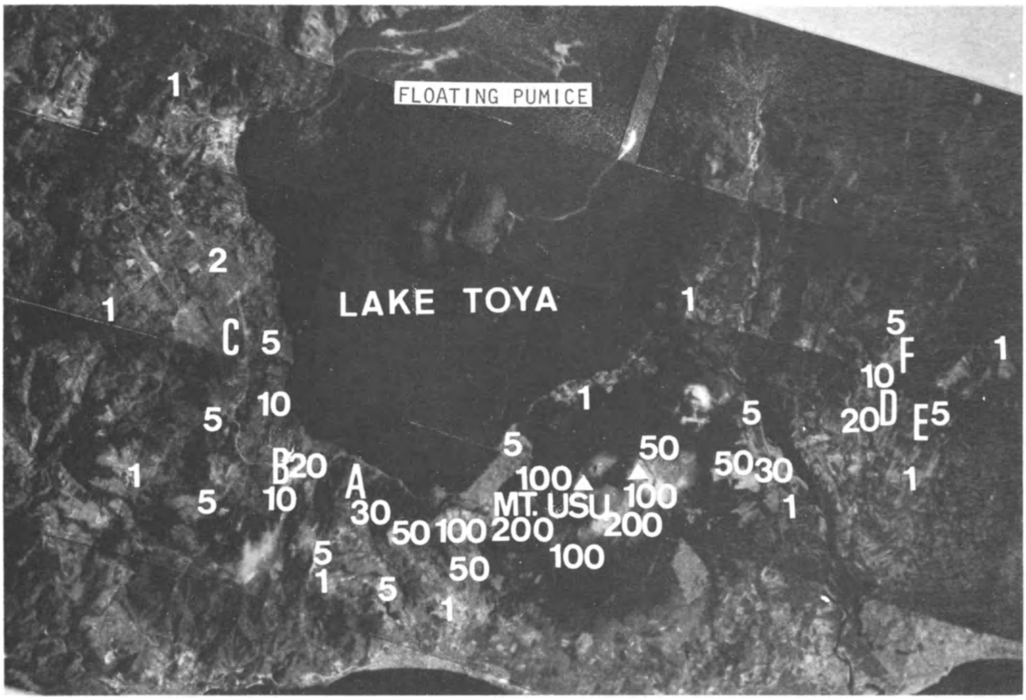

Fig. 12 Mosaic of color composite MSS data obtained by aircraft. Figures shows the depth of falling ash from active volcano Mt. Usu and Alphabet shows the point of ground truth showed in Fig. 14

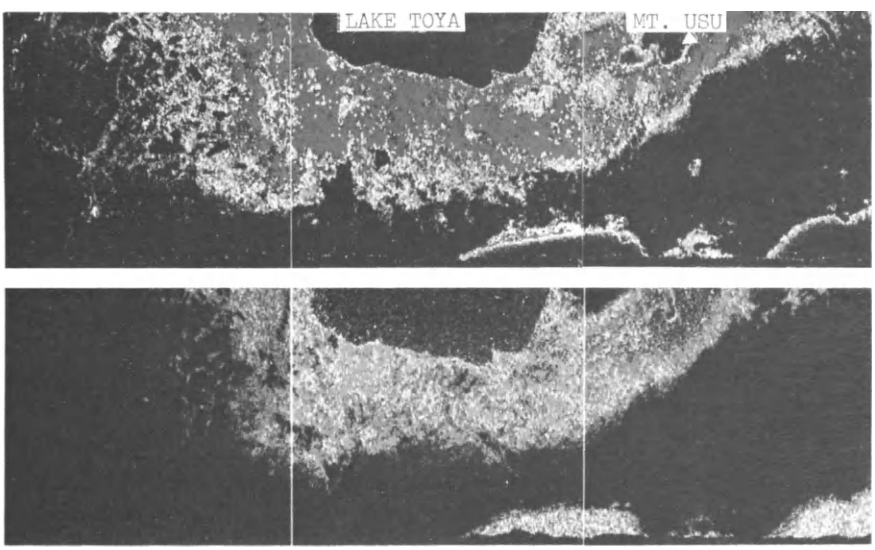

Fig. 13 Digital processed imageries showed in Figure 14.
Top —— Result of arithmetic analysis. $\frac{(Ch.7-Ch.9)}{(Ch.7+Ch.9)}$
Bottom — Result of similarity analysis.

Fig. 14 Ground truth datas of falling ash around Mt. Usu and Lake Toya.
A—— Destroyed forest. B—— Range land.
C—— Farm paved by ash. D—— Destroyed corn field.
E—— Rice field. F—— Destroyed asparagas field.

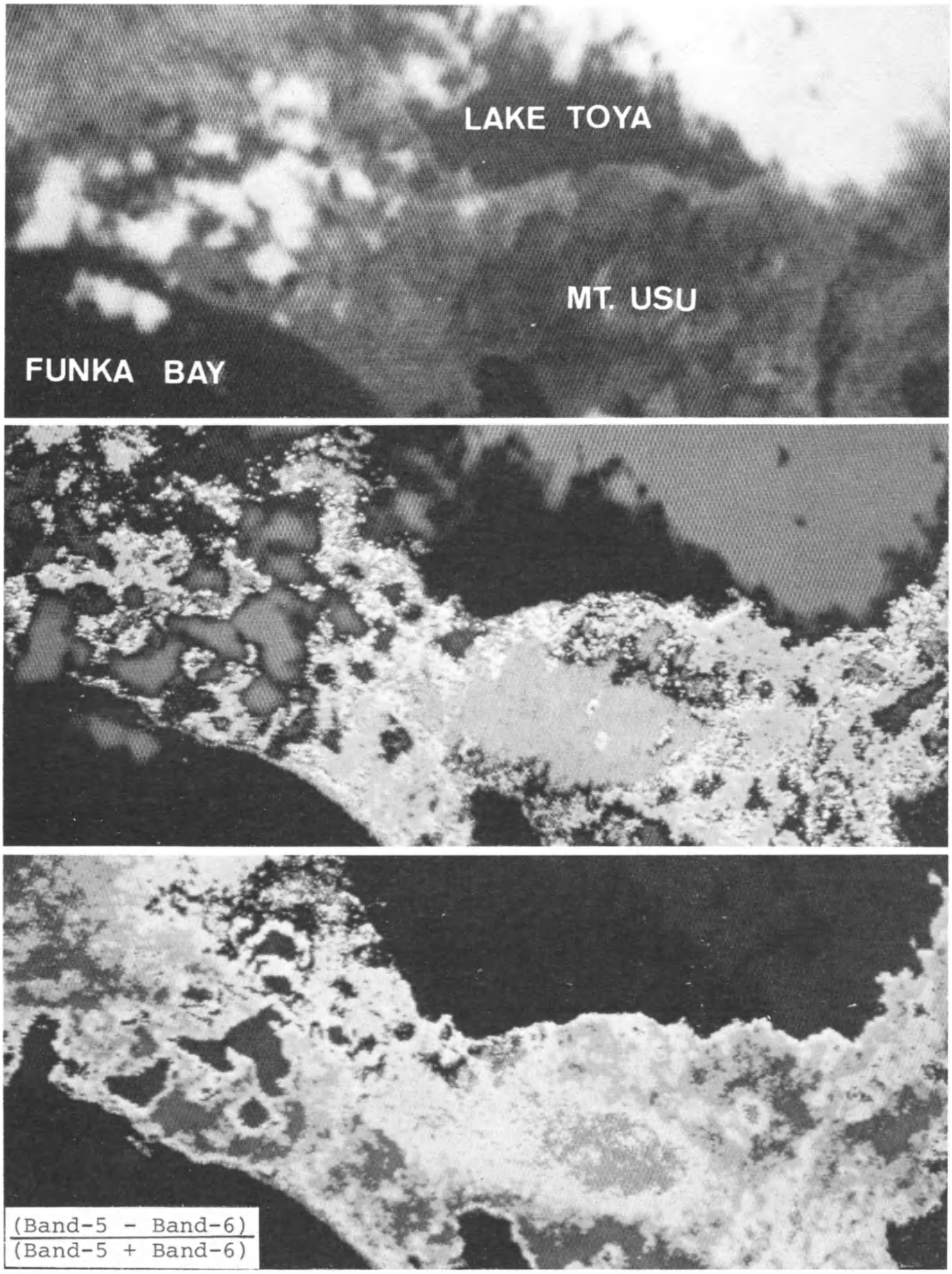

Fig. 15 Digital processed imageries arround Mt. Usu obtained by LANDSAT-2. Sept. 17, 1977

Top Color composit imagery by Band-4, Band-5 and Band-6.

Middle Result of classification by single cell.

Bottom Result of arithmetic analysis.

RUPTURAL FABRIC OF YUGOSLAVIA ON LANDSAT SCANOGRAMS

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ABSTRACT

Eighteen of the best LANDSAT scanograms taken before February 1976 have been assembled to show the general picture of the Yugoslav territory. They have been used as the data base for analysis of ruptural fabric on scale 1:1,000,000. Thus obtained original analytic sheet has been further modified to a map showing only large and/or representative fractures. Three main ruptural systems are oriented NW-SE, SW-NE and N-S. These systems are renegant to the pre-neotectonic ruptural fabric and belong to a new, nedectonic stress field; they only in places represent more ancient intermittent faults, reactivated in the late Neogene and the Quaternary. Ruptural fabric is rather homogeneous throughout the area, except for the NE portion of the country (Slovenia) where neotectonically active faults, broadly convex toward south, are conspicuous.

Ruptural fabric, seen on the imagery, can not be easily interpreted kinematically, being too complex and the most probably generated during several neotectonic phases. Morphogenetically the most significant is the NW-SE system, which mostly shows transcurrent movements. It is also connected with earthquakes, epicenters being mostly associated with intersections of these and SW-NE striking faults.

Numerous ring structures have also been found to occur in three distinct areas: the Derventa-Delčevo belt, the Kragujevac-Rtanj-Kučevo triangle (NE Serbia), and the Moriovo area (S Macedonia). The curious connection of the Derventa-Delčevo belt with young alkaline basaltoids is discussed in terms of their possible relation with a concealed subduction zone along the Adriatic coast.

INTRODUCTION

The Yugoslav territory is covered by scanograms of nine LANDSAT orbits; according to the numeration by the Fucino center these orbits are No.198 to No.206. The Yugoslav Remote Sensing Center, situated at the Faculty of Mining and Geology, Belgrade, has in possession all scanograms for the territory, made before February 1976.

Quality of this coverage is highly various: it is excellent for the northwestern part of the country, northern Bosnia and the area from the island of Hvar to Greece and Bulgaria; of medium quality for Serbia and part of Bosnia; very poor in quality for western Serbia and the whole area NNW of the line Zadar-Split; and does not exist for the Sinj domain (north of Split). More recent LANDSAT-2 imagery, for the distribution of which the Fucino center has been foreseen, unfortunately could not be utilized. Long delivery terms were a serious shortcomming of the Sioux Falls center: the interval of several months between the time of imagery taking and possibility of exploitation made the imagery inapplicable for timely monitoring of rapidly changing processes(floods, snow coverage, agriculture). Transfer of the European distribution center to Fucino, Roma, may look to the users somewhat like a complete failure of the LANDSAT project: simple exchange of letters takes several months, and the price per one 1:1,000,000-scale scene amounts to $ 100, compared with $ 6 at Sioux Falls.

METHODOLOGY

Among all available scanograms 18 of the best ones have been selected. They have been used as the base source for the analysis of ruptural fabric, on scale 1:1,000,000. This scale has been choosen for two reasons: (1) the objective of the study was to establish sets of regional fractures, long enough to clearly appear on this scale; (2) planimetric position of points on the imagery of this scale corresponds provided negligible errors to the position of points on the 1:1,000,000-scale geographic map of the SFR of Yugoslavia published by VGI in 1962.

For scanograms of each orbit a joint sheet of clear Muflon tracing film has been used. Interpretation data were directly marked on this sheet with Stabilo permanent markers F Pen 96 P. These markers proved to be sufficiently thin for generalized drawings on acetate film; for fine drawings a convenient marker has still to be found, with thickness 0.1-0.2 mm. Except for scene 1016-09104, where channel 5 was the working base, channel 7 has been normally used for the analysis. Other scanograms and channels were used as auxiliary, especially with cloud-covered areas. For the Macedonian territory (image 1102-08485) the previous interpretation by Dimitrijević and Marković (1978) has been also consulted.

THE MAP OF FRACTURES

A basic analitic sheet has been prepared as the original issue of this study, with a highly varying data density over the territory. Data density depends on the (1) number and grade of expression of fractures on the Earth's surface, (2) image quality and (3) cloudcoverage. Of all the tree factors only the first one has a geologic significance, representing the true frequency of fractures seen over a certain area. To overcome the risk of obtaining a wrong picture of the fracture distribution, the original analytic sheet has been modified as shown in Figure 1. Only large, representative fractures, as indicators of orientation, have been demonstrated.

The primary purpose of this paper is to show general geometric features of thus represented ruptural fabric, without entering for the moment the full discussion of its kinematic significance.

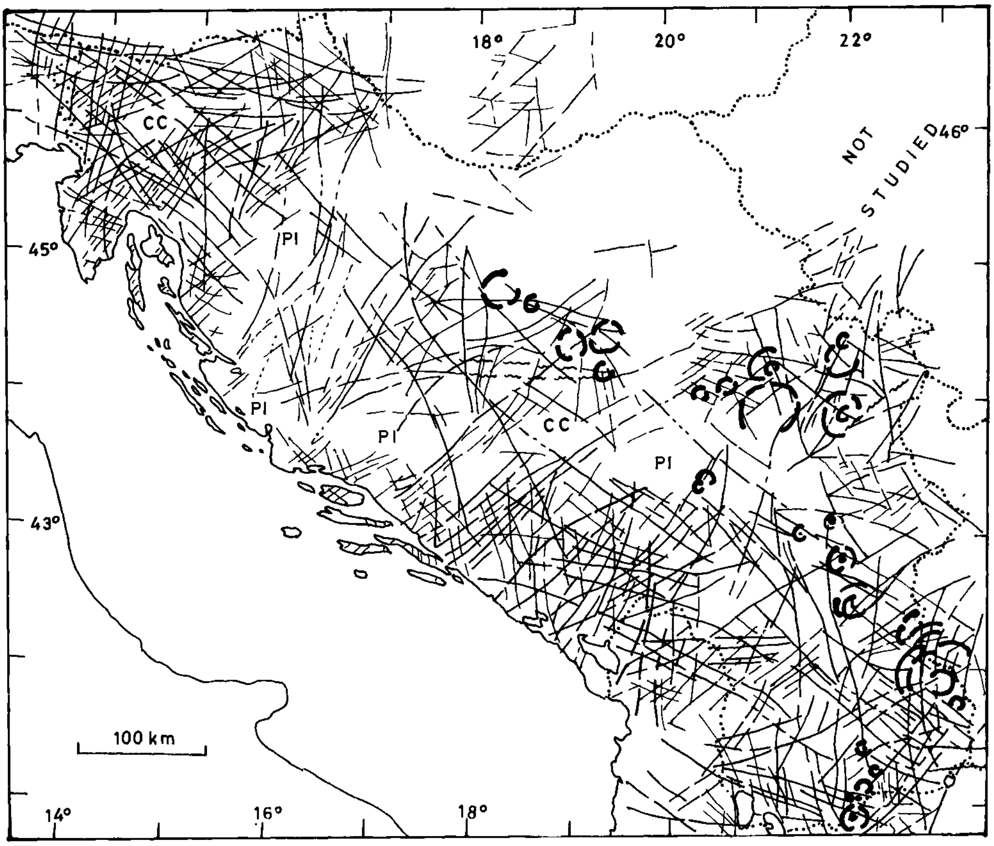

Fig.1. Generalized map of fractures and ring structures seen on LANDSAT imagery of Yugoslavia. "CC" indicates cloud cover, and "PI" poor imagery. Wavy lines represent possible fracture zones, represented by broad "lineament belts".

GEOMETRIC FEATURES

The ruptural fabric of Yugoslavia displays the following general features:

- Fractures are disclosed by lineaments shown by long straight negative relief forms (valleys, rivers) or linear sequences of short straight negative relief forms. Some of probable fractures zones are revealed by broad linear negative relief belts, too broad to be directly seen on air photographs. All these lineaments have a darker tone on the scanograms, and in belts of side lap between two images they can be observed stereoscopically as negative relief forms.

- It seems highly probable that these fractures are visible mostly on the scanograms, which were neotectonically active, i.e. the intermittent pre-Neogene fractures which were also posteriorly active, and fractures which were generated during the

Neogene and/or Quaternary.

- These fractures correspond only in places to faults known from the geological map, and in general form a completely new pattern renegant to the one shown by more ancient faults, and corresponding to a new stress field. By their orientation and/or distribution they do not reflect the pre-Neogene structural zoning of Yugoslavia, except for the area of the Sava Folds and the Alps. A similar conclusion has been reached also by Letouzey and others (1976).

- The main ruptural systems are:

SW-NE: Well developed throughout the area; somewhat less prominent in Macedonia. This system is ubiquitous and does not specify only the Zagreb-Balaton fracture zone /1/[1], as stated by Oluić (1975) and Pamić (1975).

NW-SE: A system seen also throughout the area, but particularly visible in a broad and somewhat vague belt from E. Macedonia to Ljubljana, and in SW Macedonia. In Hercegovina and Montenegro these fractures seem to be connected with fractures deflecting toward SSE (e.g. the fracture Sanski Most-Sana-Jajce-Vrbas-Bugojno-Rama-Neretva-Mostar-Metković /2/, partly corresponding to the well known Busovača fault). Some of regional fractures of this (NNW-SSE) orientation seem to be independent (e.g. Pakrac-Bosanska Gradiška-Vrbanja-Zenica-Visoko-Tręskavica-Volujak-Vojnik /3/). The NW-SE system was referred to as the "Vardar system" in an earlier contribution on LANDSAT imagery of Macedonia (Dimitrijević and Marković, 1976).

N-S: A system which is best developed in the extreme west and the extreme east of the country.

Over the Sava Folds and Southern Alps /4/ a system of fractures is seen, broadly convex toward the soth. It corresponds to the well known young faults of this area.

Numerous other fractures are recognized which cannot be clearly included into these or other systems. Some of these fractures (or groups and zones of fractures) have impressive dimensions. An example worth mentioning is the somewhat discontinuous fracture zone Knin-Travnik-Kladanj-Lajkovac-Smederevo-Ram /5/, with a basicaly W-E to WSW-ENE strike.

Similar results have been reached by Biju-Duval and others (1976), who also kinematically interpreted some faults, mostly by personal impression. Foose (1976) emphasizes the NW-SE lineaments along the Adriatic coast, neglecting other systems. One of his maps (1976, Figure 4), together with maps by Oluić (1975), Dimitrijević and Marković, (1978) and the present author, is a very good example of different interpretation styles of the same imagery.

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[1] Numbers in brackets refer to Figure 2.

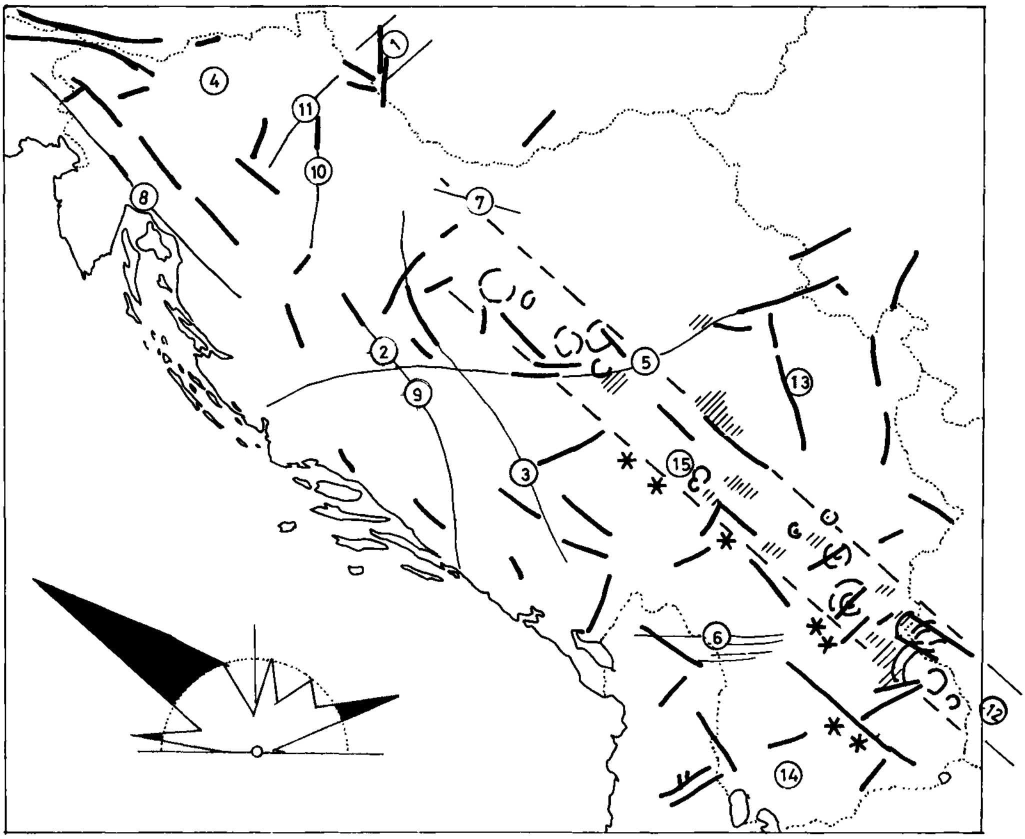

Fig.2. Interpretation of some features seen in Fig.1. Heavy lines: drainage-controlling fractures. Stars: young (Pliocene to Quaternary) alkaline basaltoids. Hatchured: main occurrences of dacite, andesite, latite and quartzlatite. Numbers: features referred to in the text. Rose-diagram: drainage-controlling fractures (dotted: arithmetic mean).

SOME INTERPRETATIONS

The fracture net, shown in Figure 1, is very complex and can not be interpreted within a simple scheme (e.g. the model of P-axes striking SW-NE; Cagnetti and others, 1978). Only some preliminary hints on connections of ruptural fabric with relief and seismotectonics, and on its kinematics can be suggested at present.

Heavy lines in Figure 2 show parts of fractures controlling portions of rivers large enough to appear in the 1:2,500,000-scale map. The rose-diagram in this figure shows orientation of these fractures. The most significant as drainage-controlling is the system NW-SE (classes 300-330°). Other directions fall within the $\bar{x}$-circle and only fractures within classes 270-285° and 60-75° are slightly more important.

In his extensive neotectonic study of Eastern Slovenia, Premru (1976) distinguishes six systems of faults which were active during two neotectonic cycles from Middle Pliocene until the present time. His study has been carried out photogeologically and accompanied by extensive field work; thus it represents the ruptural fabric of Eastern Slovenia much more detailed and accurate than the present one. Most regional fractures are shown, nevertheless, in both studies, and the orientations conform completely.

The orientation of "morpholineaments of morphostructural significance", forecasted by Klein (1975) on geomorphological grounds, coincide with all the three space-observed fractures systems. Klein suggested also a notable fourth system striking W-E which has not been detected by the present author. Such zones have been observed only north of Sarajevo (shown also by Klein) as a part of the regional zone Knin-Travnik-Kladanj-Lajkovac-Smederevo-Ram [5] and east of the Skutari lake [6].

Mioč (1975) shows almost the same fractures around Ljubljana in his neotectonic sketch map.

In the very early Kišpatić's map (1895) of seismically active fractures in Croatia, all three mentioned directions have been recorded: NW-SE as the main one, then N-S and NE-SW. Positions of fractures rarely coincide with this author's map; from the first system only the Djakovo [7], Bakar [8] and pro parte Skoplje valley [9] faults have been recognized on the imagery; from the second system was noted the Zagreb fault [10]; and from the third system the Sv. Jana fault [11].

The connection between the NW-SE and NE-SW striking fractures and earthquakes is well established in Macedonia (Dimitrijević and Marković, 1978): most epicenters are situated at intersections of these two systems. The fault-plane solution for the Skopje earthquake of July, 26, 1963 (Balakina and others, 1967) gives 105^{o} for the strike of the active nodal plane, which is parallel with the NW-SE fracture system. The movement was sinistral gravitational, according to the same authors, with orientation of the slip vector L 308/40.

Kinematics of the observed ruptural fabric seems to be very complex. The fault plane solution by Balakina and others (1967), mentioned before, would suggest sinistral transcurrent movements for the NW-SE system; field and photogeological observations of I. Djoković in Western Serbia (personal communication) speak for dextral slip. Foose (1976) explained these lineaments as "...gravity glide masses that have moved southwestward". This idea is quite untenable; overthrusts and schuppen, which might be explained also in this way, are clearly more ancient than the space-detected fractures and have no connections with them.

For neotectonic fractures in Slovenia, Premru (1976) envisaged up to nineteen movement phases, which gave in places quite different results in respect of slip directions. This author's results suggest that one general model could not be erected for the whole neotectonic period, and that kynematics of the fracture set shall be solved step-by-step.

RING STRUCTURES

The inspection of LANDSAT imagery revealed a rather broad presence of ring structures, known previously from Macedonia (Dimitrijević and Marković, 1976) and the Golija Mt. (Mudrinić and others, 1976). These structures range in diameter from less than 10 to over 50 km. They occur in three quite distinct areas:

(1) The belt Derventa-Delčevo [12], which is parallel with the NW-SE fracture system and shows a rather clear connection with its main zone,
(2) The Kragujevac-Rtanj-Kučevo triangle [13], and
(3) The Moriovo area of S. Macedonia (Kajmakčalan-Pološko) [14].

Ring structures, especially those of the Derventa-Delčevo belt, admit interesting speculations. They are not directly formed by volcanic activity, and may occur in any type of rocks. It is widely maintained that such structures indicate the presence of magmatic chambers in the depth (Wisser, 1964). Young mineralization has been demonstrated to be connected with the Golija ring structure [15] by Mudrinić and others (1976). Young alkaline basaltoids occupy a position along the Derventa-Delčevo belt of ring structures, which is very challenging. Departing from a petrogenetic viewpoint, Terzić (1976) regarded these rocks as products of a new and independent volcanism, and not (as conventionally thought) as the final phase of the Alpine volcanism. The belt Derventa-Delčevo coincides also with main occurrences of dacite, andesite, latite and quartzlatite. On the other hand, deep seismic sounding showed a thick crust beneath the maritime Dinarides (Dragašević, 1969) which has been attributed to the compression caused by young migrations of the Corsica and Sardinia toward east (Boccaletti and Guazzone, 1972) and underthrusting of the Adriatic foreland below the Dinarides (Dimitrijević, 1974). Data on earthquakes in the Eastern Mediterranean show the presence of a seismically active zone from the Hellenic trough complex through the Albanian coast to Dalmatia. The southern part of this belt is mostly regarded as a subduction zone.

Merged together, all these data point to a bold but interesting speculation on ring structures as signs of present magmatic chambers and messengers of a possible future volcanism. The direct source of magma would in this hypothetical model be represented by the subduced slab in the extension of the Dinaridic roots, and the Dalmatian coast would be a concealed subduction zone.

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APPLICATION OF A DIGITAL IMAGE PROCESSING SYSTEM TO LAND USE MAPPING FROM LANDSAT DATA

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ABSTRACT

In the course of a territorial planning study, Landsat data were used to obtain information on land use. These data were processed by means of an automatic digital supervised system and compared with ground truth within a test area. A comparison was made between the results of the automatic classification and the statistical information available from official sources. The differences between the results of the automatic classification and the ground truth are pointed out with the objective of analyzing their causes.

KEYWORDS

Remote sensing, land use mapping, digital image processing, statistical analysis.

INTRODUCTION

Italeco S.p.a was contracted by the Development Board of the Region of Lazio (FILAS) to prepare an economic development plan for an area of approximately 264,000 hectares located in northen Lazio (Alto Lazio). This work, currently in progress, encompasses two activities: the collection of current data, and extrapolations to the future. Remote sensing techniques were utilized to acquire data on the physical status of the territory, and to produce a thematic map of the land's use. To assess the area's economic development trend, a gravitational model derived from Lowry (1964) was used. Starting from initial assumptions on the siting of industrial activities, the model iteratively computes the population's spread as a function of the access time to centers of activity and services. The model subdivides the territory into elementary'cells'; for each of these, a set of numerical parameters describes the physical, demographic and socio-economic characteristics of the area. Remote sensing is well adapted to determine those physical parameters which are connected with land use. Another important application of remote sensing arises in the calibration of territorial models. To obtain an effective simulation of present conditions, regional development models must be calibrated by means of historical data series. In specific applications such as the evolution of urbanized areas, remote sensing can provide historical sequences, with accuracies not less than those of traditional statistical sources, provided that the time span of availability of remotely sensed multispectral data is sufficiently long.

SOURCES OF DATA ON THE TERRITORY

The information required for territorial planning is gathered from several sources. Principal among these are the data from the Central Institute for Statistics (ISTAT), obtained through censuses every ten years, and updated yearly. The data, which are in the format of numerical tables, are available down to the commune level. They are generally considered as representing a highly reliable inventory of the land's aggregate usage. The data are published however at least one year after their collection; moreover, they cannot be used directly for constructing land use maps. Italy's cartography is provided by the Military Geographical Institute (IGM). Their mapping is highly accurate in describing the land's morphology, yet only indicative as regards land use. Furthermore, IGM's maps are updated at ten yearly or longer intervals. In 1965, under the auspices of the National Research Council, a Soil Utilization Map of Italy was produced at a scale of 1:200,000 (C.N.R. 1965). It has not been updated since: moreover, the small scale limits its use for regional territorial planning.
The dearth of data at the national level has compelled the several regional administrations to create data banks on the use of their territory. The dominant trend is to subdivide the territory into elementary cells with surface areas varying between 25 and 625 hectares; foreach of these, all available information is provided (Piacentini 1978).
A typical problem of data collection is the rapid obsolescence of the information. Quite often the territorial situation undergoes significant evolution, between the collection of the data and its utilization for planning purposes. Remote sensing allows overcoming this problem because it provides continuously repetitive information thus making available to planners a constantly updated description of the land cover.

INTERPRETATION OF LANDSAT IMAGERY

Italeco has used Landsat imagery since 1975, as an instrument for territorial planning and management (Italeco S.p.a, 1977), interpreting it via an analog multitemporal procedure of its own devising. Italeco

has performed a specific study in this field for the Region of Lombardy (Italeco S.p.a, 1978). To obtain the thematic cartography of Northen Lazio, Italeco interpreted the Landsat imagery in two ways: using its own analog procedures and methodology, and simultaneously by employing an automatic system to provide quick results to guide the initial phase of the study. The final output of the automatic system, which was of the 'supervised' type, consisted of a map and an inventory, in twelve categories of land use, within Anderson's Level II (Anderson and others, 1976). The map evidenced problems - poor classification of the coastal area, and a lack of detail for some ur ban areas. Another problem was the discrepancy between the map's inventory and ISTAT's data. To achieve a reasonable correspondence, it became necessary to re-aggregate the data from both sources to Anderson's Level I. Even so, as can be seen from Table 1, significant discrepancies exist between the ISTAT statistics and the results of the automatic interpretation. To resolve the residual uncertainties, it was decided to perform a detailed comparison in a selected test area encompassing the Communes of Civitavecchia, Santa Marinella, Tolfa, Allumiere, Cerveteri and Ladispoli, embracing a total surface of 53,278 hectares. The area comprised by the six communes is quite varied: it includes all categories of land use from the urban and industrial area of Civitavecchia to the agricultural areas of Cerveteri and the woodlands of Tolfa, with altitudes varying from sea level to 600 meters. To perform the test, a 1:50,000 scale map of this area was constructed by means of aerial photography supported by ground checks. On the aerophotographic map, all categories of land use were isolated as far as was possible at the scale used. From this map, an inventory was derived, and compared with the ISTAT data.
In this case also, the data were re-aggregated to correspond with ISTAT's categories (Table 2). Good agreement was obtained between the inventories obtained from the two sources. The small discrepancies may be attributed in part to the land cover's evolution in the time lapse between ISTAT's survey and the aerophotographic survey, in part to the difficulty of establishing perfectly equivalent categories when using different sources of data. For example, in the category 'urban area' ISTAT includes not only population centers, but also motorways, railways, scattered housing, etc; whereas the aerophotographic map included only urban centers proper. A comparison was then made with the inventory derived from the 1965 thematic map of Italy (Table 2). The substantial differences indicate that this map should not be regarded as a reliable picture of the present situation.

ANALYSIS OF THE AUTOMATIC CLASSIFICATION

The map and inventory derived from aerial photography were taken as 'ground truth', and used to check the reliability of the product provided by the automatic interpretation system (Table 3) within the six-commune area. Significant differences did appear: especially in the classes 'permanent meadowland and pasture' and 'arboreal cultiva-

tions', and, among these, particularly the sub-class 'vineyard'.
By comparing the automatic map with the ground truth a discrepancy map was obtained, which details the classification errors between the two automatic methods. Since it was quite cumbersome to interact with the automatic system, the division into classes was obtained by analog methods, via appropriate filtering from the original film color negative and color positive of the automatic map (Fig. 1).
In this manner various maps were obtained, each showing only one category of land use. The discrepancies were obtained by superimposition into the aerophotographic map. All misclassified areas were next subdivided into elementary cells by means of a square grid. A boolean array (presence-absence) was constructed for each cell : its components represent characteristics of the ground cover (Table 4). Statistical processing by means of factor analysis (Benzécri, 1973) did reveal those components subject to systematic errors. For example the class 'permanent meadowland and pasture' was often classified as 'woodland' or 'arboreal cultivation', in particular as 'vineyard', if sparse trees and bushes were present; priority categorization as 'vineyard' was found in areas (especially within the Commune of Cerveteri) wherein the vine is cultived not in rows but as a uniform canopy; in this case, the training field of the vineyard displays a spectral signature very similar to that of meadowland. The coastline was constantly listed as 'uncategorized', due to the peculiarity of the structure of the land cover, which almost always included a railway line, a superhighway or coastal road, the sandy shore, and an almost continual stretch of low - density building.

CONCLUSION

The analysis not only pointed out the need to modify the a priori land cover class subdivisions: it supplied ground rules for such modifications. The procedure allows for the iterative refinement of the classification software adapting it to the particular region under examination. Given the particularly fragmented structure of the agrarian scene within Italy and Europe in general (Fig. 2), it appears indispensable to provide this kind of iterative adjustment, to minimize the recurrence of appreciable errors.
A significant reduction of classification errors can be obtained by using, in addition to the four spectral dimensions, the time dimension: this requires the analysis of not just a single Landsat image, but of other images taken at times which take into account the phenological variations of vegetative species. In particular, the most significant temporal dates are those which reflect the maximum difference between the reflectances of the species sought and their confusers.

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TABLE 1 Comparison between the Inventories of the Northen Lazio Area Derived from ISTAT Data and from the Automatic Digital Interpretation of Landsat Data.

	ISTAT (Δ) (hectares)		Landsat (Δ Δ) (hectares)	
Yearly Crops	90632		57431	
Meadowland and pasture	58691		3320	
Arboreal cultivations	42376		85530	
- Orchards		12141		24054
- Olive groves		13327		19870
- Vineyards		16908		41606
Woodland	59706		108113	
Urban areas	5591		987	
Inland water	7075		6902	
Uncategorized	--		1788	
Total	264071		264071	

(Δ) data from the 1971 Census

(ΔΔ) data images in 1978

TABLE 2 Comparison between the Inventories of the Test Area, Derived Respectively from Statistical Data (ISTAT), from Aerial Photography (AP) and from the CNR Land Use Map (CNR)

	ISTAT (hectares)		AP (hectares)		CNR (hectares)	
Yearly Crops	13409		16178		30844	
Meadowland and pasture	18908		17008		5983	
Arboreal Cultivations	2134		2468		628	
- Orchards		359		983		233
- Olive groves		579		569		230
- Vineyards		1196		916		165
Woodland	16475		16303		14748	
Urban areas	2351		1321		1075	
Total	53278		53278		53278	

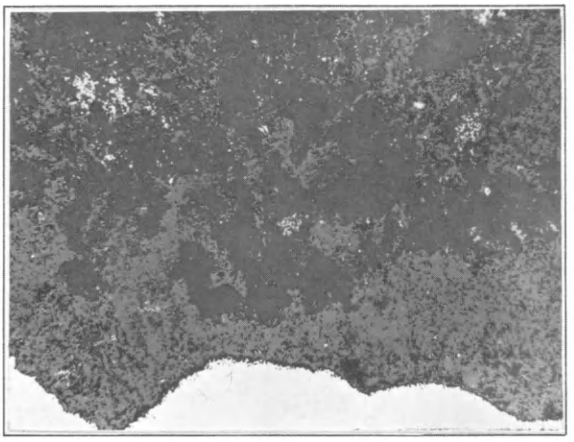
TABLE 3 Comparison between the Inventories of the Test Area Derived Respectively from the Ground Truth and the Automatic Digital Interpretation of Landsat Data.

	Ground truth (hectares)		Landsat (hectares)	
Yearly Crops	16178		17964	
Meadowland and pasture	17008		360	
Arboreal Cultivations	2468		13683	
- Orchards		983		4460
- Olive groves		569		2170
- Vineyards		916		7053
Woodland	16303		19650	
Urban areas	1321		298	
Uncategorized	--		1323	
Total	53278		53278	

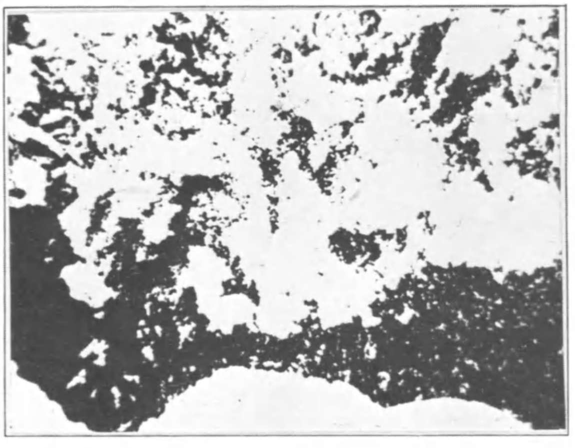
TABLE 4 Characteristics of the Ground Truth Surveyed for the Misclassified Areas.

1. Yearly Crops, single cultures
2. Treed yearly crops
3. Yearly crops, multiple cultures
4. Uncultivated area
5. Grassland
6. Pasture with bushes
7. Pasture in poor condition
8. Pasture with scattered trees
9. Orchards
10. Olive groves
11. Vineyards
12. Hazelnut trees
13. Bush (Macchia)
14. Conifers
15. Chestnuts
16. Beeches
17. Oaks
18. Mixed woodlands
19. Wood of tall trees
20. Coppice
21. Recently reforested areas
22. Gardens and urban parks
23. Industrial sites
24. Local roads
25. Motorways
26. Railways
27. Ports
28. Sandy shore
29. Rocky shore
30. Urban apartment blocks
31. Villas with gardens
32. Rural houses
33. Greenhouses
34. Archeological zones
35. Quarries and pits

Fig. 1 Discrimination of classes 'woodland' and 'permanent meadowland' by photographic filtering from original map.



original map
(the white area on the bottom is Tyrrrhenian sea)



woodland
(white areas)

meadowland
(black areas)

RESULTS OF APPLICATION OF DATA FROM SPACE TO GEOLOGICAL SURVEY IN YUGOSLAVIA

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ABSTRACT

A very good and successful use has been made of data obtained from artificial earth satellites, in various geological research in Yugoslavia. Particularly efficient and useful are those from the Landsat satellites. The interpretation of the geological composition has been made much more completely and qualitatively thanks to these images used in geologic mapping of larger areas. Tectonic data recorded on Landsat images has been of a very good use in estimating the tectonic and seismic activities in a given area. Data showing the structure and tectonics, noticeable in Landsat images in smaller scale, and those in larger scale as results of digital processing, has made possible the delineation of promising oil-bearing geologic units. Further on, reliable data in exploring copper ores in Eastern Serbia (copper ore mine Bor) has been obtained by interpreting the Landsat images; the Skylab images have discovered many interesting data in respect of bauxite ore deposits in Northern Dalmatia.

PREFACE

In surveying the Earth's composition and structure and everything that is hidden therein ores, minerals etc - the clasical methods have been added recently those of remote sensing. Such one that is very significant is the processing and use of data obtained from the artificial Earth satellites. The technology of making images from the space of the earth surface and objects thereon by means of satellites is in the phase of an ardent development giving thus way to great chances in investigating the mineral resources masked within the earth. In the sense of quality of investigation, a new one is ahead, that of deducing of details from the general data.

There are six years only since the first technologic satellite has been launched into the space with the scope of surveying the resources of the earth - it was the Landsat-1 (ERTS-1),and it can already be spoken about the significant and important results obtained by making use of data from the said satellite, and from the satellite launched next.

There are certain images made from the "Skylab" that very much contributed to the research for mineral resources. The images obtained from the satellite NOAA - 3 have usefully been used in following and determining the locations of regional tectonic faults, and in interpreting the structural composition.

The images from above said satellites have shown and identified many a useful geologic information. Generally, this data is of a regional meaning. However, if the results coming out of satellite images are digitally processed from the magnetic tape (CCT) directly, much more information becomes available, many of which represent details. Data obtained this way may be much easier and more reliably identified.

APPLICATION IN GEOLOGICAL SURVEY

Surveying the tectonic structure of the Earth Satellite. Images are those where regional geologic structures may be particularly well recorded and geotectonic structures identified. Since 1973 the Landsat imagery has been efficiently used in different geological mapping and other kinds of geologic work (Oluic, 1975, Grandic & Hanich, 1976, Dimitrijevic & Markovic, 1976, Poljak 1977).

A great many of very useful geologic information resulted from the interpretation of Landsat - 1 and Landsat - 2 images. Even those geologic information that so far had remained unknown in well surveyed areas have now come to the daylight. On the basis of such data the tectonic structure of mapped areas may be more completely and thoroughly interpreted and determined (Slide N$^{\underline{o}}$ 1 and 2). Those slides display the tectonical relationships in the surroundings of Zagreb that have been established by means of Landsat images.

NOAA - 3 satellite images (Slide 3) made by IR scanner (10,5 - 12,5μm) from the distance of 1500 km represent the middle and the southern Europe, and display larger faults and fault zones (Slide N$^{\underline{o}}$ 4). Most of them, i.e. faults and fault zones, took their origin in the neotectonic age and may be of a particular significance in the interpretation of seismotectonic activity in those parts of the Earth.

Seismotectonic activity. Information about tectonics recorded in satellite images - about regional faults in particular - may be very reliable and useful indicators as to seismic activity which might be expected in the surveyed areas (Dimitrijevic & Markovic, 1978, Oluic, Cvijanovic & Kuk, 1978).

The NW part of Yugoslavia and the adjacent part of Italy were the subject of interpretation of tectonics shown in Landsat images (Slide 1). Many tectonic data has been obtained (Slide 6) and correlated with the results of seismic research (Slide 7). A mutual relation of locations and intensity of tectonic and seismic activity was established. It has been established that a more intensive seismic activity develops on the crossings of larger faults and at the points of bordering of two faults differently extending on each other. In certain zones in the surroundings of Zagreb, Ljubljana, on the reach between Rijeka and Ljubljana and in Furlania. The mentioned areas are tectonically the most disturbed.

Geologic exploration of oil. The Landsat images have proved to be highly useful in investigations of oil and gas in the Pannonian basin. The resulting information joined with the results obtained by using other geological and geophysical surveying methods have enabled a more qualitative interpretation of oil and gas promissing units (Oluic, 1975, Oluic, Bodrozic & Kapovic, 1977). In Slide N$^{\underline{o}}$ 8 map of tectonic blocks may be seen, which are significant as far as the choice of locations for drilling for oil is considered. The map is made out according to the Landsat images and gravity measurements. Very precious geologic information resulted from the digital processing of Landsat imagery representing the area north of Zagreb, which area is covered with Pliocene and Quaternary sediments and vegetation. This information had remained masked during the previous field work (Oluic, 1978). The said data and information are expected to indicate locations where geophysical surveys and deep drilling are to be made, i.e. where hydrocarbon occurrences may be expected.

In the Slide N$^{\underline{o}}$ 9 a digitally processed Landsat image is shown, where different geological and geomorphological features may be seen.

The Slide N$^{\underline{o}}$ 10 is a map of faults in the Pannonian basin (north of Zagreb), which resulted from the previously mentioned image. There are two main directions of faults extension,NW-SE and NE-SW. The ground is intersected by the faults to smaller and larger blocks, the entire pattern reminding that of "parquetry".

Exploration for mineral resources for several years already the Landsat images have been successfully used in exploring mineral resources (Mudrinic, Djokovic & Markovic, 1976, Hanich, Koscec & Denih, 1978, Oluic 1978).

Slide N$^{\underline{o}}$ 11 - represents the Landsat-1 image (color composite) showing eastern Serbia (with the Danube). Here, larger faults and fault systems may be noticed, as well as some annular geomorphological features.

Slide N$^{\underline{o}}$ 12 - this is a tectonic map showing the faults and annular features determined in the Slide N$^{\underline{o}}$ 11. Circular and semicircular features adjacent to the faults and the crossings are of a particular significance. They very likely were once the centers of magmatic or igneous activities. These features are those where higher concentration of copper ore is noticed.

Slide N$^{\underline{o}}$ 13 - an insert from the Landsat image (Slide N$^{\underline{o}}$ 11), as the result of digital processing of the data about the copper mine Bor. Still better noticeable are the faults and annular features in this image.

Slide N$^{\underline{o}}$ 14 - is a map of faults and circular features as recorded in this image. Images obtained from the Skylab have been very efficiently used in surveying the bauxite deposits (Grandic, Oluic & Bodrozic, 1976).

Slide N$^{\underline{o}}$ 15 is Skylab color image representing northern Dalmatia. Very well identified and followed may be the faults, position of sedimentary rocks (dip and strike of beds), lithologic composition degree of karstification and bauxite occurrences.

Slide N$^{\underline{o}}$ 16 - Tectonic map drawn on the basis of the above mentioned image. New bauxite deposits which very often occur along the recorded faults have here also been discovered thanks to identified and precisely determined locations of faults.

Hence, it may be said that very useful and good results have been obtained by using the information and data from the artificial earth satellites in exploring the earth structure and its natural resources.

The interpretation and digital processing of satellite images have given in a relatively short time very precious geological data.

A good review over and preciseness of thus obtained information are the guides as to which regions the detailed field geologic exploration and geophysical surveys are to be directed, and it is not seldom that such information directly or indirectly point out to where mineral resources are to be looked for. Highest economic effects are thus obtained in exploration work and a much better data processing leading to a more complete and thorough interpretation of the geologic structure of the earth crust and changes that had taken place therein and thereon, and to the more reasonable exploration of mineral resources.

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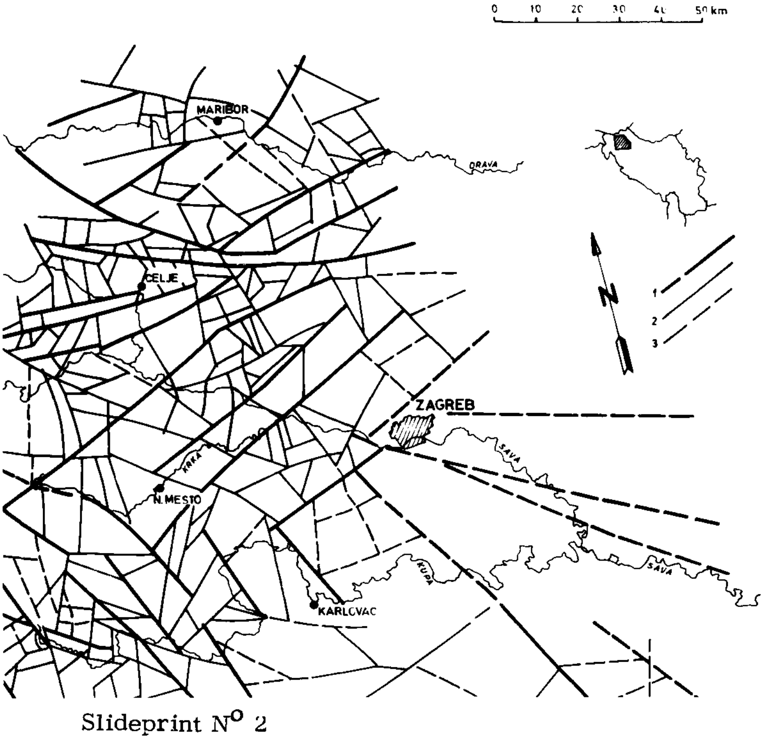
Slideprint N^{o} 1



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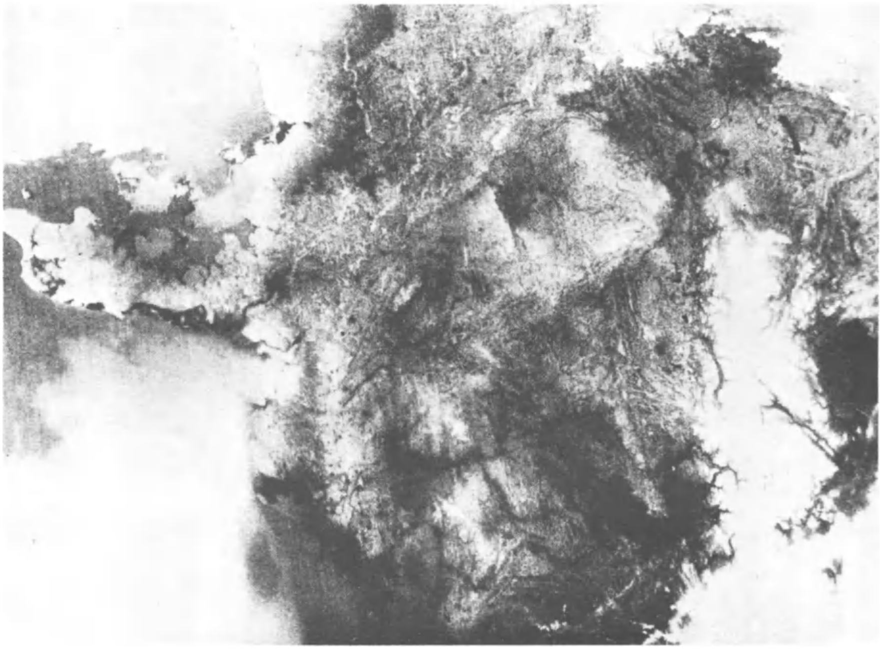

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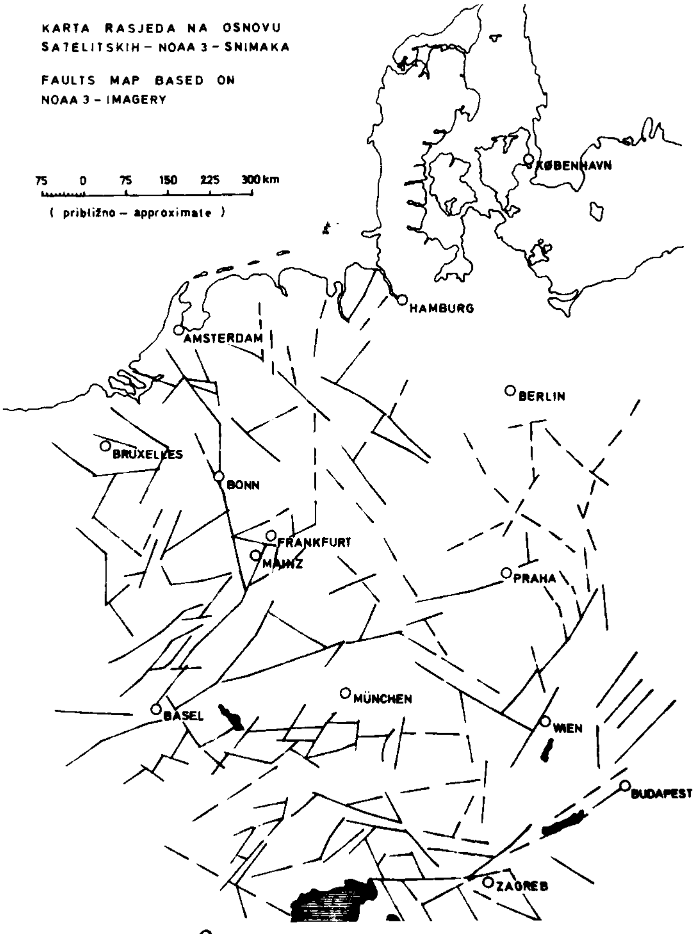

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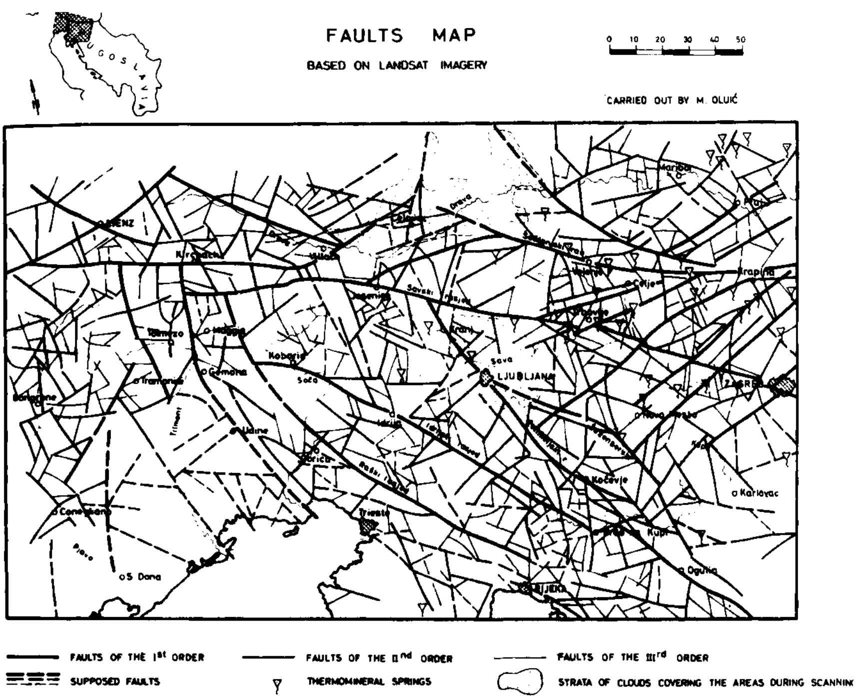

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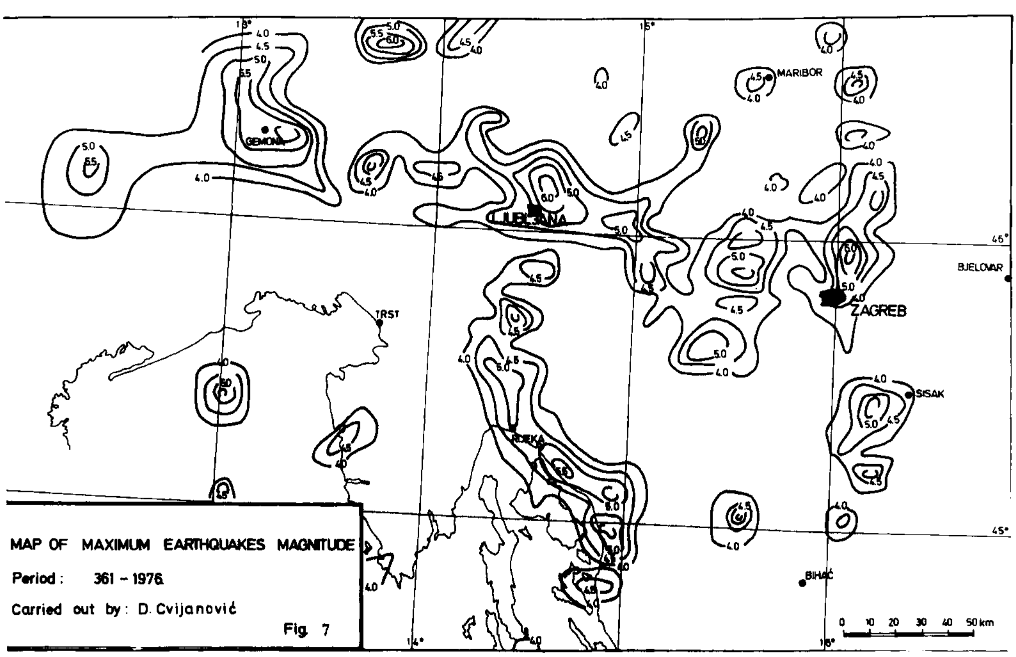

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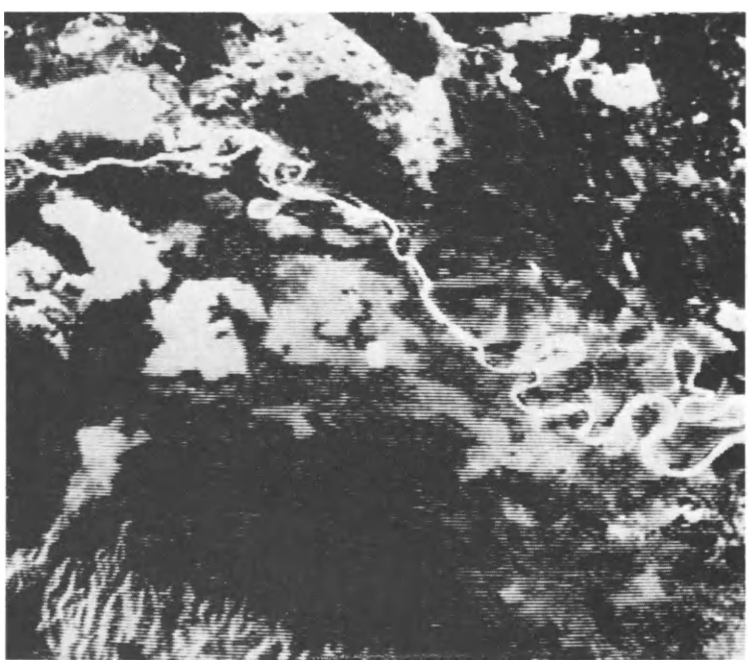
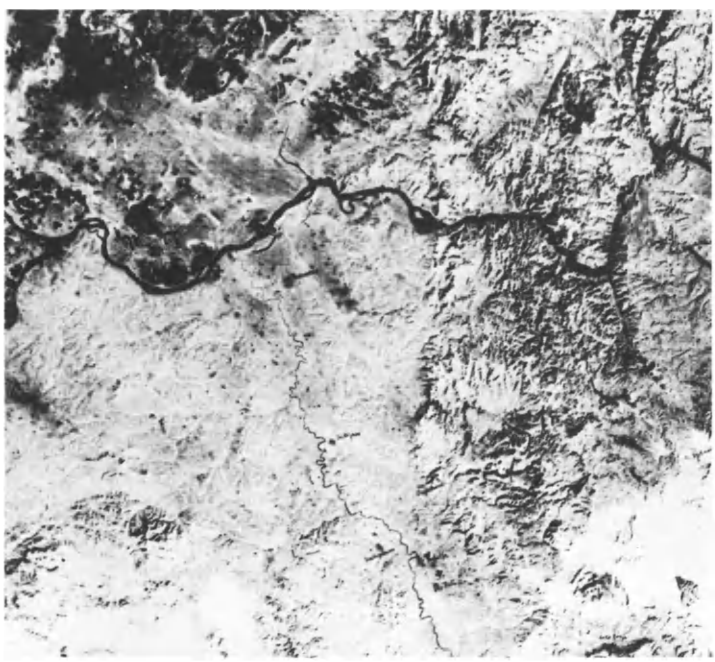


Slideprint N° 9

Slideprint N^{O} 10



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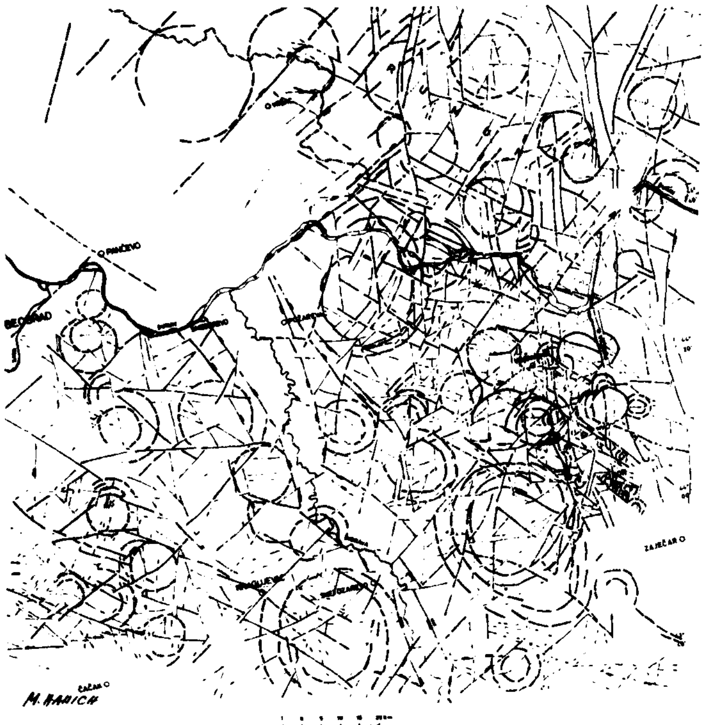
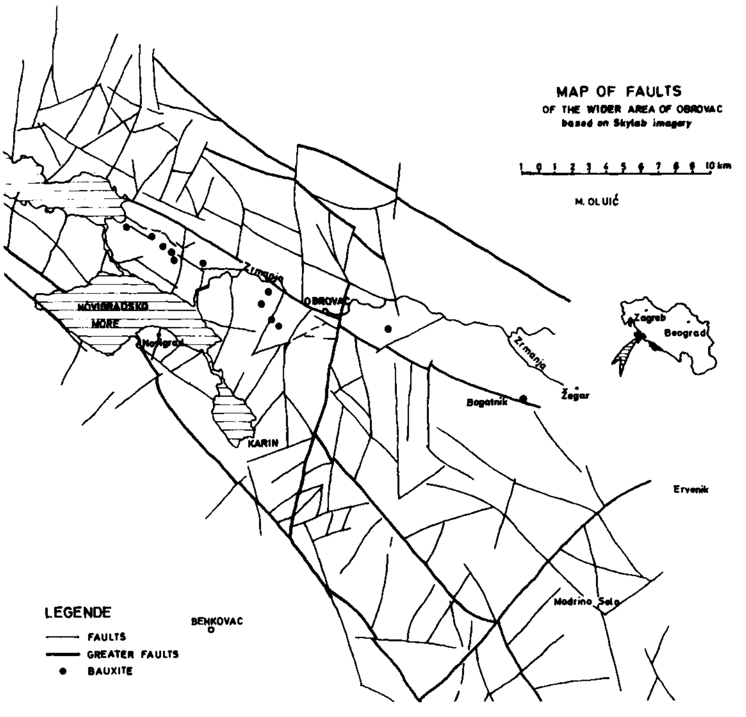


Slideprint N° 12

Slideprint N° 15



Slideprint N° 16

RECENT DEVELOPMENTS IN AUTOMATIC ANALYSIS OF REMOTELY SENSED IMAGERY

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ABSTRACT

The paper presents a critical survey of recent developments in the computer analysis of satellite images. The most promising trends in the use of spatial temporal information gathered from different platforms and sensor systems are pointed out and some researches carried out by the authors are discussed.

KEY WORDS

Satellite Image Analysis
Image processing techniques
Pattern recognition
Cluster analysis
Classification methods

INTRODUCTION

The analysis of remotely sensed images is to be considered a complex system deviced to extract, from the data, information to be used for given purposes.

It is therefore both impossible and meaningless to undertake any critical survey without characterizing, as clearly as possible, the many factors affecting the analysis. Some of the key ones are : a) type, nature and characteristics of the data; b) definition and identification of the informational content of the data; c) characterization of the uses to be made of the information, once extracted.

Even then, given the obvious space limitations, a critical survey can usefully address only a specific subsystem.

The data processing subsystem is herein broadly defined as the set of operations needed to extract the wanted information from the data. This subsystem is heavily influenced by the nature of the abovementioned factors and by their mutual relationships. It is also very complex and many solutions have been proposed ranging from simple photointerpretation to sophisticated man-interacting computerized hybrid systems.

The authors believe however that, whatever the structures and aims of a data analysis system, significant advancements are connected with and strongly influenced by the developments of computerized processing subsystems. Hence this paper critically survey progresses and try to identify promising trends in the restricted area of computerized data processing of digitalized images.
Such topics as pre- and post-processing, data compression and so forth are excluded, not only for space limitation but also because some of them are already adequately covered by exhaustive reviews. (Cappellini;Chen;Fu,76;Kak,76;Kanal;Mitchell; Rosenfeld;Thomas;Van Wie)

In the field of computerized data processing, the efforts should be devoted to the development of special rather than general purpose software particularly tuned to a well defined specific application (Erikson;Holmes). These softwares should be structured modularly and make use of standardized modules for input preprocessing and output post-processing as well as for step-elaboration (Haralick,77). This flexible structure is most ideally suited to the entire spectrum of users, which ranges from researchers to operators in the different specific fields where remote sensing provides useful tools. The former ones are interested on identifying the methodologies which are best suited to extract the information to which they are interested and in exploiting these methodologies to faster progress in their scientific fields. The latter ones are interested in packages to be used, routinely, in a straightforward, convenient and cost-effective manner.
With this scenario computerized data processing methodologies capable to exploit to the best the informational content of the data acquire a paramount role and progresses made in this area deserve update surveys.

The progress in sensor and platform technologies, and, more generally, in data collecting aerospace systems, makes now available (Dittel;Rogers) data in connection with:
-spectral information
-spatial information
-temporal information
The authors believe that the challenge is to overcome the prevailing trends that consider the three informational contents as "separate" or "disjoint" and to develop efficient techniques which would consider the contents as belonging to an "informational continuum" sampled, for technological or practical reasons, in a discretized manner.
The survey is much influenced, in the selection of topics, by this point of view.

In the body of the paper, references are made to some unpublished works by the authors. A summary of the developments is reported in Appendices A and B.

COMPUTERIZED DATA PROCESSING

Preliminary remarks

In the last years extensive work has been done in the application of data processing techniques and general tools of pattern recognition to remote sensing
To provide a unifying framework for surveying information extraction procedures we shall define observation and feature spaces with respect to which we distinguish three levels of features of increasing complexity: point feature, local feature, global feature. They can be independent or interrelated to a different extent. We evaluate methodologies with respect to their information extraction capability and pin-point the nature and type of interrelations which are not accounted for. We shall adopt the largely suggested division of methodologies into two categories: decision theoretic (or statistic) and syntactic.

The observation space is a multidimensional space whose coordinates are: the spectral wavelength coordinate, the physical space coordinates and the time coordinate. In principle,there is not an evident reason to discriminate between the different coordinates of the observation space and any type of discrimination must be specifically motivated. The resolution element of a point in the observation space is defined with respect to wavelength band, the pixel dimensions and the time (Fig. 1). The data are measurements taken at observation points and are representative of what is contained in the pixel and at the instant corresponding to the observation point.

A feature is any entity which is derived from measurements taken at points of the observation space. The feature space is in general a multidimensional space.
The point feature is any entity connected with the measurement at only one observation point. Thus,for instance, with Landsat data a point-feature is the radiance measured at a given wavelength band for a given pixel at a given time.
Let $\lambda_1, \lambda_2, \ldots \lambda_m, r_1, r_2, \ldots r_n, t_1, t_2, \ldots t_p$ denote the coordinates (wavelengths, pixel elements, times) of the observation space, $C(r_j, t_k)$ the class content of pixel r_j at time t_k and the-point feature; it will be, in general, $\mathcal{J}=\mathcal{J}(\lambda_i, r_j, t_k, C(r_j, t_k))$.
The degree of sophistication in data processing depends among other things, on the hypothesis made on the relationships between the different point-features or, equivalently, on the functional dependence of $\mathcal{J}$ or, stated in yet other words, on the dimensions of feature-space. Thus, for instance, early Landsat data analysis assume a four-dimensional class dependence feature vector whose components are the radiance measurements in four bands. In the present framework this amounts to suppose that:
a) only observation points on the sub-space t = const. are considered;
b) the point feature correlation is independent of the geometrical coordinates r_j.
Similar hypotheses are implied when the components of the feature vector are radiance measurements at different waveleng and at different times of the same scene. The signature extension problem thus amounts to find an answer to the question of how-far in the observation space (geometrical-wise and time-wise) these independence assumption hold. A recent contribution of the authors to this subject is briefly discussed in appendix A.
Local features are derived from measurements made on mono or multidimensional neighborhoods of points with the features being assigned either to the points itself or to its neighborhood. For example, one can consider in the observation space the geographical neighbourhood of an observatio pint (given pixel wavelength and time), take gradients or perform other types of transformations and assign them or to the given pixel or to the set of pixels constituting the considered neighbourhood.
Global features are entities connected with measurements taken along patterns, surfaces, volumes.
Higher level features automatically account,although to different extents, for the interrelations among lower level features.

The decision-theoretic approach deals with methodologies searching a parttion of the feature-space for the optimal solution of identification or classification problems. In a broad sense, the syntactic methodologies can be used when a-priori information is available, that can be cast into a set of rules (called morphologic or syntactic rules), describing relationships among higher level features called primitive strucutural elements (words, morphs). The syntactic approach tries to recognize allowable higher order structures in terms of primitives and their interrelationships.

We shall discuss decision-theoretic and syntactic approaches separately, to the extent to which it is feasible. For each approach we shall proceed, as a rule, in the direction of features of increasing levels, and, for each level, in the order of increasing interrelations.

Decision theoretic approach

Point-features, single-stage. For many years data processing in remote sensing analysis has been mostly restricted to the Bayesian pixel by pixel methodologies, with the feature vector constituted by gray levels in the four spectral bands (Biehl;Duda). Hence complete independence from the other coordinates of the observation points is assumed.

In supervised methods, techniques of discriminant analysis with linear or quadratic decision function have been employed. The main body of problems remains those relative to the use of trainig fields, as evidenced by numerous studies on the best use of them and on the spectral signature extension (Havens;Henderson).

In unsupervised methods the researchers' attention has been focused to:

a) global sensitive methods, wherein the clusters are represented by pivots or kernels. Main topics in these studies are dynamical clustering methodologies. Their motivation rests in the need to take into account the global characteristics of the clusters by means of point by point algorithms (Frentres;Wong).
b) local sensitive methodologies, which make use of local feature characteristics as reflected for instance in the probability density function (peak selection, mode selection). To determine the tresholds needed to partition the features-space both automatical and manual procedures have been proposed (Chhikara; Kittler;Mizoguchi). The latter ones, based on the analysis of histograms of marginal distributions, are more widely used.

Although some interesting questions are still open, the majority of researchers is working on methodologies which, as it will be shown in the following of the paper, take into account the feature dependence, not only on the gray levels, but also on the other coordinates of the observation space. Recent numerical implementations of this new methodologies have led to classification algorithms which are more accurate and require fewer computational resources than pixel by pixel algorithms (Gupta;Swain,78). We thus believe that in the near future the new methodologies will gradually replace the former ones in most applications.

A first step toward the inclusion of feature dependence upon either spatial or temporal coordinates of the observation points, taking into account the classes, is the use of joint probability distribution of the features and the classes of the pixels. The classification minimizes the misclassification risk of the whole geographical region.
The first implemented models emploing point features are based on the following two simplyfying hypotheses:

a) the correlation between the features differs from zero only in a small geographical or temporal neighbourhood of the pixel considered. Therefore one needs to optimize, each time, the classification only with respect to such neighbourhood.
b) the features are class-conditional independent. Therefore the conditional probability of the features corresponding to a pixel, given the class to which it can be attributed, is independent of the values that the features assume in the other pixels, i.e., given the classes of two pixels, the corresponding features are stochastically independent. Furthermore it is assumed that this conditional probability is also independent of the classes of these pixels. In such a way it is possible to express the joint probability of the features and of the classes of two pixels as the conditional probability of the feature of one pixel, given its class, times the conditional probability of the feature of the other one, given its class, times the joint probability of the two classes. The conditional probability of one class, given the other, is referred to a transition probability.

This approach leads to classification rules slightly more complex than those pixel by pixel, while the classification accuracy is higher. The application so far published(Swain,78) introduce, in the above sense, correlation between multi-temporal images. Other models are being developed which introduce spatial correlations.

Point-features,multi-stage. A typical multistage method is the decision tree approach. Sequential functions are used, in a tree structure, until a final choice is made. At each node features and decision rules can be selected, in an adaptive manner to enhance their discriminant power (Fig. 2). The design of the decision tree, entailing the choice, at each node, of the features that least overlap and of corresponding most discriminant decision rules, can be committed to manual or automatic optimizing procedures. The total amount of computation required may be significantly less than when all features are used in a single stage decision method, and, furthermore, since at each node only a subset of available features is employed, the overall number of training fields can often be significantly reduced. Several types of multi-stage decision tree schemes have been proposed (Chen;Fu,76; Kulkarni;Li). A recent assessment of design and potential of decision-tree classifiers is given in Swain,77.

Local features. Local features so far considered are essentially texture features. Texture feature are, in general, statistical measures of periodical recurrencies of gray levels of neighbouring pixels. They are usually computed for fixed spatial size, and their values are usually referred to the neighbourhood itself. At times, however, as in the so-called nine-point feature, the texture statistics is attributed to the central pixel (Erikson). Some 80 texture measures have been defined and studied, some of which turn out to be strongly correlated. A rather exhaustive comparative study of texture measures for terrain classification is given in (Dyer;Haralick,73;Sheinin;Wezka;Zavalishin).

Global features.Properties of a complete image can be measured using texture measures, with reference not to a region of the image, but to the whole image. At present these features may be primarily useful to extract some characteristics of the image and not to classify the whole image. The Fourier power spectrum for instance may detect if an image is empty or busy, or has a predominant structure.

Per-field classification. Techniques known as per-field classification entail two further steps in the direction of progressive sophistication: one pertaining to relationships among features and the other to feature levels.
It is assumed that regions (fields) in subspaces of the observation space (usually the geographical subspace) are "homogeneous" and the feature is defined as the collection of measurements at the set (or a subset) of the observation points falling in the homogeneous regions.

The per-field classification scheme can be briefly described as follows:
Given a set of points $(X_1,X_2,...X_n) = \underline{X}$ all of the same field, having a distribution $G(\underline{X})$, the classifier decides to which $F_j(\underline{X})$ they belong, where $F_j(\underline{X})$ is the set of distributions associated with a given set of classe (C_j). The decision is made by means of a distance $d(G,F_j)$ which measures the separation between these distributions.

Several procedures have been proposed to form homogeneous regions in a scene. Methods employed in constructing these fields are also known as image partitioning methods, and can be grouped into two broad classes: edge-detection and object detection methods. Methods of the first class are essentially syntactic and will be described later on. At any rate they appear to be not too efficient when applied to remote sensing imagery. The second methods consist in finding homogeneous regions in the image either by merging neighbourhoods equal in a given sense (conjunctive methods) or by starting with a very simple partition and subsequently subdividing it until each element satisfies a preset criterion of homogeneity (disjunctive methods). Disjunctive methods are not too efficient; they have the same accuracy as cluster methods but require lengthier calculations (Robertson).

Two promising image partitioning methods using conjunctive object detection are BLOB (Kettig) and ECHO (Extraction and Classification of Homogeneous Object) (Gupta). The basic idea is that of increasing the dimension of an initial set of pixels by annexing to it the adjacent sets (of predetermined dimensions, generally grather than one) which are homogeneous with the initial one (Fig. 3). In the supervised case this amounts , in practice, to actually classify the annexed sets in the class of the initial set. In the unsupervised case the resulting sets are classified, per field, at the end of the image partitioning process. Either maximum likelihood or Battacharyya distances are usually used.
The two methods differ in a number of respects. ECHO is a two level structure: for each set of pixel to be annexed, first an inner homogeneity test is made to decide whether or not all pixels of the set can be assigned to the same object, then a second homogeneity test between the considered test and the adjacent ones decides to which of them it is annexed. BLOB has a single level structure: the inner homogeneity test does not exist but the second one is more elaborated than in ECHO, since it uses also second order statistics.

This field of research is to be considered still open; in particular the edge-detection problem deserves further studies. A contribution by the present authors is briefly described in appendix B.

Syntactic approach

The applications of the syntactic approach to remote sensing is comparatively recent (Braverman;Rastrigin;Rosenfeld(Ed);Yu)
Its exploitation is severely influenced by the characteristics of remotely sensed imagery: great volume of data, complexity of the imagery, random noise on the data.
The first one strongly limits the allowable computational complexity.
The second one causes many difficulties and makes it almost impossible to establish syntactic rules for large neighbourhoods of points.
The third one imposes the requirements that the morph extraction and grammar rules be not sensitive to noise and be able to resolve ambiguities.
In this context the design methods which correctly detect a pattern, on the basis of one local measurement, i.e. by a single step of reading, is very difficult if not altogether impossible.
Therefore relaxation procedures have been deviced where the logical relations formalized by the grammar and syntactic rules constitute a feed-back to segment extraction to contrast the bias given by ambiguities and the noise of the data (Zucker,76). The global pattern extraction problem is decomposed, by the relaxation methods, into a network of local extraction processes whose intercommunications are governed by local consistency relations. This gives rise to a loop where the consistency relations between a segment and its adjoining one update the label or the structure of the first, and so on until a stable segmentation is achieved.
From a general point of view consistency relations may be deterministic or probabilistic. In satellite image analysis only the second ones appear to be suitable. Relations are thus expressed in terms of the probabilities that a segment is con-

nected with others and the whole pattern recognition is accomplished by maximizing the probability of the pattern.

To date, applications of syntactic methods to remote sensing are rather limited, in number and scope (Bajcsy;Fu(Ed);Keng;Lu;Zucker,77;Zucker,78). However, they appear to be efficient for forms resulting from simple primitives. Typical instances of applications are the identification or the enhancement of contours, rivers, bridges,highways.

CONCLUDING REMARKS

In the last years the processing of remote sensed data has witnessed the introduction of a comparatively large number of new methodologies.
The survey reveals, however, that the efforts has not been uniformly distributed and that the extent to which capabilities and potentialities of the methods are understood or validations for operational uses are performed varies widely. Furthermore there is a lack of published extensive analysis of relative worthiness of classes of comparable methods. As a consequence final and decisive assessments of new techniques are still untimely.

As mentioned in the introduction, one of the main goals to be achieved in remote sensing analyses is a practical and cost-efficient exploitation of the informational content of the entire observation space, with its spatial, spectral and temporal components. As the key to the attainment of this goal obviously rests in the appropriate choises of number and levels of features and of the methodologies, the following comments, in addition to those given in the body of the paper, are appropriate.

- The use of higher level local features, as for instance textural propreties, seems to be advantageous. There are however indications that accuracy increases only slightly as more and more features are used, and may even decrease when too many higher level features are involved.
- Multistage classification methods appear to be good candidates for computing time, accuracy and optimized use of a large number of features. Efforts in this directions should be rewarding.
- Another promising trend is the development of stochastic models using transition probabilites in space, or in time, or in both.
- More adequate consideration should be given to heuristic methods and to extended experimentation of given techniques to tune them on the specific practical applications. There are motivations, justifications and room for classification methods involving "free" empirical parameters to be determined, case by case, experimentally.
- The statistic approach can consider only statistical relations among features, while the syntactic approach can take advantage of structural properties at the expenses of formal complexities. Combination of heuristic, statistical and syntactical methods may overcome the drawbacks of any single method.

APPENDIX A

Bayes Classification Rules

With reference to previous researches (Apolloni,Murino,78;Napolitano;Rayment) and to some extensions of them, we summarize some results useful in bayesian classification when for some parameters of the object classes can be given only an a-priori distribution law.

These results are summarized for the typical case that there are in the image only two object classes C_1 and C_2, and that the feature $\underline{Z}_i = (x_i, y_i)$ of the i-th pixel follows a gaussian law of parameters μ_j, Σ_j; j = 1, 2. The extension to more than two classes follows the usual ways of the bayesian methods.

Given a sample of dimension N,and given the probability p that a pixel belongs to the first class, then, according to M.L. method, the optimal quadratic classification rule which minimizes the classification risk :

$$(1 - p)\int f_1(\underline{Z})t(\underline{Z})d\underline{Z} + p\int f_2(\underline{Z})t(\underline{Z})d\underline{Z} \qquad (1)$$

where $t(\underline{Z})$ is the probability that $\underline{Z}$ be attributed to C_2, is:

$$\underline{Z} \in C_1 \quad \text{if} \quad pf_1(\underline{Z}) \geq (1 - p)f_2(\underline{Z}) \qquad (2)$$

According to the moment method a linear suboptimal classification rule is:

$$\underline{Z} \in C_1 \quad \text{if} \quad (x,y) \text{ and } (\mu_{1,x}, \mu_{1,y}) \qquad (3)$$

are on the same side with respect to the moment method discriminant plane

$$ax + by + c = 0$$

where a,b,c are functions of the parameters of the distribution laws of the two classes.

When the probability p has not an a-priori known value, but follows a gaussian distribution law with parameters μ_p, σ_p, then the M.L. classification rule becomes:

$$\underline{Z} \in C_1 \quad \text{if} \quad \|\underline{Z}\|_{\Sigma_1} \leq \|\underline{Z}_R\|_{\Sigma_1} \qquad (4)$$

where R is the integer chosen to maximize

$$Q = \left[\sum_{i=1}^{R} \|\underline{Z}_i\|_{\Sigma_1} + \sum_{i=R+1}^{N} \|\underline{Z}_i\|_{\Sigma_2}\right]\left(\frac{R/N - \mu_p}{\sigma_p}\right)^2 \qquad (5)$$

In the one-dimensional case, when $\sigma_1 = \sigma_2$, the classification rule has the simple form:

$$x \in C_1 \quad \text{if} \quad x \leq x_R \qquad (6)$$

where R is chosen to maximize

$$R^{-1}S_R^2 + (N - R)^{-1}(S_N - S_R)^2 \qquad \text{where } S_k = \sum_{i=1}^{k} x_i \quad (7)$$

In this case the search of R is easy and requires only little computer time, but also in the bidimensional case the search does not require much computer time because the sample points (x_i, y_i) may be easily selected in the search of the minimum of Q.

When the mean μ_j of the class j follows a gaussian distribution law with parameters $\underline{m}_j, \Sigma_{\mu_j}$, the M.L. classification rule becomes

$$\underline{Z} \in C_1 \quad \text{if} \quad \hat{f}_1(\underline{Z}) \geq \hat{f}_2(\underline{Z}) \qquad (8)$$

$$\text{where } \hat{f}_i(\underline{Z}) = \begin{cases} f_i(\underline{Z}) & \text{if } i \neq j \\ f_j(\underline{Z}/\hat{\mu}_j) & \text{if } i = j \end{cases}$$

and $\hat{\mu}_j$ is estimated by

$$\hat{\mu}_j = \left[\sum_{i=1}^{N_j} \underline{Z}_j \underline{\underline{\Sigma}}_j^{-1} - \underline{m}_{\mu_j} \underline{\underline{\Sigma}}_{\mu_j}^{-1}\right] \left[N_j/N \underline{\underline{\Sigma}}_j^{-1} - \Sigma_{\mu_j}^{-1} \right]^{-1} \qquad (9)$$

As showed in previous works, the M.L. rules are usually improved by introducing an estimate of p. Therefore rule (8) can be improved by transforming it into:

$$\underline{Z} \in C_1 \quad \text{if} \quad \hat{p}\, \hat{f}_1(\underline{Z}) \geq (1 - \hat{p})\hat{f}_2(\underline{Z}) \qquad (10)$$

where $\hat{p}$ is an estimate of p.

APPENDIX B

A Conjunctive Image Partitionning Method

The authors are carrying on investigations about an unsupervised conjunctive partitioning method useful both for seeking objects,whose boundaries form a partition of the image,and for detecting these boundaries.
The algorithm (Apolloni,78) consists in dividing the image in small groups of pixels (typically 1 ÷ 9) and in merging them by successive annexations. The only hypothesis is that adjacent groups of pixels belonging to the same object have close mean gray tone values in the various spectral bands. Therefore the algorithm can be successfully used to extract objects with colour shadings.
The number of pixels forming the group and the treshold values for the annexation are heuristically estimated in dependence of the texture of the objects. Annexation of a group of pixels with the neighbouring group of pixels proceeds along horizontal and vertical directions from the left to the right and from the top to the bottom of the image. An object is supposed to be constituted at least of three groups of pixels in either the directions. therefore boundaries are found in the groups of pixels which are not homogeneous among them in either the directions.
For instance, in special applications of cartography, objects may have a high degree of homogeneity. In this case instead of considering a group of pixels it is sufficient to consider only a pixel at a time.
This method has been tested, as usual in pattern recognition, with computer simulated images. The results show an improvement of about 10% in classification accuracy with respect to the maximum likelihood unsupervised classifier, with a reduction in computer time of one order of magnitude.
Present researches are directed toward the analysis of contour edges and lines.

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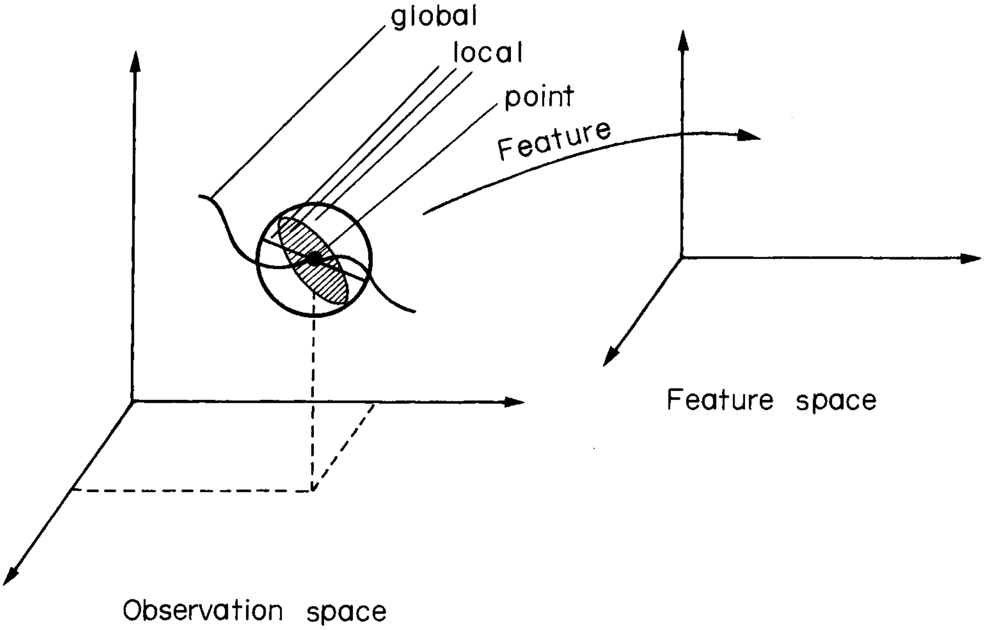

Fig. 1 Features

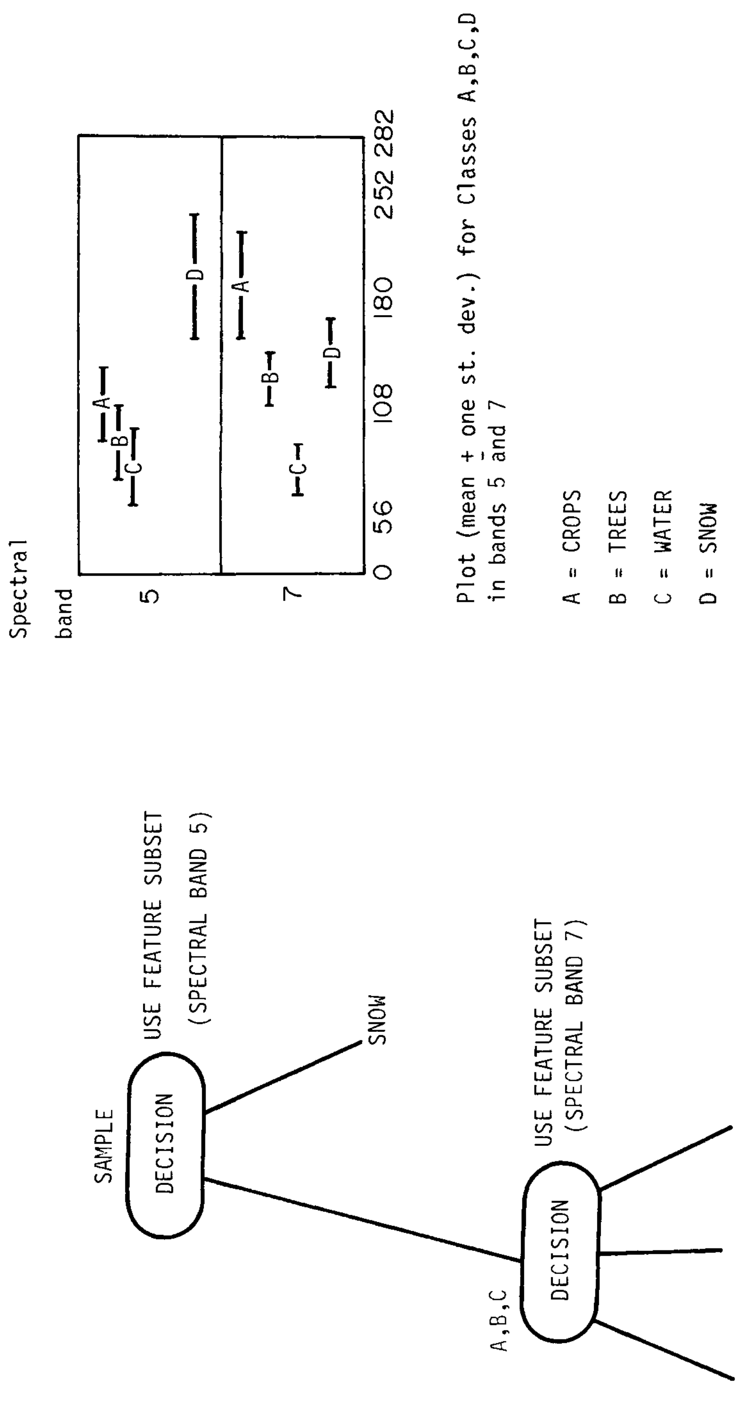

Fig. 2 Decision tree example

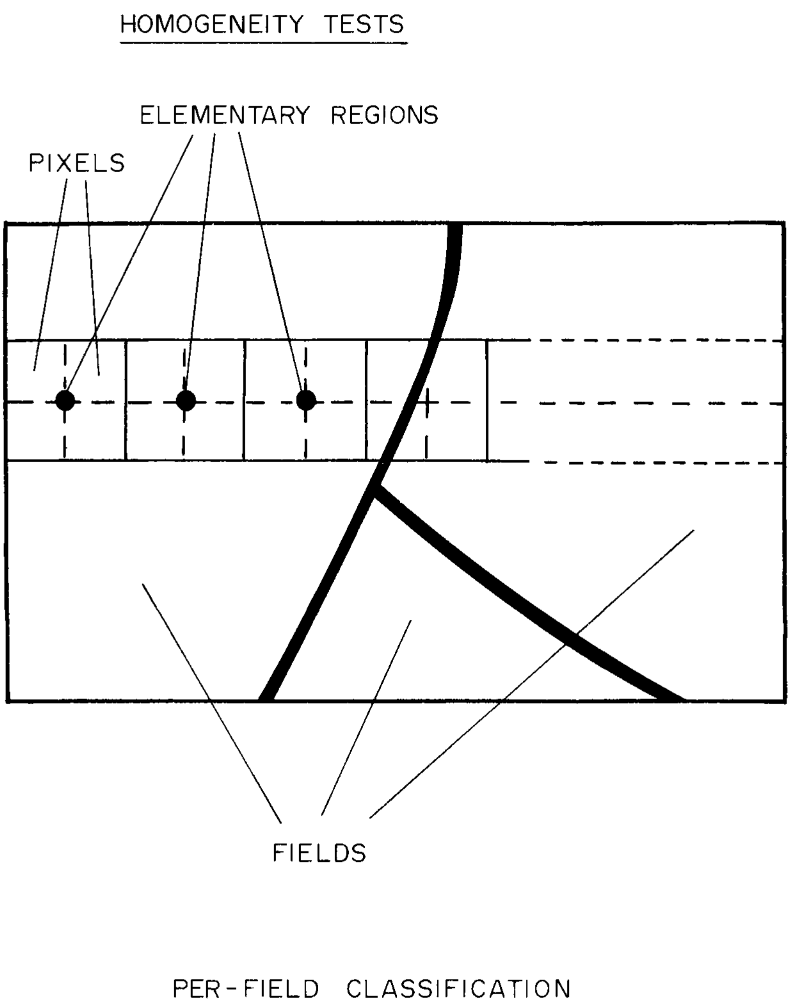

Fig. 3 Object and boundary seeking

THE EVOLUTION OF SATELLITE INDIRECT SOUNDING OF TEMPERATURE AND MOISTURE FOR OPERATIONAL WEATHER FORECASTING

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ABSTRACT

The history of indirect sounding at the National Environmental Satellite Service for the past decade is reviewed. Characteristics and limitations of current products are examined with special attention to the question of impact on 2-3 day numerical forecasts. The thrust for the next decade, with emphasis on instrument development, is explored. Finally, recent results of current efforts in man-computer interactive data processing are presented. Success in this undertaking is expected to contribute significantly to problems of short-term weather forecasting.

Keywords: meteorology; remote sounding; numerical weather forecast; man-computer processing.

INTRODUCTION

As originally conceived, the vertical sounding program held promise for substantially improving routine weather forecasts by complementing the traditional radiosonde network, especially over the oceans. A real economic benefit, and the justification for the program, was envisioned in improved medium-range forecasts when better observations over the oceans would evolve into better predictions over continents. This paper is an attempt to summarize briefly to what extent the vision has been realized and to explore the current direction of indirect sounding research and application within the National Environmental Satellite Service. The first section deals with the evolution of sounding instruments, their characteristics and the quality of data produced with them, and their impact on numerical weather forecasts. The second section considers the future in instrument development beyond the next generation of operational sounders (TOVS). The final section describes procedures currently under development to make maximum use of the TOVS for the First GARP Global Experiment (FGGE) and for short-term forecasting.

PAST PROGRESS

Characteristics of Measurements and Instrument Development

The first temperature sounder SIRS-A, a grating spectrometer measuring in the 15 μm CO_2 absorption band, was flown in April 1969 on the Nimbus 3 satellite. On the same day, the historic first sounding was achieved near the radiosonde site at Kingston, Jamaica. The close correspondence of the two profiles (Fig. 1) initiated great enthusiasm for the new data source. It appeared that the supposed data deficiency over the oceans was overcome, and indeed very soon thereafter (Smith and Fawcett, 1970), the inclusion of the satellite data defined a cut-off low with intense jet to the north which was represented as a diffuse trough in the conventional analysis (Fig. 2). In this instance, the additional data apparently contributed to reduced forecast error in the 72 hour predictions over North America. Furthermore, early estimates of the absolute accuracy of satellite data were encouraging (Hayden, 1971). Although somewhat larger than anticipated from simulation studies, comparisons with radiosondes showed near parity, allowing for degradation in severely cloud-contaminated soundings. As evidence of the confidence in this new data source, NMC began using the soundings operationally barely a month after launch.

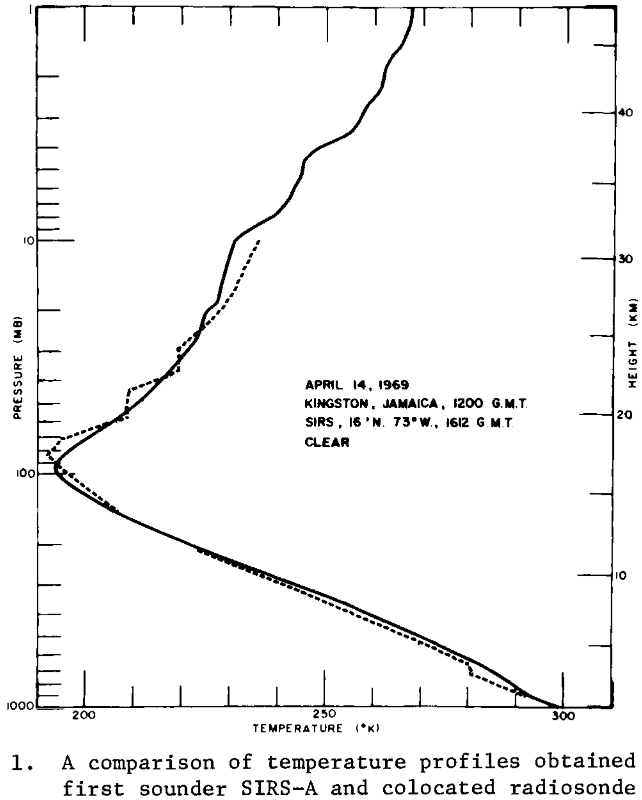


Fig. 1. A comparison of temperature profiles obtained with first sounder SIRS-A and colocated radiosonde at Kingston, Jamaica.

The first sounding instrument had known deficiencies which offered room for improvement. The most serious was the problem of cloud contamination masking radiance information below the cloud tops. Related was the problem of spatial coverage, since the SIRS-A instrument viewed at nadir only. These deficiencies were partially alleviated with SIRS-B, launched in 1970, which possessed a limited side-scan capability. However, due to detector limitations, the SIRS-B still required a large field of view (225 km), and coverage was still severely limited by clouds. A breakthrough in detector technology allowed the next generation of sounders to achieve much improved horizontal resolution (30 km). This, combined with an "Adjacent Field of View Method" for eliminating cloud effects from two contiguous, partly cloudy fields of view (Smith, 1969), contributed to greatly improved data coverage. The first operational sounder to use these developments was the VTPR, launched with the initial NOAA satellite in 1972. An example of the spatial coverage obtainable with this instrument is shown in Fig. 3, though in practice such coverage has never been achieved because of areas with solid cloud cover.

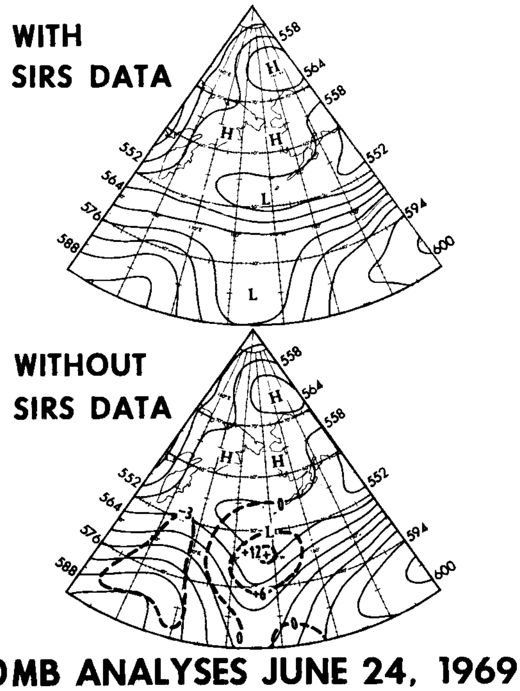
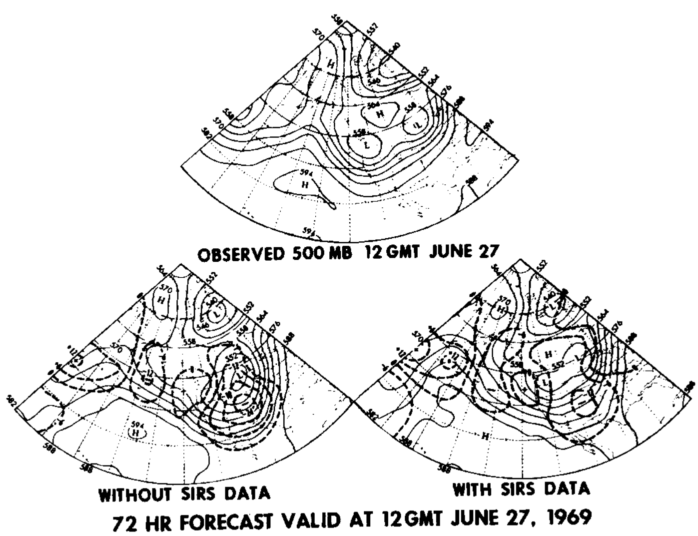


Fig. 2. Top: 500 mb geopotential analyses with and without SIRS data. Dashed contours give change (dm) effected by satellite. Bottom: 72 hr. forecast 500 mb geopotential. Dashed contours give forecast error.



The Nimbus 5 satellite carried experimental sounders designed to further reduce the cloud problem. A second window measurement at 3.7 μm permitted better estimates of surface temperature. Also, a microwave sounder in the 0.5 cm O_2 band allowed measurements which were unaffected except by the heaviest and thickest clouds. A combination of CO_2 and O_2 measurements, as will be done with the operational TOVS, allows almost complete spatial coverage on the synoptic scale.

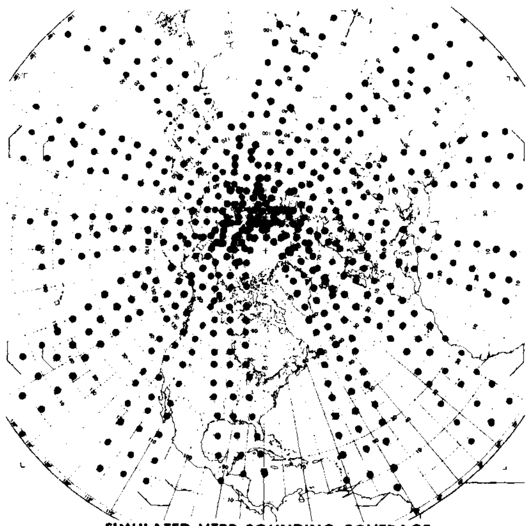


Fig. 3. Spatial coverage attainable from NOAA satellite Vertical Temperature Profile Radiometer (VTPR).

A second major limitation of the first sounder was the vertical resolution of the measurements. The signal received by the satellite is contributed by a fairly deep layer of the atmosphere. This feature is usually described by "weighting functions" which represent the transmittance properties of the atmosphere as a function of measurement frequency. An example for the 15 μm band is shown in Fig. 4. For the frequencies shown, 668 to 750 cm^{-1}, the depth of the contributing atmospheric layer is approximately the half width of the curves. An example of the sensitivity of measured brightness temperatures as compared to temperatures at constant pressure levels is shown in Fig. 5. Two examples are shown for channels which have the peak of their weighting functions near 700 and 100 mb. The figure shows that the brightness temperatures faithfully represent the temperature pattern, but even at this horizontal scale (approximately a 200 km grid), details of the gradients are smoothed in the satellite measurement.

Improvements to vertical resolution have been sought through instrument development. In June 1975, Nimbus 6 introduced a sounder sensing in the 4.3 μm CO_2 absorption band. Figure 6 shows an example of a simulated 4.3 μm channel (2211 cm^{-1}) response which can be compared with the 15 μm channel (732 cm^{-1}) shown in Fig. 5. Both channels have weighting functions which peak in the vicinity of 700 mb, but the greater sensitivity of the 4.3 μm channel is obvious. Due to the success achieved with Nimbus 6, the operational TOVS will carry 4.3 μm channels.

Better vertical resolution can also be achieved with finer spectral resolution. This approach is being actively pursued in current development efforts (Kaplan, 1978), but practical problems of signal-to-noise have thus far prevented implementation.

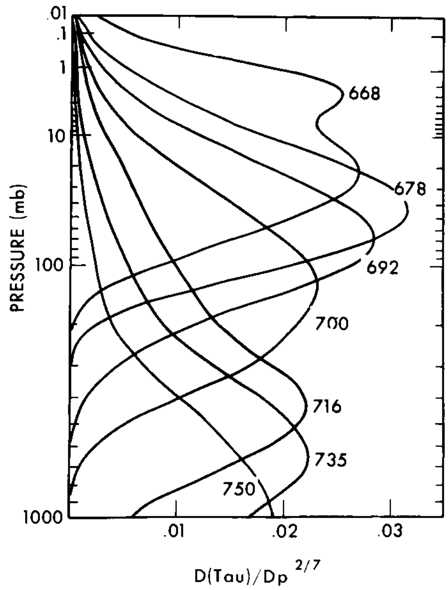


Fig. 4. Transmittance "weighting functions" in the 15 μm CO_2 absorption band.

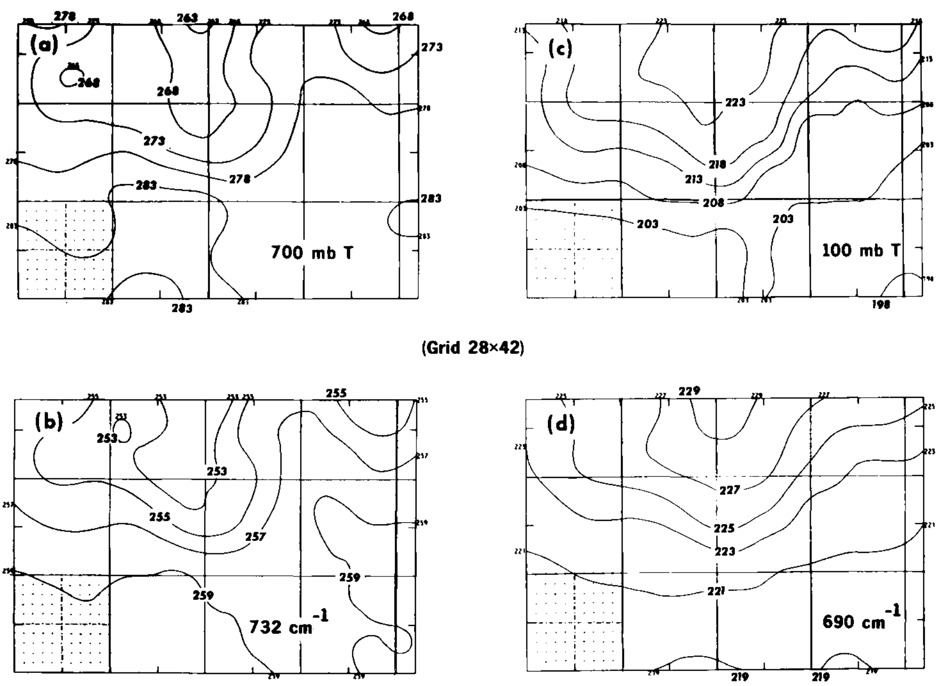


Fig. 5. (a) and (b): Constant pressure level temperatures analyzed on a 200 km grid. (c) and (d): Simulated brightness temperatures for 15 μm CO_2 channels with peak response near levels shown in (a) and (b).

In the decade separating the launches of SIRS-A and TOVS, notable improvements have been made in instruments and measurement techniques. The TOVS has high spatial resolution channels at 15 and 4.3 μm and medium spatial resolution channels at .5 cm for sensing temperature. It has wide angle scanning capability and two window channels to facilitate the removal of cloud contamination. Whether or not these advances will lead to improved specification of the meteorological parameters or to improved forecasts is the subject of the following sections.

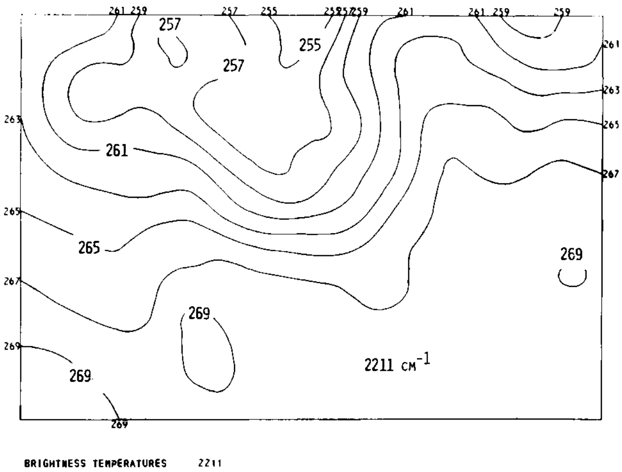


Fig. 6. Simulated brightness temperatures for 4.3 μm CO_2 channel with peak response near 700 mb.

Characteristics of Meteorological Data Derived from Satellites

From the outset of remote sounding, as exemplified by Fig. 1, results have been evaluated by comparison to the radiosonde. As mentioned above, early returns were encouraging. Comparison on a level-by-level basis usually yielded 1.5 - 2.5°K r.m.s. discrepancies, and it was anticipated that the accuracy would improve with better instruments and inversion techniques. However, improvement has been agonizingly slow. Even with the TOVS prototype, r.m.s. statistics have remained steadfastly close to 2.0°K which compares unfavorably with the GARP requirement of 1.0°K. Part of the difficulty lies in the verification technique. In comparing the two data sources, mismatches in time and space add noise. Also, the radiosonde profile contains high frequency oscillations which are "noise" to numerical forecast models with coarse gridpoint resolution. However, very careful analysis with both real and simulated measurements has shown that 1.5°K is a realistic limit to level temperature accuracy achievable from a passive spectrometer.

Vertical resolution was considered above from the viewpoint of the transmittance weighting function. It can also be considered from the aspect of weights contributing to the temperature profile solution:

$$\bar{T} = \underset{\sim}{C}\bar{B}$$

where $\bar{T}$ is the vector of temperatures at different pressure levels, $\bar{B}$ is the vector of brightness temperatures from the satellite measurements, and $\underset{\sim}{C}$ is a weight coefficient matrix relating the two. There are a number of techniques for obtaining $\underset{\sim}{C}$. Two of the more popular are simple linear regression and "minimum information" (Strand and Westwater, 1968). The weights associated with these solutions are shown in Fig. 7 for the ITPR, SCR and NEMS instrument complex of Nimbus 5. Note that the regression solution gives greater vertical resolution as indicated by the higher frequency of the oscillation in the vertical. In practice, (e.g., the VTPR) simple regression has found favor over the more theoretical solutions, because it takes advantage of interlevel correlations within the temperature structure of the atmosphere to improve vertical resolution. The solution weights are ultimately constrained, however, by the intrinsic vertical resolution of the measurement, and the constraint translates into the 1.5°K absolute accuracy for level temperatures.

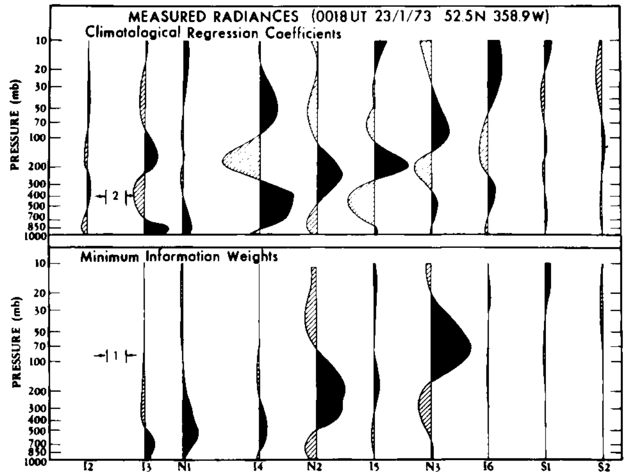


Fig. 7. "Weight" coefficients for minimum information and regression solutions to the radiative transfer equation. I, N, S refer to channels of the ITPR, NEMS, and SCR instruments of Nimbus 5.

At least as important as absolute accuracy are relative accuracy and spatial error correlation. Satellite data by virtue of consistency in measurement and processing have excellent relative accuracy for determining gradients, although the lack of vertical resolution occasionally gives large and spatially correlated bias errors (Fig. 8). The good relative accuracy can be exploited to identify thermal wind maxima and define the circulation in areas (in space and time) between rawinsonde observations (Horn et al., 1976). An example of thermal winds at 300 mb calculated from Nimbus 6 measurements is shown in Fig. 9b. These can be compared with aircraft and rawinsonde reports plotted in Fig. 9a.

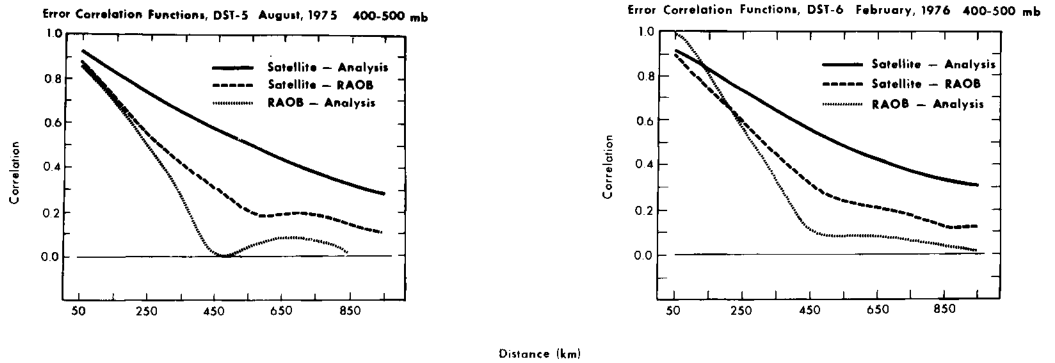


Fig. 8. Spatial correlation of errors in satellite determinations of the 400-500 mb thickness. Satellite is compared to objective analysis values and to individual radiosonde observations. Third curve compares radiosonde observations to objective analysis showing smoothing of high frequency oscillations in raob.

Some note should be taken of moisture as well as temperature profiling. Problems of vertical resolution are even more critical for moisture, both in derivation and verification. It is fair to say that whereas total water vapor content of the atmosphere can be specified with some skill, details of the profile are not recoverable. Some progress is being made currently with processing methods described in the section on current developments.

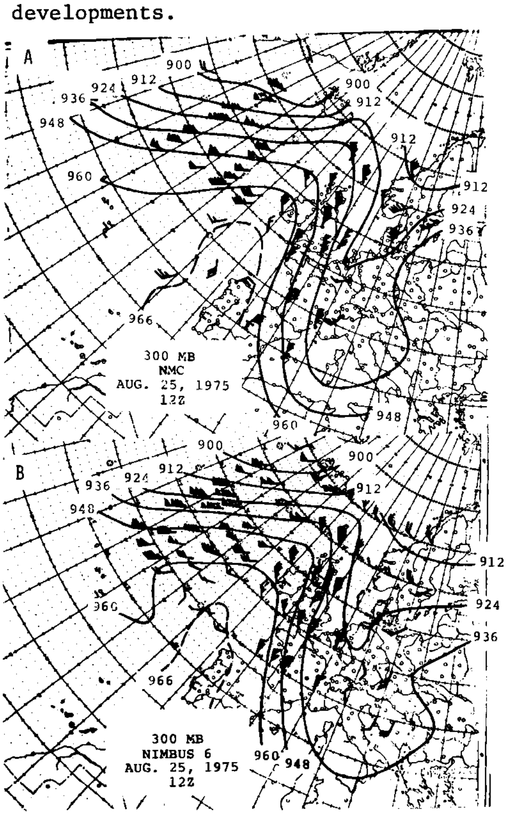


Fig. 9. (a) NMC 300 mb geopotential height analysis for 25 August 1975, 12Z. Aircraft and rawinsonde wind values plotted. (b) 300 mb geopotential height analysis from Nimbus 6 with geostrophic winds (from 2.5° latitude/longitude grid) plotted.

Impact on Numerical Forecasts

Given the limitations of data derived from passive spectral measurements, it is natural to examine their utility in numerical forecasts. Have we been able to achieve better 72 hour forecasts as originally hoped? Here the picture is unclear. NMC (Tracton and McPherson, 1977) has consistently shown minimum impact from satellite data. Other groups, the Goddard Institute for Space Studies and the Geophysical Fluid Dynamics Laboratory have reported positive but limited benefits from special data sets generated during the NASA data systems tests. Only in the southern hemisphere has forecast improvement been unambiguous (Kelly et al., 1978). An example is shown in Fig. 10 and 11 where the forecast of a surface low over the Tasmanian Sea is much improved when satellite data are included in the initial state.

There is considerable controversy over the different levels of impact experienced by different modeling groups, especially in the northern hemisphere. The NMC argues that their forecast/analysis system performs with a background error level sufficiently low as to render the satellite data superfluous. Other systems, for whatever reasons, have a higher error level which permits the satellite to make a contribution. Evidence would appear to support the latter assertion, but not necessarily the former. Unquestionably, as will be demonstrated in the final section, satellite sounder data can improve the depiction of the atmospheric circulation. It is entirely possible that from the standpoint of the accuracy of NMC 48-72 hour forecasts, the NMC system data is saturated with traditional sources. Even with lower absolute error levels in satellite data, we might not see forecast improvement without better data assimilation techniques and better forecast models.

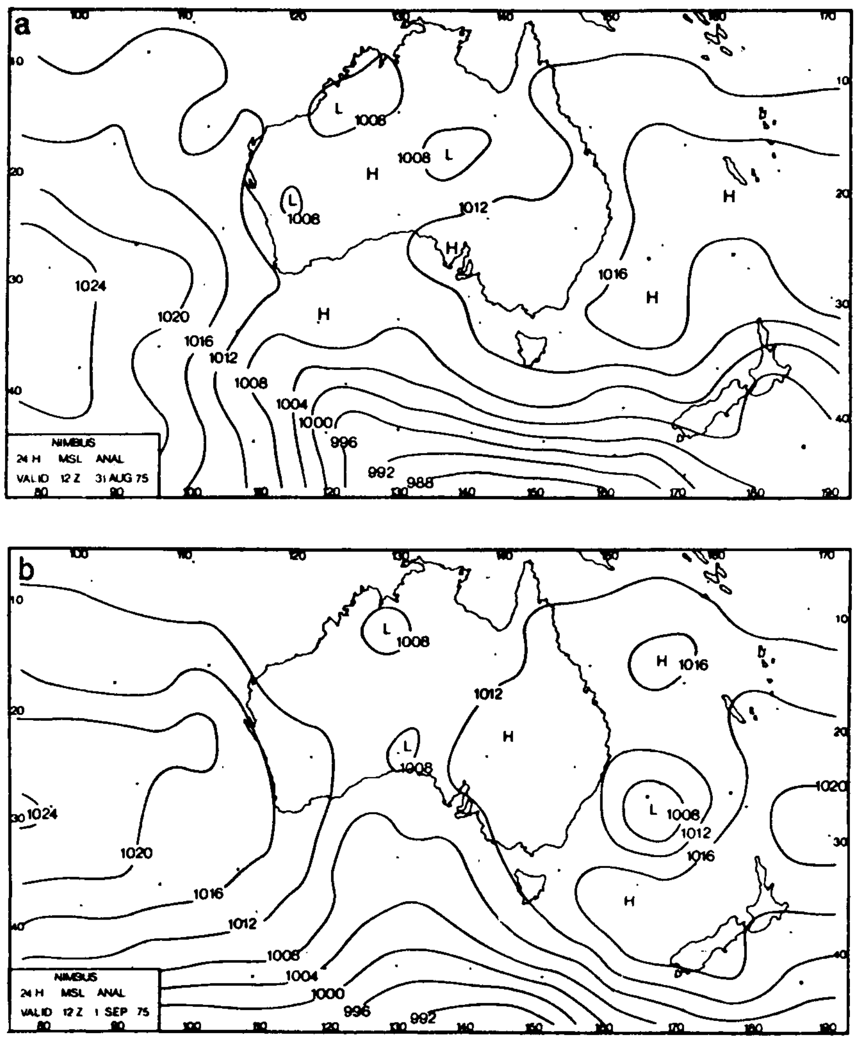


Fig. 10. (a) Initial sea level pressure analysis for 31 August 1975, 12Z.
(b) Verification sea level pressure analysis for 1 September 1975, 12Z.

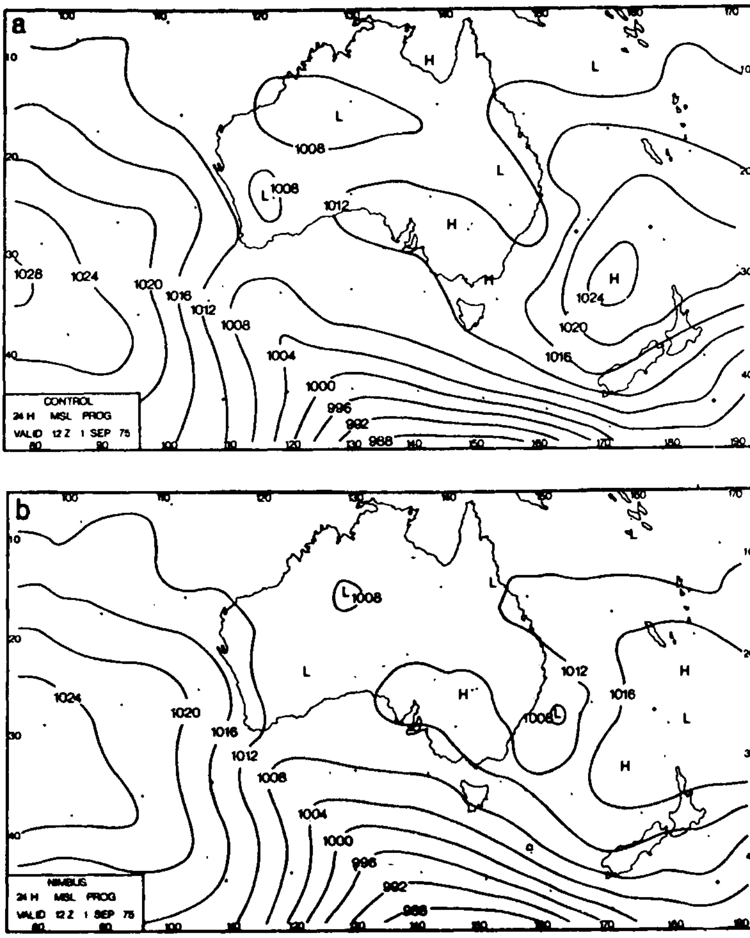


Fig. 11. (a) 24 hour sea level pressure forecast valid 1 September 1975, 12Z without satellite data. (b) Same as (a) but including satellite data.

FUTURE DEVELOPMENT

VAS

The VISSR Atmospheric Sounder is an instrument under development which will include a capacity for passive spectrometer sounding from a geostationary satellite. To a large extent, the output will be similar to that available from the TOVS polar orbiting instrument. The horizontal spatial resolution will be approximately the same. Similar channels in the 4.3 and 15 μm CO_2 absorption bands will be used. The major difference in instrumentation will be the absence of microwave measurements at 0.5 cm. This should be compensated by the capability to sound with high temporal resolution such that the same area of the atmosphere can be viewed repeatedly as cloud formations change. The VAS is designed for application to subsynoptic and mesoscale applications. It is highly doubtful (given the previous discussion on past progress) that the VAS will make any significant contribution to improving the 48-72 hour forecast. Rather, the emphasis will be on the short-term forecast or the nowcast. Under current plans, the VAS is to be flown experimentally on GOES-D with launch scheduled for the late summer of 1980.

HIS

The High resolution Interferometric Sounder is a proposed instrument to sound by interferometric radiance observations rather than by spectrometer. Whereas a spectral radiance measurement at a particular frequency examines the emission of lines within the narrow spectral resolution of the instrument, an interferometric measurement examines an interference pattern from a broader spectral resolution, the interference caused by splitting the radiation, delaying one branch by phase delay δ, and recombining at the detector. For different δ, different layers of the atmosphere make major contributions according to the interference of the lines within the (partial) spectrum. As an approximate analogy, different delays with an interferometer sounder correspond to different channels in a spectrometer sounder. The advantage of the interferogram method is that it improves weighting function characteristics and has better signal-to-noise ratios in the observations.

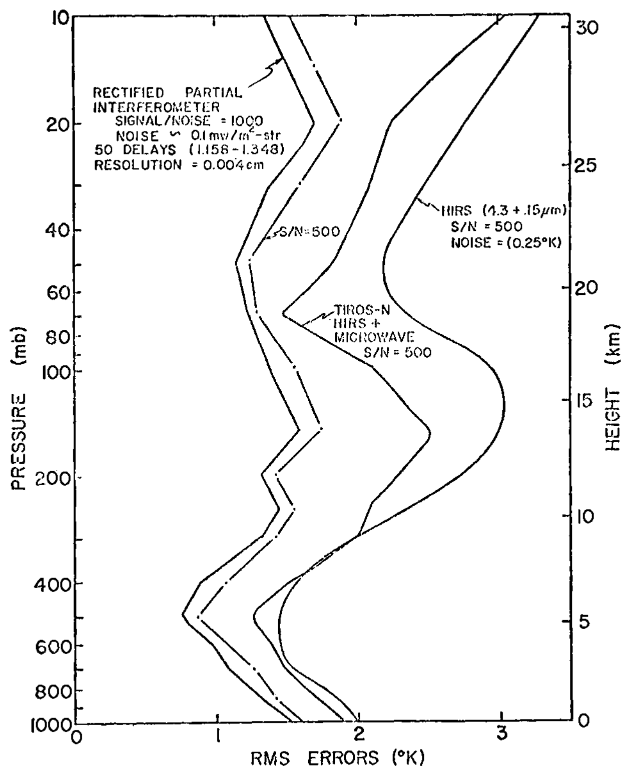


Fig. 12. Comparison of simulated temperature profile errors associated with TOVS radiometers and with HIS, a proposed interferometer sounder.

Results obtained with simulated interferometers in the 15 μm CO_2 absorption band are encouraging. Figure 12 compares temperature accuracy estimates at various pressure levels for the TOVS (TIROS-N HIRS + microwave), a modified TOVS without microwave, and partial interferometer with two signal-to-noise ratios. The figure shows nearly a 0.5°K improvement in r.m.s. comparison with radiosonde profiles (from which the radiometric signals are synthesized). Since the improvement is almost independent of signal-to-noise, it must evolve from better vertical resolution.

CURRENT DEVELOPMENT

Given the limitations of vertical resolution in satellite soundings and their apparent lack of impact on numerical forecasts in the 48-72 hour range, emphasis has turned from emulating the radiosonde to exploiting features unique to remote sounders. The major advantage is the relatively high horizontal resolution (30 km). A related advantage is that the same instrument and data processing scheme affects each measurement, ensuring absolute consistency. Clearly these attributes apply more directly to the subsynoptic or regional meteorology than to large scale synoptic weather systems. Consequently, current development effort is directed to the subsynoptic problem where the satellite is asked to fill in horizontal detail unavailable from the radiosonde network. Specific atmospheric phenomena of interest include the proper positioning of upper level fronts, the location and intensities of jet streams, and the location of local areas of thermodynamic instability. The subsynoptic development program is aimed ultimately for application with the geostationary VAS, which will provide data at high temporal as well as spatial frequency. However, the concept is adaptable to polar orbiting satellites and the TOVS will be viewing the same area four times each day.

Because data accuracy and reliability become increasingly critical as the scale of the observed phenomena decreases, it is necessary to have direct interaction between a meteorologist and the data processing computer. In cooperation with the Space Science and Engineering Center of the University of Wisconsin, NESS is developing a hardware-software system for real time processing of TOVS radiance data for regional meteorological application. The data will be processed on an orbit-by-orbit basis with a capability of amalgamating conventional data by objective analysis techniques.

In preparation for TOVS, archived data from the Nimbus 6 satellite have been used to develop software for man-computer interactive temperature and moisture retrieval processing. The man has available a television set which can display images created from geostationary or polar orbiting satellite data and overlay color graphics to show contour analyses or symbols. A second cathode ray tube is available for displaying messages. The operator interacts by manipulating a cursor to indicate positions in the displayed data and by typing commands on a typewriter-type keyboard. The TV display system has a digital refresh disk which can store 12 images for instant access. In a typical situation, the operator can display, in rapid succession, several sounding channels or the difference between channels to facilitate site selection in avoiding cloudy areas. An example of a display for a portion of two orbits for the Nimbus-6 6.3 μm water vapor channel is shown in Fig. 13. Note the small squares which are individual observations (the white areas are calibration gaps). In this example, the polar jet is clearly defined by the sharp moisture discontinuity stretching from Spain to Norway.

In addition to satellite data, the Wisconsin system provides current surface observations and radiosonde reports. These can be accessed, analyzed and displayed either in normal map projections or in satellite coordinates. Active use is made of these data to improve the satellite product. In particular, surface data is used to define the lowest level temperature and humidity which are not easily sensed from a satellite. Upper air data are used for quality control and also to indicate where more data coverage is required.

A large body of ancillary software is under development to improve the editing function, as it often proves difficult to determine the validity of soundings. A good, but not infallible, measure is close correspondence between neighbors. To make such comparisons it is possible to display complete profiles on Stüve diagrams, and overlay these. Also, isentropic cross sections can be constructed from a series of soundings. The editing function has been found so effective there are plans to use the system to improve operational TOVS products in Washington and also, possibly, to enhance data sets obtained during the special observing periods of FGGE.

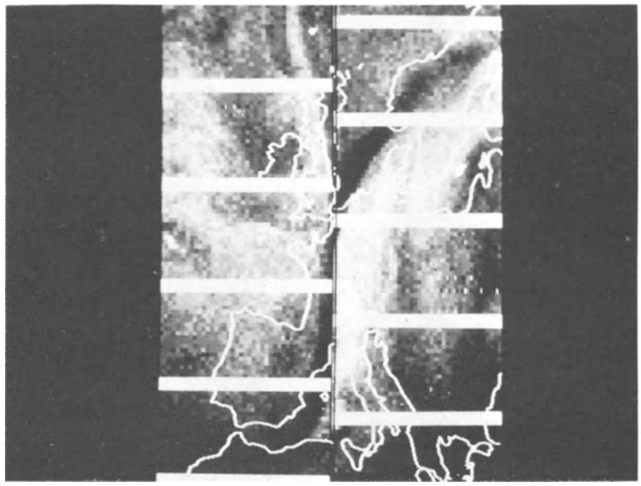


Fig. 13. TV display of 6.3 μm channel from Nimbus 6 for two partial orbits over Europe. Graphics geography is overlaid.

Figure 14 is an example of 500 mb geopotential (dashed lines, 30 m contour) obtained by man interactive processing over a squall line in the central U.S. on 25 August 1975. The solid lines (60 m contour) represent an average of 00 GMT and 12 GMT operational NMC analyses for this situation. It is apparent that small scale features have been introduced by the satellite. Since the detail is below the resolution of the radiosonde network (and off time as well), it cannot be directly verified, except to note that it does not obviously disagree with the radiosonde data. An indication of possible validity is very active weather systems in the areas of highest gradient as shown by comparisons of Fig. 14 and 15. Right or wrong, however, it is important to note that the detail is useless to the large forecast model and would apply only to a limited area high resolution model or some type of advective nowcast.

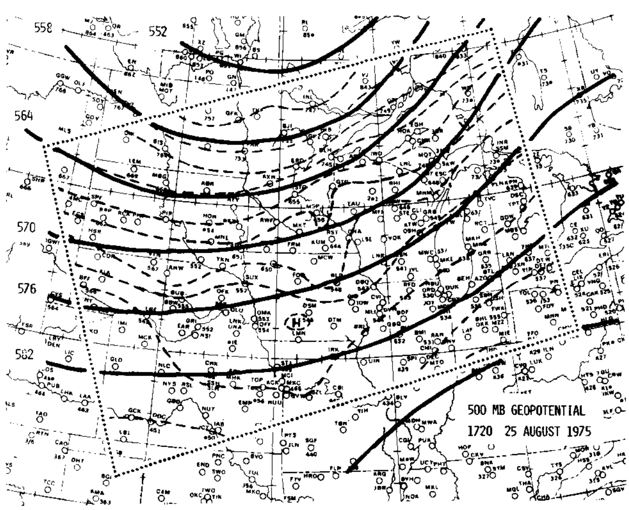


Fig. 14. 500 mb geopotential obtained from NMC analyses (solid) and from man-computer interactively processed Nimbus 6 data.

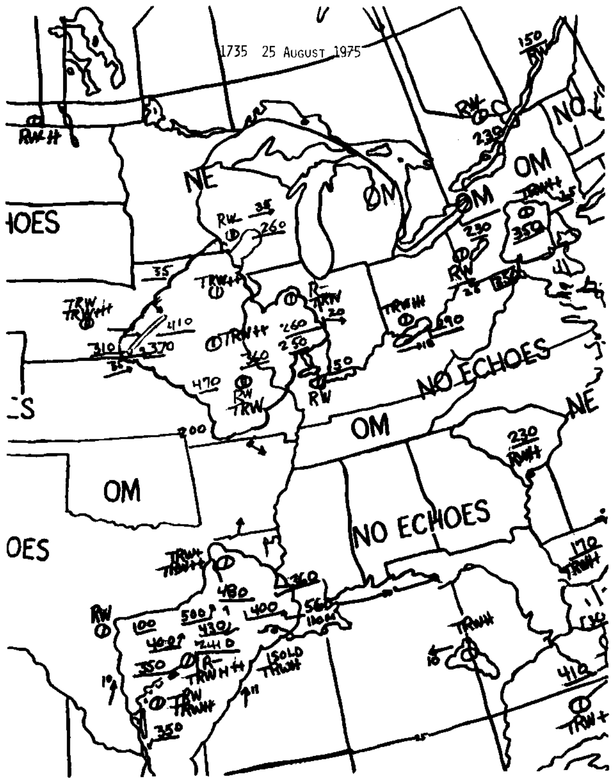


Fig. 15. Operational weather radar chart approximately coincident with satellite data used to obtain geopotential of Fig. 14.

A major innovation under development with the Wisconsin system is the simultaneous processing of satellite-derived temperature profiles and cloud-drift winds. To permit this, the polar orbiter data will be remapped into a geostationary projection appropriate to the GOES satellite images used to produce winds. An example of the remapping is shown as Fig. 16. The two data sets should enhance each other. For example, high resolution surface temperatures will be available from GOES. Cloud height information will be available from the polar orbiting sounder. Thermal winds derived from sounder data can be used to edit cloud-drift winds, and vice versa. The processing technique should greatly facilitate generation of a consistent data set; probably within the FGGE time frame.

SUMMARY

This paper has looked briefly at the evolution of satellite indirect sounding, the progress and the future. The progress has perhaps been disappointing. Indirect soundings have not, as hoped, contributed to significantly improved weather forecasts. But it seems that this was a false hope if we accept evidence that numerical forecast models are not data limited, at least from the standpoint of 2 to 5 day forecasts. And so, while there will be a continued effort to improve the quality of remote soundings, an even greater effort is directed to new areas of application. Man-computer processing of satellite data for regional short-term forecasting has arrived, and is very promising.

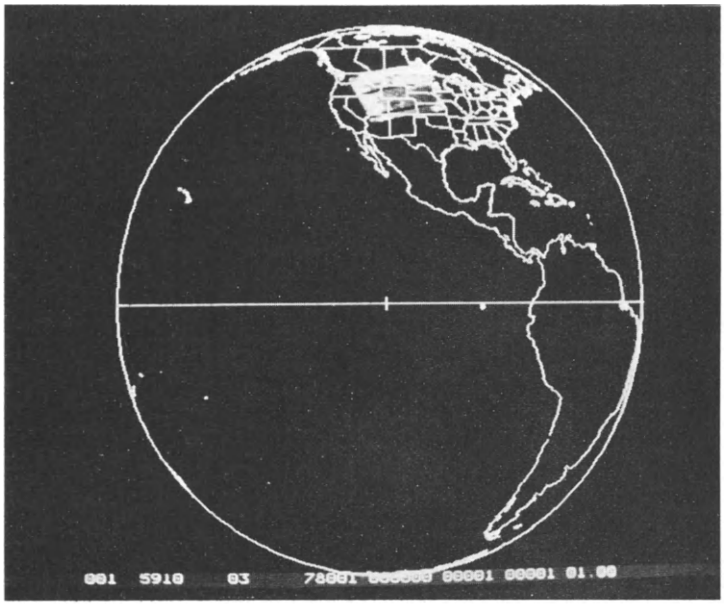
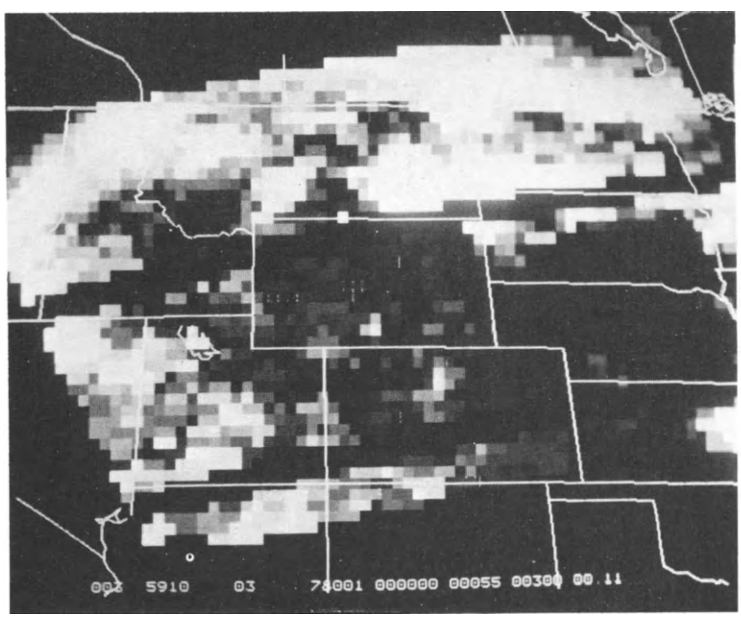


Fig. 16. Top: Full disk projection for geostationary satellite simulated at 110°W longitude with data from polar orbiting sounder remapped into geostationary coordinates.
Bottom: Zoom of sounder data shown in top figure.



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USEFUL SPACEBORNE SYNTHETIC APERTURE RADARS

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ABSTRACT

Synthetic aperture radar, nearly three decades after its conception, is about to bear fruit as a potentially powerful tool for exploring the earth from space. Substantial literature now exists describing many of the potential applications of SAR. Ocean waves, ice and current boundaries, geological formations, soil moisture and cities represent a partial list of features or phenomena which yield new information when actively stimulated with microwaves. A number of civilian spacecraft now exist or are in the planning stage in which synthetic aperture radar is expected to play a key role.

One might conclude from this rash of activity that the sensor problems are solved, and that spaceborne SAR is about to enter the mature operational phase of its evolution. This is not the case, however, for a number of reasons. Spaceborne SAR's place imposing requirements on present technology in many areas.

This paper attempts to summarize the fundamental design parameters of the radar system which have a major influence on image quality, and which must receive increased attention as spaceborne SAR systems evolve toward useful remote sensors.

Keywords: synthetic aperture radar, imaging radar, remote sensing, Seasat-A, spaceborne radar

INTRODUCTION

The concept of a synthetic aperture radar is now nearly three decades old. Much of the first decade was devoted to exploring practical means of converting signal records to imagery, and much of the second applying the results to military needs. Although proposals to perform oceanography from space using SAR were made at least as early as 1965 (Ewing, 1965), only within the past decade has the technology become widely available to the general scientific community. Even in this most recent phase, many of the surveys have been accomplished from aircraft over small regions of the earth. In the past five years, however, the technology has become sufficiently widely disseminated that a number of parallel international efforts are now directed toward spaceborne SAR.

The first fruits of this effort have recently been yielded by the SAR on the U.S. oceanographic satellite, Seasat-A. In the first three months of operation, even though the SAR is exercised a maximum of one hour each day, more than 100 million square kilometers of the earth's surface have been successfully recorded for processing. The Seasat-A SAR clearly represents a significant milestone in the technology of spaceborne remote sensing.

As the technical novelty wears off, however, increasingly critical questions will be asked regarding the scientific and operational utility of SAR. The SAR is, after all, an expensive instrument requiring significantly more sophisticated processing than do the analogous visible remote sensors. It must, therefore, deliver a sufficiently unique and necessary service to the user community to justify its cost. To what extent SAR can provide this unique and necessary service and in what areas it will excel remain to be demonstrated.

SOME GENERAL COMMENTS ON SAR

There are applications for which the spaceborne SAR is clearly indispensible. Venus, much like the earth in gross physical properties, is quite different in the evolution of its surface conditions. It remains the only terrestial planet not yet mapped. Because its heavy cloud layer defies penetration with conventional visible sensors, the mapping of Venus is clearly an application for which the SAR is uniquely suited.

In a sense, we are only slightly more fortunate here on the earth. Nearly half of our planet is obscured by clouds. Fortunately, the clouds are cooperative enough to move from place to place, and if time is of no consequence, then eventually we can see any part using visible sensors. There is a problem here, however, because time is often of consequence. Moreover, many of the natural phenomena of interest are inherently associated with cloud cover. Local flooding rarely waits for the storm to clear. The winter North Atlantic is most hazardous because of the combination of clouds with high seas. Ocean wave generation from hurricanes is difficult to observe remotely with other techniques. Seasonal variations of the polar ice are much more easily monitored using cloud-penetrating radar.

As the applications list is increasingly expanded, however, the uniqueness of radar depends less upon its cloud penetrating ability and more upon its surface interaction characteristics. For these applications, examples of which are soil moisture determination, crop and forest classifications, and perhaps urban morphology, SAR is often used in conjunction with other visible sensors. In the LANDSAT perspective, it becomes "merely another channel". This last class of applications imposes much more strict requirements upon sensor performance, in that the precise value of the radar return becomes increasingly important. Radiometric calibration and transfer function stability are essential for these applications. In addition, if the SAR is to be used as an auxiliary LANDSAT channel, then good geometric fidelity in a relative sense is required; otherwise registration will be impossible.

Radiometric calibration in an absolute sense is probably neither feasible nor necessary for SAR systems. Control with a uniform set of ground "primary" standards, such as corner reflectors or invariant extended sources is much more practical for earth-oriented systems. Since the number of such primary standards will necessarily be limited, however, the SAR system must remain invariant between calibrations. Short term variations are particularly detrimental.

SOME POTENTIALS AND LIMITATIONS OF THE SEASAT-A SAR

As Fig. 1 illustrates, Seasat-A is now providing coverage of a large portion of the Northern Hemisphere. This coverage may be extended in the future with the addition of either fixed foreign stations or a mobile U.S. station. The station

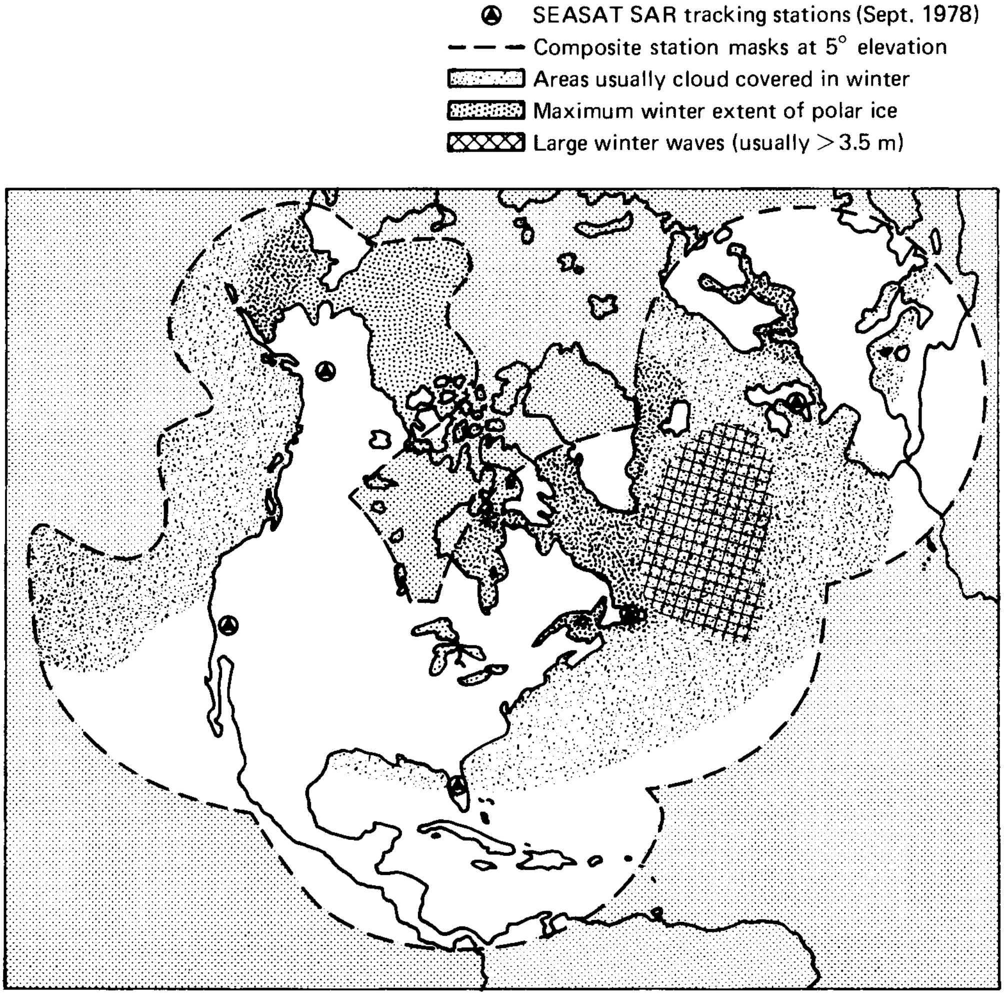

Fig. 1. Composite coverage of the Seasat-A SAR as of September 1, 1978.

masks are illustrated out to 5° elevation, unless the horizon obscures the mask prematurely. Even though good imagery can be obtained to these limits from stations equipped with 9 m antennas, the composite mask in Fig. 1 is slightly optimistic. For operational reasons the SAR is routinely turned off somewhere above 10° elevation.

Figure 1 also illustrates some of the particular subjects of interest to the Seasat-A SAR. As a climatological atlas will show, much of the Northern Atlantic and Pacific above about 30°N are usually cloud covered during the winter months, when seas are also most hazardous. Some regions of the North Atlantic can regularly expect seas of 3.5 m or greater most of the time during the winter. The Seasat-A SAR may be useful in studying the waves generated by these winter storms. Some additional subjects of interest are (1) seasonal variations of the polar ice cap, (2) the mapping of ocean current boundaries, (3) wave generation and propagation in hurricanes, and (4) iceberg drifting from the Straits of Labrador. Many of the potential applications are presently being investigated as a portion of the Seasat-A SAR validation experiments (Teleki and Ramseier, 1978).

Figure 2 is a small portion of the Seasat-A SAR imagery obtained on the 150th orbit on July 7, 1978 showing a portion of the coast of Baja California. The image quality has yet to be completely analyzed for resolution, dynamic range, and inherent noise. The discussion which follows, therefore, is based largely upon pre-launch considerations.

The insert is Fig. 2 is an enlargement of a typical uniform backscatter area and illustrates the often overlooked coherent nature of SAR imagery. As Moore and Thomann (1971) have pointed out, one cannot accurately deduce radar backscatter value from a SAR at a scale of one resolution element unless extensive integration is employed. Approximately 100 independent returns are necessary to reduce the measurement variance in radar backscatter from a uniform field to 10%. In the Seasat-A SAR, which is inherently a 25 m x 6 m system (although a resolution element or "pixel" is defined as 25 m x 25 m), one is required to form resolution cell sizes of 80 m square to discern two adjacent fields with backscatter differences of 2 dB with something less than 10% error.

Figure 3 better illustrates the problem of level discrimination for the Seasat-A SAR. A single-valued scattering field produces a Gaussian distribution of outputs that appears to have originated from a wide range of input backscatter values. Discrimination on the scale of a single resolution element, of 25 m x 25 m, therefore, can be done only to within about 3 dB at the 70% confidence level or 8 dB at the 90% confidence level, yielding only two to five distinguishable grey scales in a 15 dB dynamic range of inputs, depending upon the confidence criterion. Figure 4 shows the situation when Seasat-A imagery is spatially integrated from 25 m to 80 m resolution. One can now expect to detect differences with 90% confidence of the order of 2 dB, and the number of distinguishable grey scales correspondingly increases. The noise equivalent σ^0 (the input backscatter value for which the signal is equal to the noise) has also improved by approximately 5 dB, improving the quality of the low backscatter sites significantly.

In fact, Fig. 4 is a somewhat optimistic indication of system performance. Neglecting strong point sources, which tend to remain linear by virtue of the two-dimensional compression ratio, the instantaneous dynamic range is only about 10 dB. In general, then, sources of strength less than 10 dB below the average will be overwhelmed by energy leaking from the adjacent strong sources. The apparent advantage of spatial integration mentioned above, therefore, is real only for fields consisting entirely of weak scatterers.

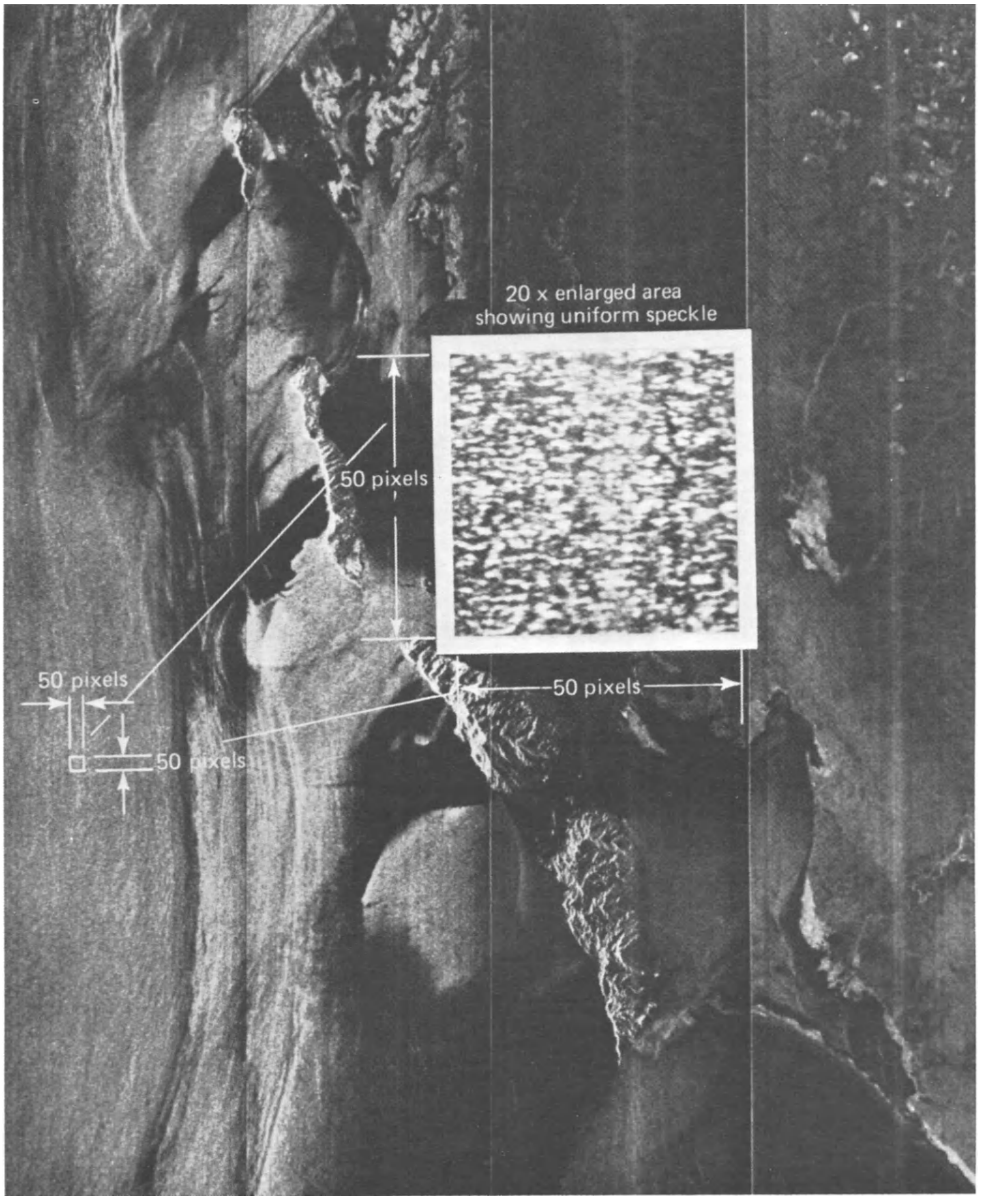

Fig. 2. Typical Seasat-A SAR output imagery, July 7, 1978, showing nature of coherent speckle (approximately 90 km horizontal swath width).

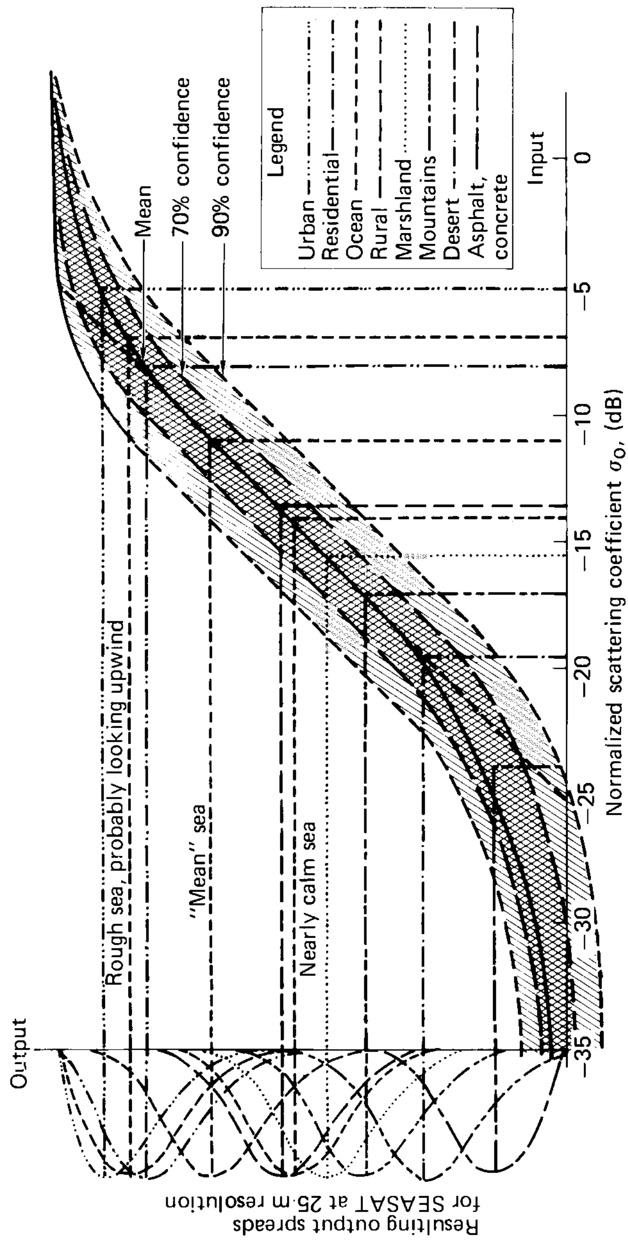

Fig. 3. Typical class confusion on Seasat-A resulting from four independent samples. Backscatter values given are typical for L-Band, HH polarization, 20° from nadir.

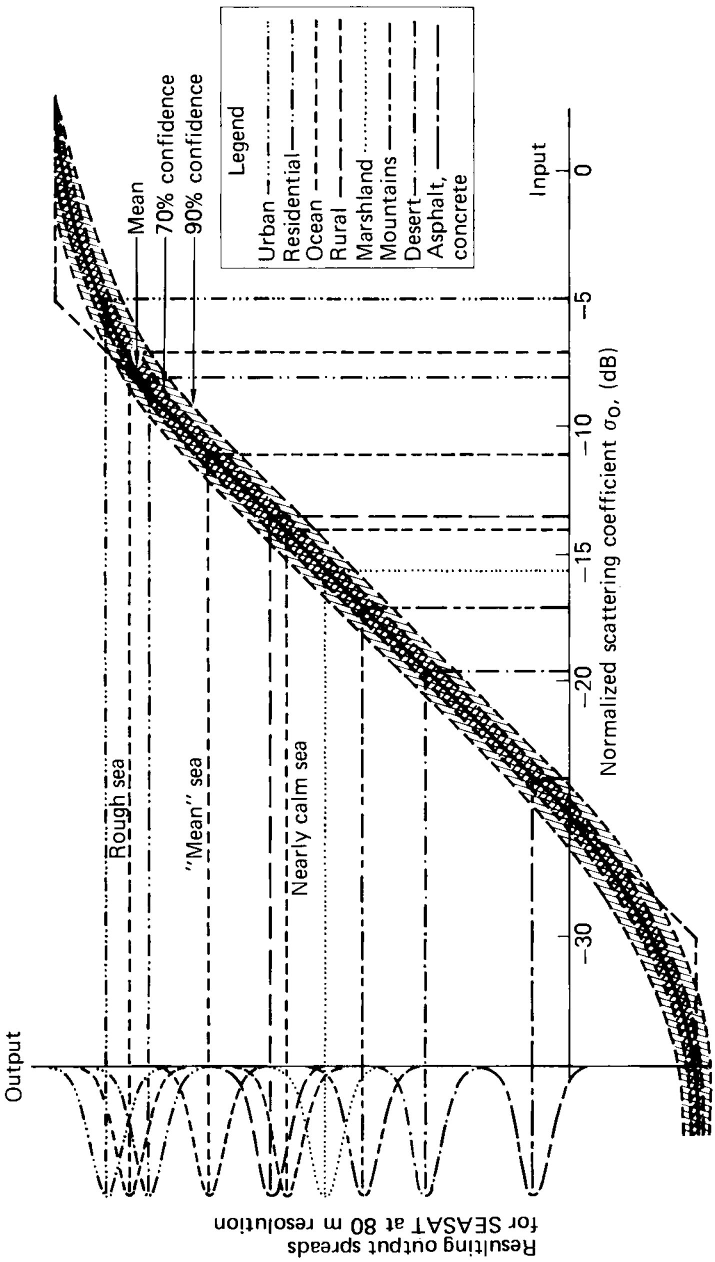

Fig. 4. Spatial integration to LANDSAT resolution (80 m) on Seasat-A, 40 independent samples.

The chief contamination sources resulting in low contrast are high frequency (i.e., many cycles over the correlation interval) amplitude, phase, and timing errors. In the range dimension, this is caused by transmitter pulse timing jitter, data link timing jitter, and amplitude and phase ripple in the pulse compression filter. In the azimuth dimension, similar contamination might be caused by reference oscillator instability, antenna departures from a plane along the flight vector, or by long-term amplitude variations anywhere in the system, including atmospheric scintillations.

The low end of the Seasat-A SAR transfer function lies somewhere between -25 and -30 dB (area-normalized backscatter, σ^o), depending upon the degree of spatial integration employed. As Figs. 3 and 4 illustrate, this sensitivity would provide good discrimination for nearly all natural and cultural targets, if the signal variance could be reduced. The instantaneous dynamic range, however, is limited not only by the above mentioned phase, amplitude, and timing contamination, but by the limitations imposed by a constant gain setting in the receiver in conjunction with the limited dynamic range of the data link (Jordan, 1977) and ground processing and display equipment. In practice, therefore, the Seasat-A output imagery will generally be saturated for urban areas and dominated with thermal noise in desert and other low reflectivity regions.

RADIOMETRIC ACCURACY CONSIDERATIONS

There is a widespread feeling that the SAR must ultimately yield absolute radar backscatter. While this would be useful, it is by no means necessary for even some of the more challenging applications such as soil moisture determination. It is far more important that the SAR can measure changes in backscatter accurately, than that it can measure the absolute value of backscatter. Colwell (1968) describes the value of change detection in visible photography, as opposed to absolute identification. Many of his comments are applicable to SAR today and should serve to remind us of the danger of over specification. (In the same article, Colwell candidly describes the major operational limitation of visible photography --- excessive cloud cover.)

The following list of the types of radiometric errors that can occur in the measurement of relative backscatter is probably incomplete but serves to illustrate the complexity of the problem.

(1) Reference of some point in the image to a primary (not necessarily absolute) standard.

(2) Small scale local error caused by strong scatterers contaminating adjacent regions containing weak scatterers.

(3) Large-scale systematic but unknown variations in the system transfer function, caused by, e.g., antenna pattern uncertainties.

(4) Long-term temporal variations in the system transfer function, caused by, e.g., processing variability.

(5) Coherent speckle caused by insufficient averaging, resulting in backscatter variances already discussed.

Within a single pass, therefore, at least five separate classes of error can be experienced. Even if complete knowledge of each is available, an extremely sophisticated and non-linear algorithm would be required to map output amplitude back to input backscatter coefficient. In the Seasat-A SAR, much of the knowledge to create this algorithm is lacking. Within certain limits, however, by formulating a proper calibration philosophy, a number of major error sources can be reduced or even eliminated.

To perform quantitative radiometry, simply to verify that the measurement system is invariant, some primary standard is required. A primary standard could theoretically be created by constructing a "rough", i.e., perfectly diffuse scattering area of perfect conductors. A perfectly diffuse, lossless collection of scatterers with an area which is large compared to the measurement resolution exhibits a normalized scattering coefficient of one (σ^o = 0 dB). Constructing such a standard is not trivial. Practical surfaces are neither lossless nor perfectly diffuse. Corner reflectors are common practical answers to the problem. One must be careful, here, however, to use an "effective area" in calculating an equivalent backscatter ratio. Also, errors are introduced via edge effects at large angles from the normal. In spite of these limitations, it seems clear that, for precise radiometric measurements, spaceborne SAR transfer functions must be calibrated either through commonly agreed upon large surfaces of invariant backscatter (if any exist) or through a collection of uniform and well-designed corner reflectors or point sources placed at strategic locations.

The second source of error listed above (small scale local errors in the vicinity of strong sources) is actually a natural consequence of a system having limited dynamic range and contrast. Spurious energy in the tails of the point spread function add to adjacent cells and are indistinguishable from adjacent sources of backscatter. For extended sources on Seasat-A, this effect is of the order of 10 dB. The only way to reduce this radiometric error source is by systematically reducing phase, amplitude, and timing errors throughout the entire system. The major effect of this contamination source is to restrict the instantaneous backscatter range over which calibration is possible.

The third and fourth sources of error listed above are closely related large scale effects which prevent the extrapolation of calibration from one point in the image to all other points. The third source usually manifests itself in range; the fourth, in azimuth. The system response as a function of range is modulated by the antenna pattern. Usually, as in Seasat-A, the antenna pattern is sufficiently sharp that a spacecraft roll of one degree can result in a change of several dB in system gain at a particular range. In addition, the backscatter function itself (for a homogeneous partially specular target) is varying rapidly with angle, especially at angles near nadir. Consequently, even for attitude control systems accurate to a fraction of a degree, the steeply varying antenna pattern can result in errors of several dB.

Long term temporal variations in gain further limit accuracy. A major source of this type error is a change of system gain with temperature. This type of error (except for the antenna portion) is easily removed by periodically transmitting a stable reference amplitude (or family of amplitudes) through the system. Changing atmospheric path loss introduces additional errors of this class. Unfortunately, in the Seasat-A SAR, the reference amplitude signal is inoperative, and temporal variations in the system transfer function will be extremely difficult to deduce.

The final cause of uncertainty in backscatter value is due to coherent speckle. In the Seasat-A instrument, for example, fields of identical scatterers, in the absence of other contamination sources, produce backscatter variances of several dB at the scale of a single resolution element. As discussed above, there is no effective way to reduce this variance except to employ spatial integration. The variance will decrease roughly proportionally to the square root of the number of cells which are spatially integrated.

GEOMETRIC ACCURACY CONSIDERATIONS

Every imaging system forms its image with a unique perspective. If the mapping from object to image is one-to-one, with a known mapping function, then no information is lost, and it might be said that the geometry is absolutely accurate. The synthetic aperture radar also has its own perspective, making measurements of time delay and doppler frequency, from which geocentric latitude and longitude must be inferred. Any discussion of geometric accuracy, therefore, must be centered about the ability to make this inference.

Assume a spacecraft in a perfectly circular orbit around a perfectly homogeneous stationary spherical earth. The spacecraft velocity and altitude are therefore constant. Finally, assume that the orbital parameters of the spacecraft are known, so that its position in terms of geocentric coordinates is a known function of time. In this ideal situation, the mapping between SAR parameters and geocentric coordinates is trivial. For vacuum, the radar time delay is uniquely related to range from the spacecraft. Therefore, the radar time delay defines a sphere of unique radius centered on the spacecraft. Similarly, a particular doppler frequency shift defines a unique angle with respect to the spacecraft velocity vector, the locus of which is a cone. The full set of range and doppler frequencies measured by the radar, therefore, can be visualized as concentric families of spheres and cones centered on the spacecraft. The intersections of these spheres and cones with the spherical earth result in a corresponding family of circles and hyperbolae, and allow a unique mapping from "range-doppler" space to geocentric coordinates. In particular, if processing is performed about "zero-doppler", i.e., the position of a point is defined by the time at which it has no radial velocity component, then the only concern need be with the intersection of circles with a plane normal to the velocity vector (the degenerate form of the hyperbola).

In reality, the spacecraft is in a non-circular orbit. The earth is neither stationary nor spherical. A non-circular orbit implies a rate of change of altitude and a zero-doppler plane which no longer passes through the sub-satellite point. In Seasat-A, for example, a 1 m/s altitude rate produces nearly a 100 m shift in the zero-doppler plane at the surface of the earth. It is, therefore, necessary to know and correct for altitudes rates of 0.25 m/s to limit geometric errors caused by this source to 25 m. The Seasat-A orbit has been intentionally adjusted to reduce this error to insignificant proportions in the Northern Hemisphere.

The rotating earth produces an angular offset to the zero-doppler plane of about four degrees at the equator, sinusoidally decreasing to zero at the higher latitudes. For the Seasat-A geometry, at 20 degrees from nadir, this rotation amounts to a lateral shift of about 150 m.

The non-spherical earth distorts the family of range and doppler curves according to the local figure and terrain (or tidal) properties. Much of this error can be eliminated by using the proper earth model. Local terrain variations, however, are generally unknown a priori, and will introduce significant displacements. A mountain whose peak is 1 km higher than the surface of the corresponding earth model will, in the Seasat-A geometry, be apparently displaced by 3 km. This type of local distortion will significantly complicate efforts to register LANDSAT and Seasat-A imagery.

A number of significant error sources will drive the system geometric-location accuracy on Seasat-A to at least 100 m, and, more likely, several hundred meters. The final performance will probably depend to a large extent upon the creativity of individual investigators, and the use of local references.

SOME DIRECTIONS FOR FUTURE IMPROVEMENT

Every spaceborne SAR system represents a large number of sensitive compromises. One is generally constrained in image quality by the available power. Given a fixed power, the only practical options for improving image quality are: (1) to decrease the range, or (2) to increase the antenna area.

Even these variables are generally driven by additional considerations such as frequency of coverage, desired swath width, resolution, and compatability with complementary sensors. For economy and reliability, the next few U.S. SAR systems (the first U.S. Shuttle Imaging Radar, Seasat follow-on, and the Venus Orbiter Imaging Radar), most of which are summarized by Barath (1978), will probably be generically similar to the Seasat-A SAR. That is, they will be solid state, L-band systems with average transmitter power of about 50 watts, employing planar arrays of length around 10 m. The primary potential for substantial improvement over the Seasat-A imagery will come from reduced range. This is an especially attractive approach since every factor of two reduction in range results in a factor of eight improvement in lowest detectable backscatter, a factor of eight reduction in required power, or nearly a factor of three reduction in signal variance, with identical geometries.

Assuming, however, that "LANDSAT quality" SAR imagery is desired, there is little alternative to larger, more powerful systems. This will be especially true for the more quantitative applications such as crop and forest inventories and land use classification at Level I (Anderson, Hardy, and Roach; 1972). Moreover, classification at Level II would seem to be a worthy goal for future earth-oriented SAR systems, so that at least cursory compatability with the planned Thematic Mapper (National Academy of Sciences, 1976) can be achieved. A ground resolution of at least 20 m is required to achieve Level II classification.

As discussed in a previous section, however, high spatial resolution can be meaningless in a coherent system, except for point, edge, or repetitive pattern (e.g., ocean wave) discrimination. For most classification problems, grey scale resolution is essential, and can be obtained only by increasing the received power. The grey scale resolution available in LANDSAT, or planned in the Thematic Mapper, is attainable in a spaceborne SAR only by collecting several hundred, perhaps even thousands, of independent samples per resolution element. As Moore and Thomann (1971) have pointed out, excess bandwidth is the most straightforward approach to obtaining the independent samples. The excess bandwidth naturally introduces additional noise power, and so must be compensated with additional transmitter power. Consider, for example, the two systems whose characteristics are summarized in Table 1. System A corresponds closely to the existing Seasat-A SAR parameters. System B is a hypothetical system for the purpose of illustration, significantly more powerful than System A, in which,

(1) the additional power is used primarily to reduce the signal variance through excess bandwidth, forcing an increase in operating frequency,

(2) the swath width is increased to be identical to LANDSAT and the Thematic Mapper, which, together with the increased operating frequency, forces the antenna to become twice as long and 16 times as narrow,

(3) the spatial resolution is increased slightly, and the grey scale resolution is increased significantly, possibly permitting Level II classification compatibility with the Thematic Mapper, and

(4) the altitude is lowered slightly to permit coverage synchronized with the Thematic Mapper.

TABLE 1 Comparison of Two SAR Systems*

Parameter	System A	System B
Prime Power (kW)	0.5	10
Operating Frequency (GHz)	1.275	10
Bandwidth (MHz)	20	1000
Average Transmitter Power (W)	50	2500
Altitude (km)	800	700
Swath Width (km)	100	185
Spatial Resolution (m)	25	20
Noise Equivalent σ^o (dB)	-27	-27
No. Independent Samples	4	80
Noise Equivalent $\Delta\sigma^o$ (dB) (90% confidence)	8	1.5
Angle from Nadir (deg)	18 to 24	14 to 28
Antenna Dimensions (m)	2.16 x 10.7	.135 x 20
Relative Losses (dB)	0	3

*based on Eq. (76) given by Cutrona (1970)

System B is not meant to be a proposal for a future system, since it possesses no specific applications rationale. For arguments related to optimum SAR characteristics for particular applications, see National Academy of Sciences (1977) and Simonette (1976) as an indication of the controversy surrounding this issue. The System B parameter set does, however, concisely illustrate the technical cost of significantly improved image quality, regardless of the application. A large swath requires a long and narrow antenna; good spatial and amplitude discrimination require high power. Although an alternative option of lowering the spacecraft altitude exists, it has the disadvantage of allowing widely varying incidence angles, introducing an additional complication into the signature problem. System B also imposes precise requirements on spacecraft attitude to accomplish proper azimuth compression.

As an additional perspective, the engineering changes summarized in Table 1 are approximately those required to improve system discrimination capability from that shown in Fig. 3 to that shown in Fig. 4 (modified slightly by compensations for swath width, resolution, and altitude).

SUMMARY

Spaceborne SAR is still in its infancy. It is too early to predict its utility either for earth resource inventories or for oceanology. The Seasat-A SAR represents our first opportunity to perform controlled experiments in many areas of potential utility. International cooperation on Seasat-A, combined with a healthy level of research support, will undoubtedly help crystalize many of the potential and unique applications of spaceborne SAR. A number of these applications may be verified during the first year of operation. Experimenters accustomed to the image quality of LANDSAT, however, will be disappointed in the lack of comparable image quality from Seasat-A. This discrepancy can best be rectified in the future with a substantial commitment to larger and more powerful systems.

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ARGUS-SPAS, AN EXPERIMENTAL SHUTTLE PALLET SATELLITE FOR EARTH OBSERVATION*

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ABSTRACT

ARGUS-SPAS is the synonym for the application of a Shuttle Pallet Satellite (SPAS) in an Earth's remote sensing mission. Earth observation by remote sensing via near polar orbiting satellites at low altitudes requires cost effective space platforms offering large mounting areas and volumes besides high electrical power so far active or passive microwave radiometers are concerned. The Shuttle optimized SPAS, to be used as an experimental research platform for the European user's community requirements in the mid 80's will open the way to a low cost development and in orbit transportation approach for European developed payload instruments.

KEYWORDS

ARGUS-SPAS, Earth Observation Remote Sensing Satellite, SHUTTLE optimized multimission spacecraft, MOMS, SAR, IMR, DCP, IDTS, SPAS-Structure.

1. OBJECTIVES

For experimental/preoperational Earth's remote sensing operation - starting hopefully around 1985 - ARGUS-SPAS could be a low cost, but powerful space platform optimized for a SHUTTLE launch into a low, near polar orbit. ARGUS-SPAS is conceived for the European user's community requirements, i.e. for high resolution multispectral optical sensors and in particular for both, for powerful SAR instruments and/or for large passive microwave radiometers. Payload instruments tested and flown in Spacelab missions could be reused or rebuilt directly (with minor modifications) for the proposed free-flying platform. Consequently ARGUS-SPAS could be either the next development step for the establishment of an European Remote Sensing System or thanks its modular approach - in its advanced version a logical supplement to ARIANE dedicated conventional Earth observation Satellites.

The European regional needs have been identified by ESA in context with the user's community and could be summarized to the following key topics

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+This paper is partly based on a relevant study for DFVLR-BPT on behalf of BMFT. Views herein expressed are those of the author and not necessarily of DFVLR-BPT.

- statistical information on agricultural products and on forestry,
- land use classification and urban mapping,
- water resources management (snow/ice sensing, soil moisture, floods, water quality)
- coastal zones surveys (continental shelf operations, sea/ice detection, oil pollution, aid for fisheries)
- monitoring of the Northern polar regions (e.g. Greenland, Iceland, etc. for ice surveys).

Concerning the latitude of the European countries with their special sun incidence angles and their frequent coverage by clouds, moreover considering the smaller European agricultural pattern, the envisaged high resolution multispectral optical scanner and the high resolution C-Band-SAR will form a remarkable baseline payload dedicated for European needs.

So far as land application and coastal oceans satellite missions are concerned ARGUS-SPAS will be best suited, moreover due to its modular approach and its high growth potential ARGUS-SPAS will be a promising candidate for both, advanced land application and open oceans monitoring remote sensing missions.

Besides operation within the coverage zone of the European Earthnet Data Acquisition Stations, it is of course possible - and from the effectivness point of view highly desired - to provide remote sensing service also to other countries in the world, in particular in context with development aid programmes. For this application either regional/national ground stations must be available or data transmission via TDRSS may be considered (intermediate onboard storage is constrained). In general ARGUS-SPAS could be kept as a worthwile element within a worldwide Earth Observation System for multiple civil applications.

1.1 The SPAS-Concept

The SPAS concept is based on the development of bridging structures for Shuttle pallets and the idea of free-flying platforms launched directly by the shuttle itself.

MBB has defined a simple and low-cost platform for shuttle fixed or free-flying missions, optimized for the Shuttle cargo bay constraints and for transportation, launch and retrieval (if required) directly by the shuttle and for operation by the remote manipulator arm. SPAS has been designed for

- o extensive modularity
- o maximum cargo bay utilization
- o large payload mounting and radiation areas
- o high electrical power provisions
- o minimum launch cost

A SPAS element as shown in Fig. 1 has a span of 4.2 m and a width of 0.7 m. The basic module consists of two elements with the dimensions 4.2 x 1.4 m, whereby the width can be increased in steps by 0.7 m to 2.1 m, 2.8 m ... etc. The maximum allowance for the cargo bay volume and mass has been considered with 1 670 kg/m. The load capability of one element (0.7 m width) is 1 170 kg for a safety factor of 1,8 and for the basic module 2 340 kg (1.4 m width and safety factor 1.8) respectively.

The primary structure of SPAS is a framework consisting of carbon-fibre (CFRP) tubes inter-

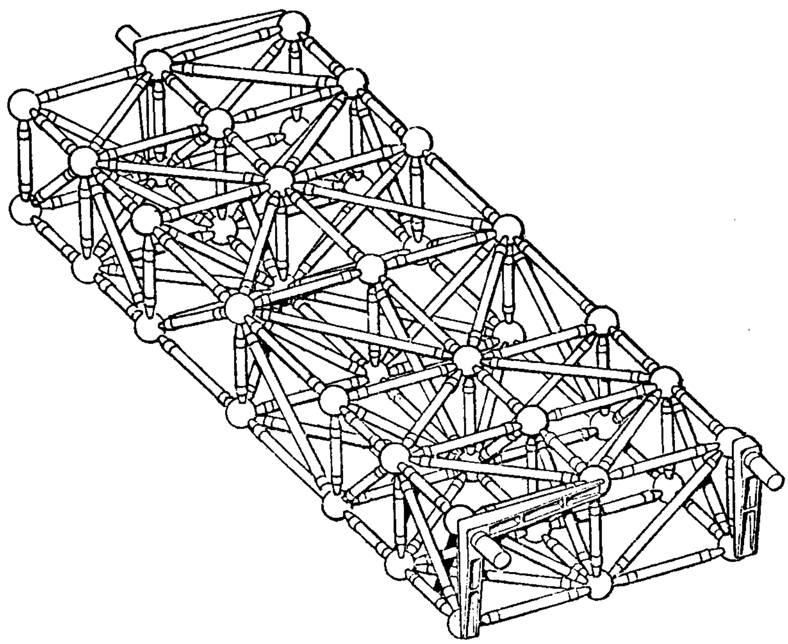

Fig. 1 SPAS - Structure - Module (2-elements)

connected by Titanium node elements providing high mechanical stiffness (eigenfrequencies higher than 10 Hz) and thermal stability and is flexible to specific load requirements.

The spherical Titanium alloy node elements and the secondary structure elements are shown in Fig. 2. The secondary structures are standardized Aluminium alloy plates (integrally milled) for the two vertical and horizontal compartment sizes with a specific mass of 8 kg/m^2 and hole pattern of 70 x 70 mm. Instruments or equipment boxes could be mounted either directly on the node elements or on the secondary structure plates. The subsystem components are housed in equipment boxes, which are mounted inside the truss structure.

Details of the node element connections are presented in Fig. 3.

The bridging structure is supported by a static stable three point system, i.e. by two sill fittings at the cargo bay longerons and by the keel fitting, see Fig. 4.

The weight for a basic model including the primary and some secondary structures, moreover the platform equipment boxes amounts to 300 ./. 350 kg.

Release (and capture for retrieval) of the platform will be performed by the remote manipulator arm. When the SPAS has reached its safety distance to the Shuttle, the onboard thruster engines will provide the final manoeuvre and transfer capability.

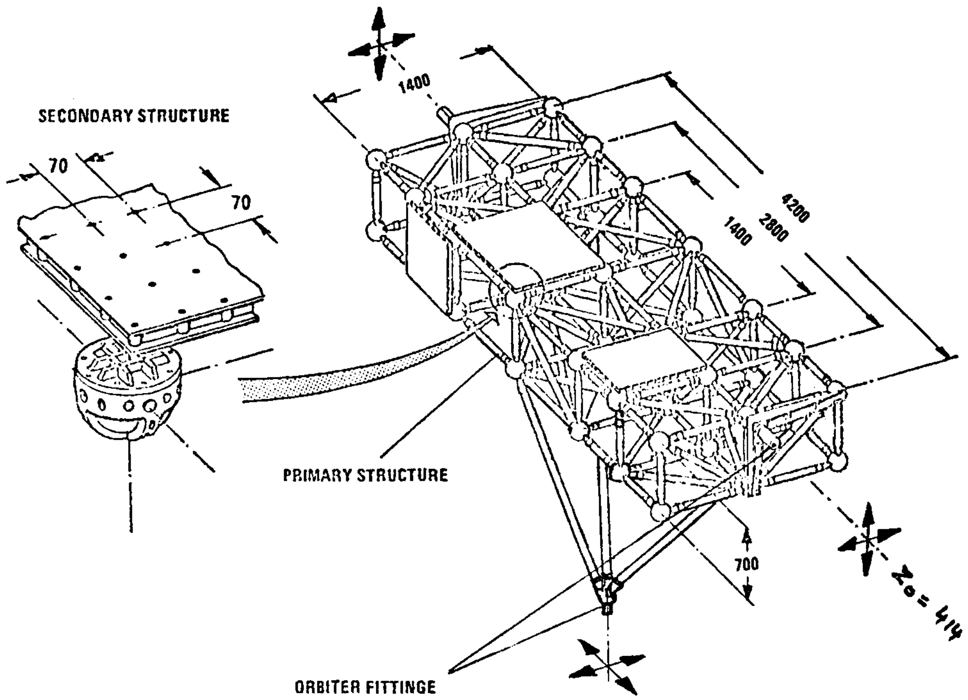

Fig. 2 Node elements and secondary structure elements

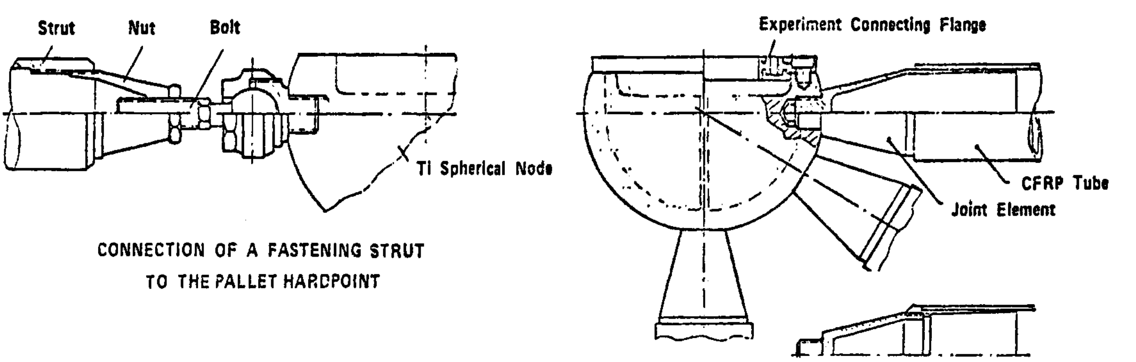

Fig. 3 Node element connections

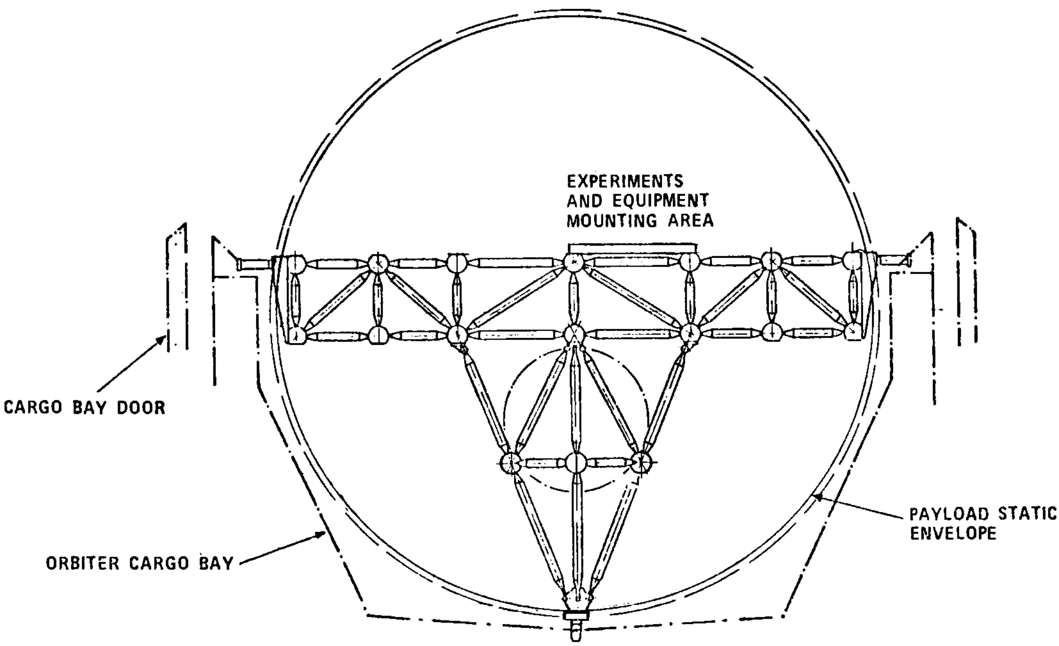

Fig. 4 SPAS structure and SHUTTLE cargo bay mechanical interfaces

1.2 The SPAS-Family

SPAS is a multimission Shuttle optimized, low cost spacecraft, flexible for a variety of missions and payloads. MBB has identified a whole family for the SPAS application with the following designations:

- SPAS 0 — a non-free-flyer payload support structure
- SPAS 1 — a simple free-flyer for passive experiments (comparable to LDEF)
- SPAS 2.1 — for space processing (i.e. high solar power, dawn/dusk orbit with moderate attitude requirements)
- SPAS 2.2 — for astrophysics (i.e. medium solar power by sun tracking panels, precise attitude control)
- SPAS 3 — for Earth-oriented applications at low orbits, e.g. for meteorology, climatic research, Earth resources survey, ocean observative missions. The power and attitude control requirements depend on the individual demands. For the

transfer (and retrieval) from the Shuttle orbit (300 km) to the target orbit (600 - 1 200 km) a 400 N-engine (Symphonie, Galileo) is foreseen.

- SPAS 4 for geosynchronous missions, like TVBS-multination services, where the IUS is replaced by the integrated bipropellant propulsion system with a 22 KN-thrust engine, available from the ASTRIS development programme.

The degree of the equipment complexity and of the considered mission lifetime (some weeks, or 2 to even 10 years) depends on the mission demands.

Provisions are conceived for fast and simple servicing on ground for reloading of propellant tanks, exchange of batteries, degraded components (e.g. solar generator, TWT-amplifier) or degraded or failed electronics. Servicing on board of the Shuttle of a retrieved SPAS vehicle appears to be feasible too.

1.3 The ARGUS-SPAS concept

ARGUS-SPAS is the synonym for a Shuttle dedicated Earth observation satellite applying the SPAS concept. It is in terms of the SPAS-family terminology a SPAS-3 spacecraft.

Conceived as a multimission spacecraft, ARGUS-SPAS will fly as an Earth observation satellite in near polar and at low altitude orbits, demanding large mounting areas for its large active and/or passive microwave antennas and the associated high power solar generator. Both, the payload mass with the dedicated payload telemetry system and the power supply during the instrument operational phases and the eclipse by a battery set require for an envisaged mission lifetime of 2 ./. 3 years a total spacecraft mass between 1.5 and 2.3 tons. Therefore, the Shuttle will be an appropriate launch vehicle into a low orbit (300 km e.g.). The transfer into the final circular orbit at 600 ./. 900 km altitudes will be performed by the ARGUS-SPAS 400 N-transfer engine. On the other hand SPAS will be best suited as a simple low-cost but powerful space platform optimized for the near future low-cost launch system - the Space Shuttle Transportation System.

2. THE ARGUS-SPAS CAPABILITIES

2.1 Fundamentals

ARGUS-SPAS as shown in Fig. 5 comprises in general

- the basic structure (2-element block carrying
  - o inside the subsystem equipment boxes and payload electronic boxes,
  - o at the bottom side the tank system with the 400 N transfer engine, moreover a payload telemetry tracking antenna for a relay satellite (e.g. TDRS) if required,
  - o at the top side the optical payload and attitude Earth sensors, the antennas for the active and/or the passive micro-

wave sensors, moreover the necessary antennas for telemetry and telecommand traffic, at the longitudinal side walls radiation plates for thermal control,

o the one wing sun-tracking solar generator, providing free space for radiation cooler (e.g. for TIR-detectors) at the opposite side,

o the subsystem equipment to operate the spacecraft.

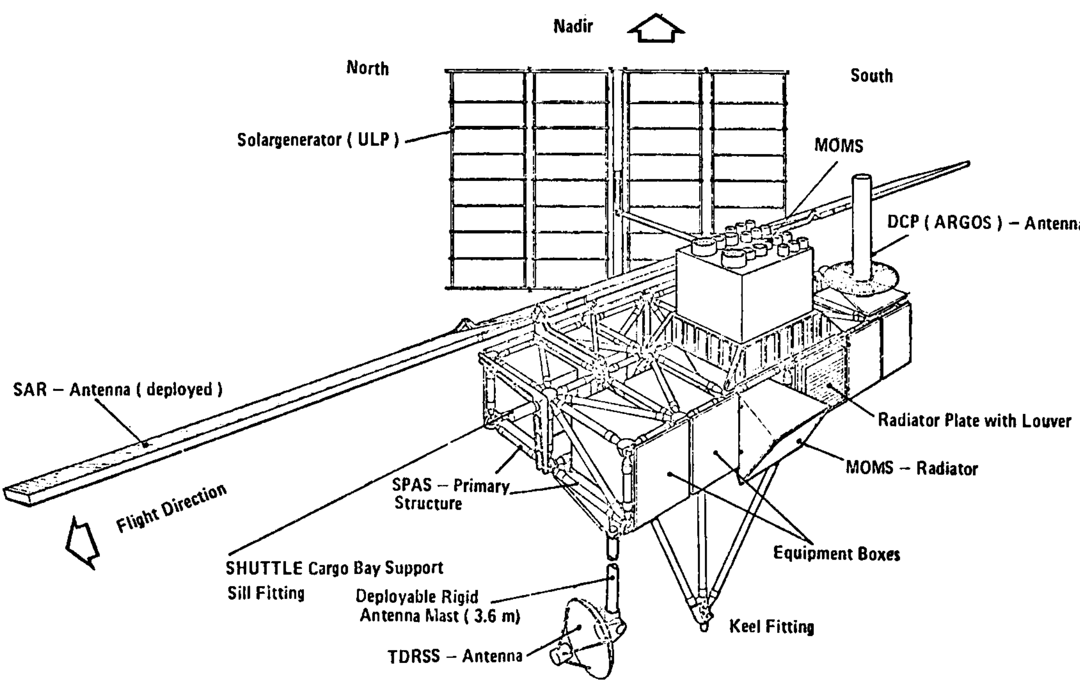

Fig. 5 ARGUS-SPAS system concept (MOMS, SAR and DCP (ARGOS))

2.2 Payload Accommodation Capabilities

ARGUS-SPAS is well suited to carry a payload package, combining e.g. a

- Modular Optoelectronical Multispectral S canner (MOMS; a high resolution scan radiometer in the visible and infrared spectral regions, based on the push-broom and linear CCD-detector arrays - with cryogenic or direct radiation cooler for longer mission lifetime - with the following typical features (750 km altitude)

  o visible spectral region
  4 channels 0,53 ./. 0,95 μm
  subsatellite ground resolution 30 m
  swath width 300 km
  quantisation 8 bits/pixel (256 gray levels) and a stereo panchromatic channel for 19 m altitude resolution and 120 km swath width

- o medium infrared region
  2 channels 1,5 ./. 2,3 μm
  subsatellite ground resolution 60 m
  swath width 240 km
  quantisation 8 bits/pixel
- o thermal infrared region
  1 channel 10,2 ./. 12,5 μm
  subsatellite ground resolution 120 m
  swath width 300 km
  quantisation 10 bits/pixel

whereby the channels, the swath width/ground track within the 300 km) and moreover the resolution/ quantisation could be selected by telecommands.

The interface data of MOMS (as shown in Fig. 6) are

- o dimensions 1,05 x 0,95 x 0,75 (height) m^3
- o total mass 110 kg
- o DC-power 110 w
- o bit rate 80 ./. 100 Mbp

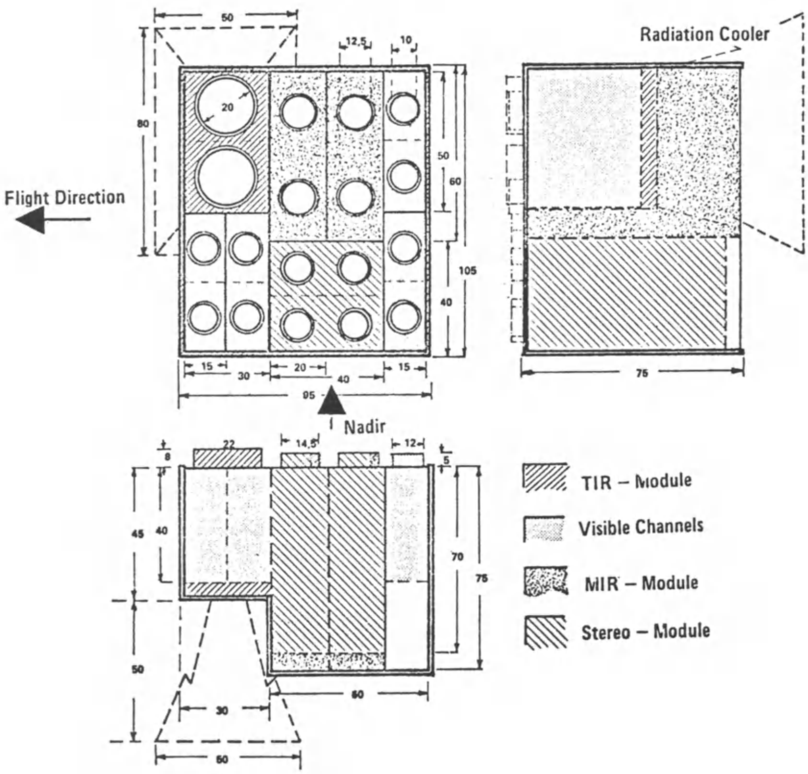

Fig. 6 Modular optoelectronical multispectral scanner (MOMS)

A MOMS-module for the visible spectral band has been sucessfully tested in several aircraft flights.

- Synthetic Aperture RADAR (SAR) with a planar foldout phased array antenna (e.g. 5.3 GHz for soil moisture or coastal ocean monitoring purposes). The features are the following

  polarisation HH or VV
  radiometric resolution 2 dB
  ground resolution 30 m
  swath width 100 km
  depression angle 70^{o}
  quantisation 2 x 4 bit

  The interface requirements are described by

  o antenna dimensions $11 \times 0,8 \times 0,15$ m^3
  o antenna mass 100 kg
  o SAR-electronics 90 kg
  o RF-power 175 W
  o total DC-power 1300 W
  o bit rate 80 Mbps

- Passive Multifrequency Microwave Scan Radiometer (PAMS or IMR) with either a cylindrical paraboloidal reflector antenna with linear phased array feeder, and/or planar phased array antennas as shown in Fig. 7 for a frequency range between 5,6 and 33 GHz.

  It is also possible to accommodate easily a set of mechanically conical scanning reflector antennas on ARGUS-SPAS.

  The performance data are

  two polarisations per channel
  four frequency channels: 5,6; 10,6; 19,3 and 33 GHz
  temperature resolution (relative) better 0,5 K
  ground resolution $\leq$ 20 km
  swath width 300 km
  quantisation 10 bit/pixel

  The interface requirements can be obtained from the list below

  o antenna dimensions
     5,3 GHz $3,6 \times 3,4$ m^2
     10,6 GHz $3,4 \times 3,4$ m^2
     19,3 GHz 2×2 m^2
     33 GHz $1,1 \times 1,1$ m^2
  o antenna mass 430 kg
  o radiometer electronics 130 kg
  o total Dc-power 740 W
  o bit rate 6 Kbps

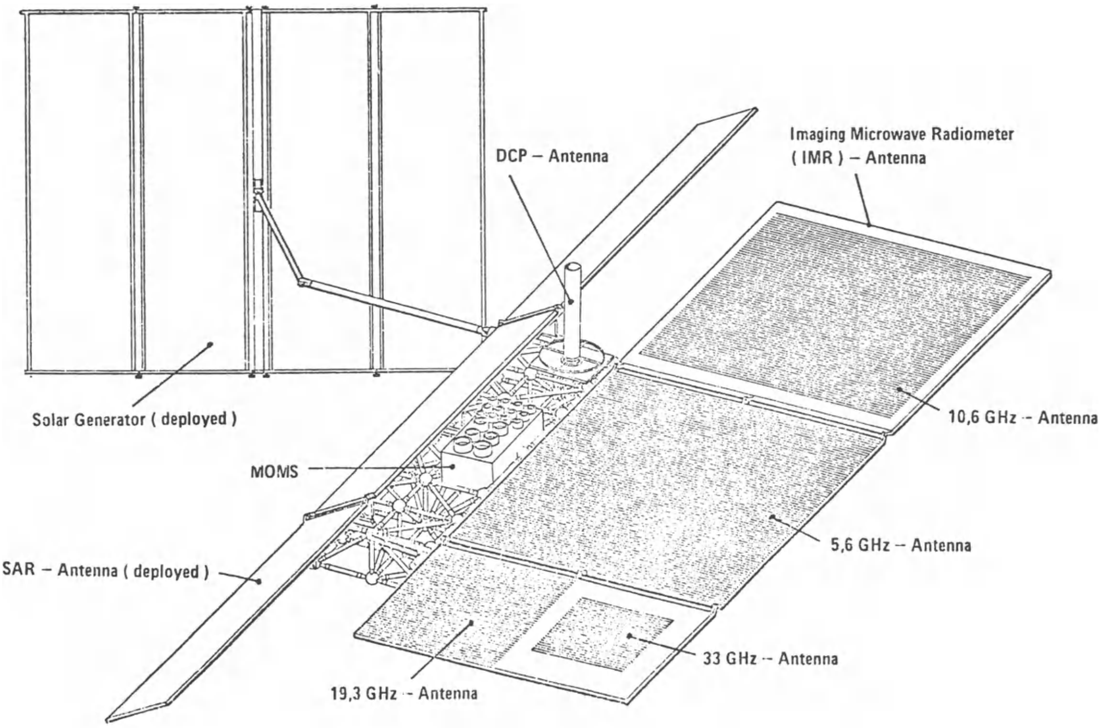

Fig. 7 ARGUS-SPAS, system concept for a payload configuration comprising MOMS, SAR, DCP and IMR

Data Collection Package (DCP) and localisation package for data transmission from automated stationary or mobile stations like the ARGOS-system.

ARGUS-SPAS is able to accept a combination of a SAR and an IMR (both of the planar antenna type) or to have onboard 2 SAR-antennas for 2-frequency and 2 polarisation operations. As far as payload telemetry is concerned, special X-band transmission to ground stations and K-band transmission to the TDRSs have been considered with regard to the high total data stream, moreover high data storage by tape recorder if required.

In the stowed configuration, ARGUS-SPAS with folded solar generator, SAR-antenna and TDRS-antenna will occupy a rather small disk of the available SHUTTLE Cargo Bay volume. Out of the 18,3 m bay length only about 2 m are required for ARGUS-SPAS with its appendages. The stowed configuration is shown in Fig. 8 .

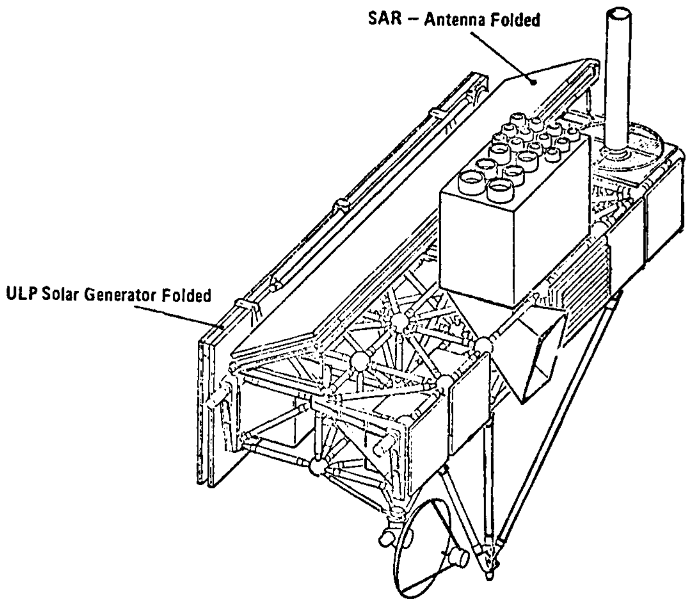

Fig. 8 ARGUS-SPAS, stowed configuration

2.3 Mission Flexibility

ARGUS-SPAS has a broad flexibility in mission application. Equatorial and polar orbits have been considered, where for polar orbits all sun-synchronous nodal times could be covered by the baseline elements. Non-sunsynchronous orbits for a SAR-mission (planar fold-out antenna) appears in general feasible with some modifications for the existing SG-drive-system and the thermal control system. The passive detector radiator cooler could be replaced in this case either by dual stage cryogenic solid cooler (methane/ammonia) or by a closed loops active refrigerator system. Non-sun-synchronous missions could provide a greater flexibility for the coverage/repetition rate for constrained inclination and swath width conditions.

The orbit altitude could be between 600 ./. 900 or 1200 km and will be a compromise between the RADAR and telemetry transmission power vis-a-vis the propellant mass and the frequency of orbit control manoeuvre, i.e. the envisaged mission lifetime.

A typical ARGUS-SPAS altitude may be 771 km providing an equator coverage for the optical sensor (300 km swath width) within 10 days, a final equator coverage for the SAR (100 km swath width) within 28 days, whereby each SAR track will be complemented by a succeeding tracks within 3 days. The orbital parameter for a sun-synchronous orbit are

altitude 771 km, inclination 98,57°
period 100,14 min, number of resolutions per day 14,38.

In case a repetition accuracy (after 28 days) of 20 km is demanded, an altitude accuracy of 200 m is required, or consequent orbit control manoeuvre every 31 hours. For a three years mission lifetime the total number of correction manoeuvres becomes 850 and the propellant mass required about 50 kg.

Besides by the onboard propellant mass, the mission lifetime is influenced by the degradation of solar array cells, by the wear-out processes of TWTs and battery cells e.g., by the allowable mass which could be spent for redundant battery cells (high number of operational cycles) and for electronic components.

Where for an ARIANE dedicated Earth observation satellite a mission lifetime of 2 years is typical, for ARGUS-SPAS a lifetime equal or longer 3 years could be considered.

2.4 Configuration Flexibility

The modular approach to integrate the equipment and payload housing boxes, the tank accommodation platforms and the radiator plates are demonstrated in Fig. 9.

- Mounting Volume

  For the baseline structure (2-element), the mounting volume amounts to
  a - 2.2 m^3 inside the truss structure
  a - 16 m^3 for external mounting, e.g. for payload accommodation.

  These figures can be increased to 3.3 m^3 and 24 m^3 respectively for a 3-element-structure.

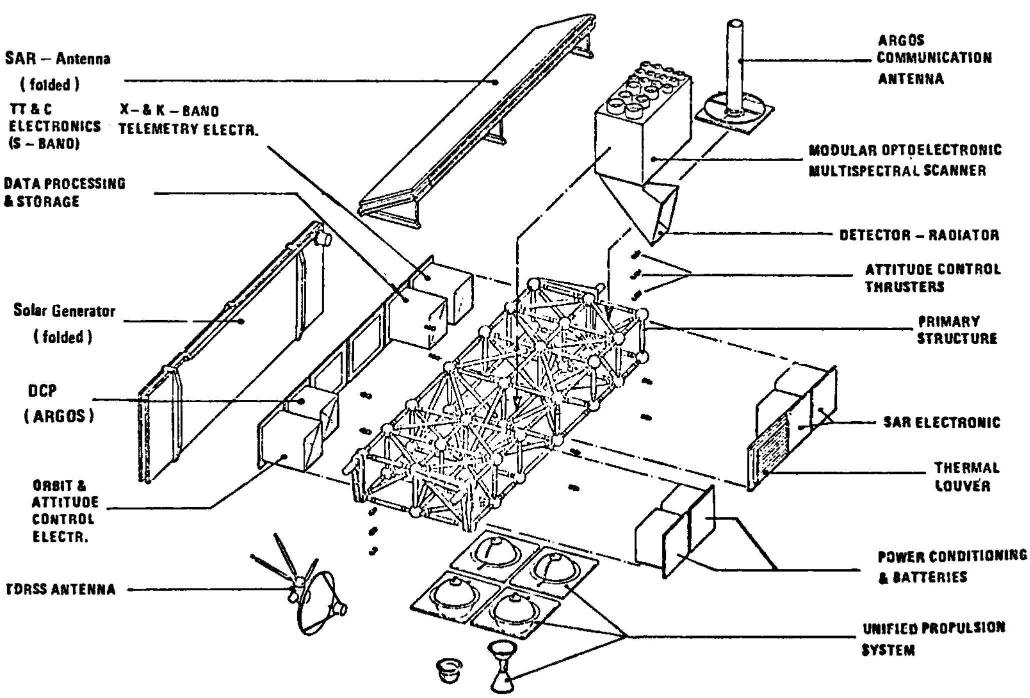

Fig. 9 ARGUS-SPAS, concept of the modular structure and equipment boxes system (exploded view).

The four (4) external compartments of the SPAS structure are foreseen for subsystem and payload equipment boxes, whereby the four internal compartments are dedicated for the tank system and for mounting of both payload dedicated and converter/shunt regulator dedicated radiator plates.

The platform subsystem components are housed in four equipment boxes with a volume 4 x 170 l or 4 x 300 l. Each box has its own thermal control provisions and its internal harness, the box weight ranges between 12 and 25 kg depending on size and internal mounting brackets.

The same box volume is available for integration of payload electronics and/or for the payload telemetry and data management systems.

The unified tank system for the transfer orbit and orbit/attitude control thruster engines is mounted at the bottom side of the internal larger compartments. Four (4) tanks with zero-g-mangement system with a diameter up to 600 mm Ø for a propellant[x)] mass up to 500 kg could be carried, further the associated pressure He-gas tanks.

- Mounting Area

  The external usable mounting area amounts to 16 m^2 for the baseline structure, whereas the upper deck - primarily dedicated for large payload antenna accommodation - is 5.8 m^2.

  The mounting area inside the equipment ranges from 0.4 ./. 2 m^2 depending on size (depth) and internal provisions, hence the total area amounts for the 2 x 4 equipment boxes to 3.2 m^2 ./. 16 m^2.

- Radiation Area

  Each equipment box has its own radiation area up to 0.42 m^2, or in total for 2 x 4 boxes 3.4 m^2. In particular for the payload electronics and for the platform converter and shunt radiator assemblies special radiator plates have been conceived. There are defined a radiation plate with 0.42 m^2 and a weight of 5.8 kg including louvres. Assuming radiator plates for the 4 internal components, the area amounts in total to 1.7 m . Using not only the longitudinal side walls, or increasing the radiator plates over the structure height of 0.7 m, the total radiation area could be increased by a factor up to 4, the total baseline radiation area is ≤ 5.1 m^2.

2.5 Subsystem Capabilities

2.5.1 Platform. The standard of the subsystem equipment depends on the payload and mission requirements which will be met by a modular approach.

- Structure, as described above
- Thermal Control

  Individual passive control of the equipment boxes by superinsolation and radiation areas covered with OSR and provided with a louversystem to consider the frequent

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[+)] bipropelland system with Monomethyl Hydrazin and Hydrogenperoxyd sun- and eclipse phases, moreover the low duty cycle of the power mission profile. Heater elements are added where necessary, for payload instruments or for battery cells, e.g..

The special radiator plates equipped with louvre systems are connected with the heat sources by heat pipes or closed loop systems. Phase Change Cells may be employed also to radiate the heat flux of "hotspot" sources more uniformly considering e.g. an operation time of 10 min per orbit for the payload. The payload radiation area required is e.g. 2.3 m^2 for a sunshinephase dissipating power of 1300 W (sensing and transmission period) or an average dissipating power of 400 W in order to keep the component temperatures within - 10° and + 80°C. The temperatures of each component depend of course on the dissipating energy and the payload operational duty cycle.

For the high power amplifier (e.g. a TWT or Klystron) direct radiation of 2/3 of the power losses has been assumed.

- Solar Generator

For ARGUS-SPAS, the solar generator consists of a one-wing array of 4 semirigid ultralight panels (ULP) with hold down, release and sun tracking mechanisms (BAPTA). The BOM power is 1 360 W (S.S.) for platform and heater supply and for battery recharge. The solar generator power could be increased accordingly to the number of panels, to e.g. 5 ./. 7 kW if required corresponding to 2 x 8 ./. 10 panels or a SG area of 3.2 m x 19 ./. 24 m.

- Battery Systems

The battery system will be used to operate the payload day and night and to supply the platform during the eclipses (35 min/orbit) with electrical power. The energy to be stored in the battery system depends on the mission profile and the payload average power demand. For the ARGUS-SPAS the required energy is typical 380 Wh. The layout of the battery depends strongly on the mission lifetime, i.e. on the number of cycles which determines the allowable depth of discharge. For ARGUS-SPAS a NiCd-Battery system with redundant 2 x 20 Ah-cells has been considered for a DOD of 25 %, thus the battery weight becomes $\geqq$ 50 kg depending on the cell type. The growth potential may be characterised by a factor of 4.

- Power Control

A conventional regulated DC power control system (e.g. S^3 controller) will be employed for the main payload and the platform essential bus supply. Charge and discharge (boost) regulators for the battery, further a battery cell monitoring and and surveillance system will be used, managed by a mode controller. 50 V main voltages appears desirable for this class of power supply. All solar generator modules (two per panel) and both batteries will fead into common 50 VDC bus, to supply as well the SAR modulator of the klystrons, as both, the power converter for the remaining payload instruments and for the platform subsystems. This concept has been chosen to assure high mission flexibility and reliability.

- Attitude Measurement and Control System

The attitude measurement system comprises two concical scanning Earth IR-sensors, acquisition and fine sun sensors, and a three-axes-rate integrating gyro package. The gyropackage comprises a set of four RIGs, whereby their random drift shall be ≤ 0.03 sec/sec. The attitude determination accuracy will be between 0.05° and 0.1°. In case a higher accuracy is required, an attitude fine measurement sensing system (star mapping sensors) will be added to allow an improvement by a factor of at least two.

The attitude control system employs a central digital control electronics (e.g. Modus) managing a set of 4 reaction wheels (a 7 Nm sec). Electromagnetic torquers (three) will be used for wheel unloading. The pointing accuracy will be 0.15° or better aorund all three axes.

The required drift stability for the most critical optical sensor (allowance of one pixel element displacement per image frame time period, 3 5 sec e.g.) like

0,24 sec/sec for roll and pitch
1,2 sec/sec for yaw motion

could be met by the conceived attitude measurement and control system.

- Reaction Control System (RCS)

  The RCS for orbit and attitude control (during orbit corrections) and for acquisition manoeuvres 14 x 10 N engine have been considered, moreover a 400 N engine for the transfer puses between the SHUTTLE orbit (e.g. 300 km) and the circular target orbit (e.g. 770 km). The propellant mass for the baseline ARGUS-SPAS has been selected to 300 kg corresponding to a total $\Delta V = 635$ m/sec, whereby for transfer operations and inclination correction (1°) 500 m/sec has been considered.

- Telemetry, Tracking and Command System (TT&C)

  A TT&C-system for the unified S-Band with antennas providing nearly spherical coverage will be used for the transfer, acquisition and platform operational phases. The tone range method provides an orbit position determination accuracy of 200 m.

  Housekeeping data from platform components and payload instruments as well as attitude informations could be transmitted either directly via S-Band to the ground stations, or via K-Band to the TDRSS, therefore the TT&C-System is allocated within the payload telemtry equipment box.

2.5.2 Payload supporting systems.+)

- Payload Telemetry (PL-TLM)

  The following telemetry demands have been considered (for the envisaged altitudes)

  o optical sensor (digital) 45 ./. 80 Mbps
  depending on the number of channels, ground resolution, swath width

  o SAR (digital) 60 ./. 80 ./. 110 Mbps
  (analog) 16 ./. 20 MHz
  depending on the number of multilooks, resolution element, swath width

  o IMR and DCP $\leq$ 1 Mbps or in total 160 Mbps (typically).

+) called also IDTS (Instrument Data Telemetry System)

For a direct transmission to ground data acquisition stations, the X-Band (8 ./. 8.5 GHz) and to the TDRSS the K-Band (13 ./. 15 GHz) will be used. For direct ground transmission a shaped beam antenna with view angle of $\pm 66^{\circ}$ has to be used. The low antenna gain and the high bit rate requires a high transmission power of about 55 Watts. For the TDRSS-telemetry link a tracking reflector antenna will be used, hence the transmission power will be about 26 Watts only.

- Onboard Data Management (OBDM)

  The OBDM for the payload consists of the data handling and data storage system. Assuming a continuous data stream of 2 Mbps - generated e.g. by the TIR-chanels of MOMS and by the IMR -, further a recording time of 90 min, the data to be stored amounts to 1×10^{10} bit. The playback bit rate for a 10 min passage time over a data acquisition antenna station will be 18 Mbps, which has to be considered in addition to the bit stream of the just measured data The interface requirements for a set of 2 of 5 tape recorders have been taken into account for ARGUS-SPAS.

3. THE ARGUS-SPAS-SYSTEM

3.1 System Budgets

The platform budget is given in Table 1, whereby the dry mass amounts to 760 kg (w. 10 % margin) and 120 ./. 150 Watts for the envisaged ARGUS-SPAS example. The payload budget, Table 2, points out a mass demand of 540 kg and a power requirement between 350 and 1900 Watts.

TABLE 1 Payload Budget

	M (kg)	P (W)	BR (Mbps)	Remarks
– MOMS	110	110	≤ 80	7 ./. 9 chanels
– SAR w. Antenne	190	1300	80	5.3 GHz 30 x 30 m 2 dB, 100 km, 20 $^{\circ}$, 1 Pol
– DCP	21	20	7 K	
– NL–OBDM	126	59	–	2 out of 5 tape rec. 1×10^{10} bit
– NL – TLM				
X – Band	28	230	160	Ground Station
K–Band	6	76	(160)	TDRSS
– TDRSS–Antenne	7	5		1,4 m$^{\phi}$ Reflector Ant.
Subtotal	488	1724	160	
Develop. Margin	49	172	16	10 o/o
Payload	537	1896	176	

TABLE 2 Platform Budget

	M (kg)	P (W)	
– Structure	360	–	Primary, Secondary Equipm. Boxes
– Thermal Control	32	10 – 40	
– SG + BAPTA	40	8	4 ULP–Gener. 50 V
– Battery + BPU	53	4	2 x 20 Ah, Eagle Picher, H.D.
– Power Supply	57	18 ./. 13	
– AOCS	51	67	4 RW à 7 Nmsec
– RCS (dry)	37	(3)	1 x 400 N, 14 x 10 N
– TT & C, DH	26	10	S–Band
– Harness	30	2	
Subtotal	686	119 ./. 144	
Develop. Margin	69	13	10 o/o
SPAS (dry)	755	145	
Propellant	300	–	Δv = 600 m/sec Tf + orbit control

The overall requirements for the entire spacecraft as given in Table 3 are

- 1650 kg (loaded)
- 2.3 kW.

The margins are

- 650 kg w.r.t. 2300 kg allowance (safety factor 1.8)
- 787 W w.r.t. 3090 W allowance for 12 min SAR operation/orbit.

TABLE 3 ARGUS-SPAS- Budget-Summary (3 years mission life time)

	M (kg)	P (W)	BR (Mbps)	
Payload	537	1896	176	
Platform	755	145	0,01	
Converter Losses	–	105	–	569 W, 50 o/o, η = 73 o/o
Battery Losses	–	157	–	Sun Phase, Discharge Open
Subtotal	1292	2303	176	
Balance Mass	58			
Propellant	300			
Total	1650	2303	176	
Margin	650	787 (EOM) s.s.		2300 kg 3090 W (1170 WSG + 1920 WB SAR for 12 min/or bit

3.2 The Growth Potential

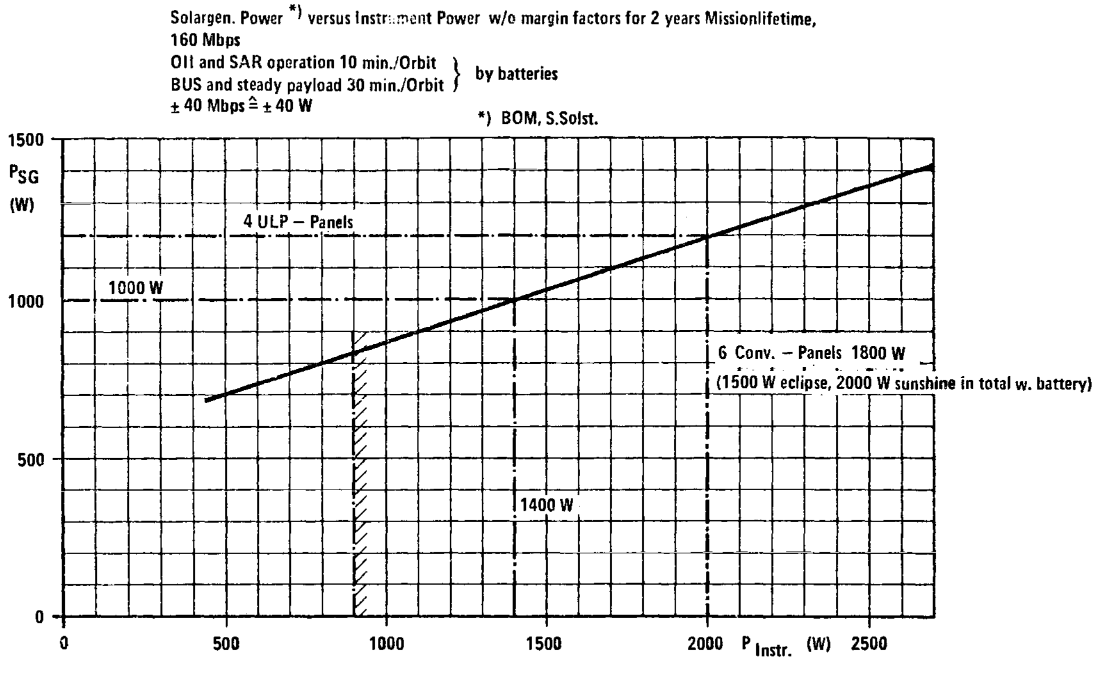
As shown in Table 4 the instrument power could be 2.5 kW to require a 4 ULP-Solar Generator. The power supply could be easily increased by a factor 2 increasing the panel number. The limiting factor would be more or less the heat dissipating power or consequently the radiation area.

In Table 5 the function of the total mass versus the instrument mass is presented; besides there are given the boundaries for the ARGUS-SPAS-2- or 3-element structures for different safety factors. An instrument mass up to 900 kg could be considered (with present 650 kg+) for a conventional ARIANE-platform).

The most interesting mass versus power diagramme for the optical and/or microwave payload instruments is given in Table 6. The present figures could be increased to about 2.5 kW and 1000 kg for a 2-element SPAS-platform.

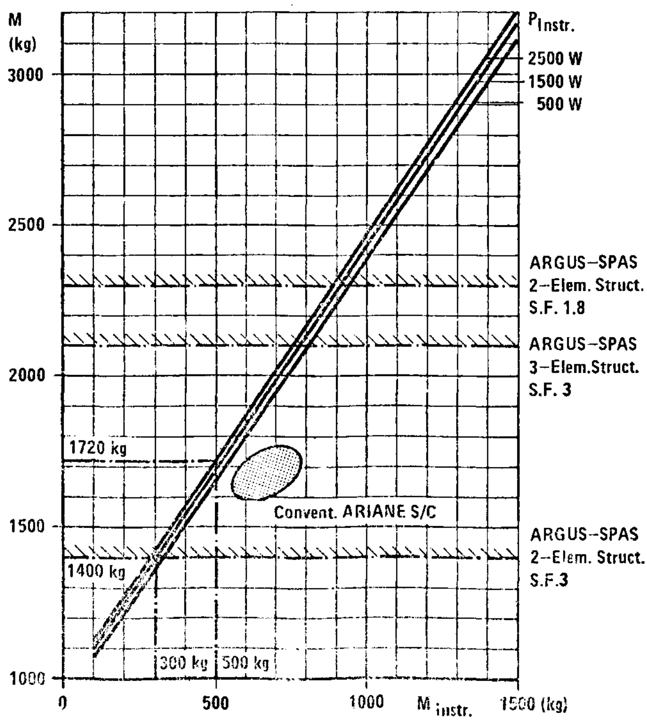
The capabilities of a conventional ARIANE-platform are comparable in terms of mass, because it was not the design goal for the SPAS-concept to have a mass optimized system, but to provide a low cost platform with a large mounting area and with high electrical power. Static momentum constraints do not exist for a SPAS-platform.

TABLE 4 Growth Potential Demonstration, ARGUS-SPAS (OII+SAR+DCP)



+) total payload mass allowance 800 kg including PI-TLM and PI-OBDM

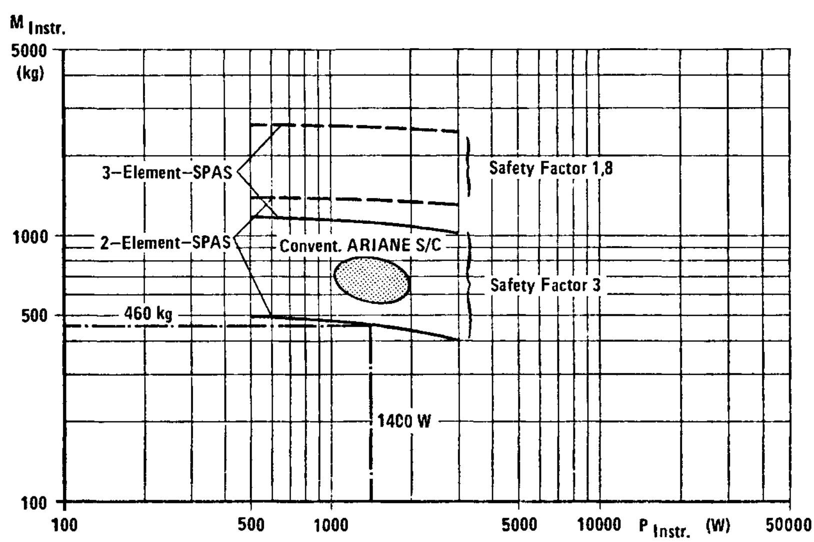
TABELLE 5 Growth Potential Demonstration, ARGUS-SPAS (OII+SAR+DCP)



Total Mass M (kg) versus Instrument Mass w/o margins for 2 y Missionlifetime
160 Mbps, $1 \cdot 10^{10}$ bits stored
Δ BR ± 40 Mbps ≙ ± 25 kg
0 bit storage + 160 kg
890 km altitude

TABLE 6 Growth Potential Demonstration, ARGUS-SPAS (OII+SAR+DCP)

Instrument Mass (kg) versus Instrument Power (W), w/o margin factors for 2 years Missionlifetime sunsynchron, near polar orbit, 890 km 10^{10} bit stored data, 160 Mbps bit stream,
0 bit stored data ≙ + 160 kg, ± 40 Mbps ≙ ± 25 kg



The growth potential for the ARGUS-SPAS is at least a factor two in terms of instrument mass and power required, and could be increased to a factor 4 applying instead of a 2-, a 3-element structure with a bridge width of 2.1 m instead of 1.4 m.

4. COST ESTIMATES

The overall cost to run an Earth's Observation System may be subdivides into the devlopment and production cost for the space segment (e.g. ARGUS-SPAS), the launch cost, the development and installation cost for the ground segment (data acquisition and control stations), and the operational cost for the entire system.

So far the ground segment and operational cost are concerned, the European Earthnet (conceived to begin with the reception of Landsat C/D and Seaset A data) could be assumed to be available too for an own European Space segment and will be kept in service.

The major differences in cost with respect to conventional satellite and launcher systems are due to the launch cost. One could launch e.g. 6 ./. 9 ARGUS-SPAS with one Shuttle flight into a 300 km near polar orbit- of the 2-element, 2,3 tons - version, or it must be spent only approx. 20 % of the launch cost for an expendable launcher (ARIANE, 2600 kg 750 km sunsynchronous) for one ARGUS-SPAS (w/o transfer).

The first launch for ARGUS-SPAS is expected for 1985, therefore, it is too early in the programme to present absolute costs, in particular this is true for the payload instruments, which are within the beginning of their development phases. However, a first guess could be made concerning the respective cost savings. We expect the following cost savings:

- launch cost 80 %
- structure manufacturing due to the simple truss design 2 %
- less critical mass constraints for instruments and subsystem components 8 %
- less critical volume/mounting constraints for intruments and subsystem components 10 %

A total cost saving of at least 80 % for the launch cost and of 20 % for the spacecraft could be expected with respect to conventional satellite/expendable booster systems.

5. CONCLUSIONS

The ARGUS-SPAS-system dedicated for a direct Shuttle launch appears to be a low-cost, but high performance space platform, able to carry large and heavy payload instruments with a high power demand. The SPAS concept applicated for Earth observation missions seems to be best suited, in particular due to its considerable growth potential.

Acknowledgement

The author thanks his colleagues for their fruitful discussions and contributions to this subject, in particular H. Laube (SPAS structure development) and B. Kunkel (MOMS and IMR development).

THE SIRIO SHF EXPERIMENT AND ITS FIRST RESULTS

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ABSTRACT

SIRIO is an italian geostationary satellite, launched on August 26, 1977 and positioned at 15°W, to carry out propagation and communication experiments (SHF-experiment) at 12 and 18 GHz. These frequencies are used in the down-link and in the up-link, respectively. The SIRIO programme has been developed under the responsibility of the National Research Council (CNR), in the framework of the italian national space activities, according to a proposal made since 1967. Two stations (17 m antenna) have been provided by Telespazio and are located at Fucino and Lario A third small only-receiving station (4 m antenna), is located at Spino d'Adda, near Milan. The possibility of providing a fourth only-transmitting station to be used for diversity experiments is still under study. Other stations have been set up by the following Institutions to participate to the experiments: Appleton Laboratory (UK); German Post Office; COMSAT (USA); Technical University Eindhoven (The Netherlands); IBA(UK); CNET(France); Netherland Post Office Technical University of Helsinki (Finland); IRT-Munchen(D). Up to now about 93% of the time has been devoted to propagation experiments, whilst the remaining 7% has been devoted to communication experiments. In the paper, the principal characteristic of the satellite and of the earth stations, and the configuration of the experiments will be given. In the propagation experiments the following measurements are performed on the effects of precipitations: absolute attenuations at 12 and 18 GHz; differential attenuation at 12 and 18 GHz over a frequency interval of about 700 and 500 MHz, respectively; phase distortion at 12 GHz over an interval of 500 MHz; cross-polarization coupling and atmospheric noise at 12 GHz. The first obtained results will be also given. Concerning communication experiments, these include FM television transmission with threshold-extension demodulation and, later on, digital television transmission with redundancy reduction.

1. FOREWORD

The SIRIO programme originates from a proposal, made in 1967 /1/ and accepted in 1968, for a propagation and communication experiment at 12-18 GHz (SHF experiment) to be carried out using the european ELDO-PAS satellite, which was being built in Italy in the framework of the ELDO activities.

At the end of 1968 the ELDO-PAS programme was cancelled for financial reasons and in 1969 Italy decided to proceed with the development of the satellite of the 12-18 GHz experiment in the framework of the national space activities: the programme was named SIRIO /2/ /3/. Its aims were to develop in Italy industrial capabilities in space technology up to the level of managing the development and the operation of a complete system, with reference to a satellite communication system capable of producing experimental results of wide interest for future applications.

The satellite was originally foreseen to be launched in 1971, but delays in the programme development occured, due to legislative, financial and organizational problems.

A final and operative decision was taken in 1974 /4/ /5/ and the launch of the satellite was successfully performed on August 25, 1977. It makes now available experiments to be carried out continuously for the two-years nominal life of the satellite.

The programme is sponsored by the Ministero per il Coordinamento della Ricerca Scientifica e Tecnologica and the responsibility of its development has been assigned, as for all national space activities, to Consiglio Nazionale delle Ricerche (CNR). Within CNR (fig. 1), the management and control of the various contracts and of the satellite in orbit has been - or is being- carried out by the Servizio Attività Spaziali (SAS), whilst the scientific direction is under the Centro di Studio per le Telecomunicazioni Spaziali (CSTS) at the Politecnico di Milano. In

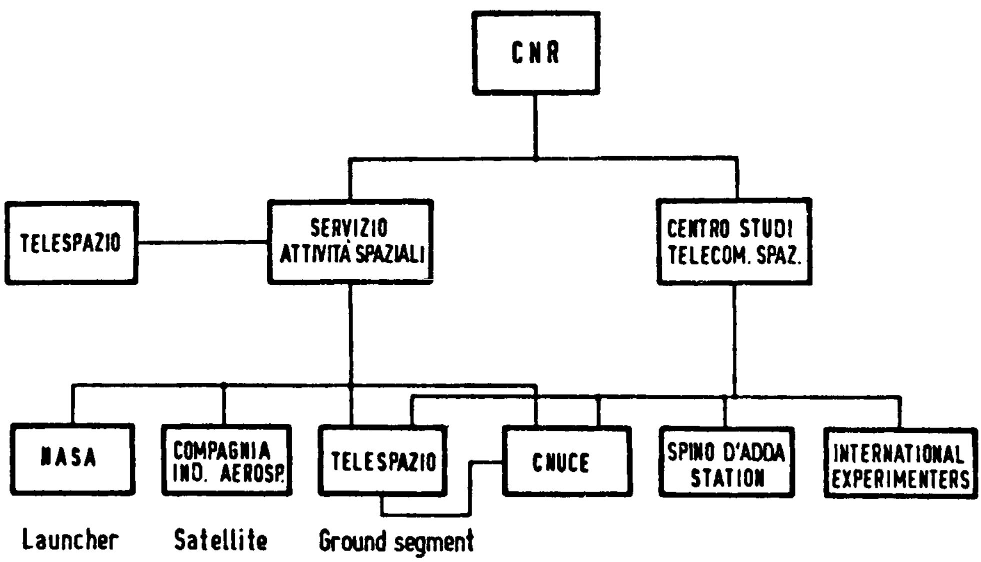

Fig. 1

such a position, the latter performs directly the scientific data reduction /6/ /7/, operates the Spino d'Adda Station (see paragraph 4 and /8/) and provides the coordination of the external participation to the experiments.

The satellite has been built by Compagnia Industriale Aerospaziale with the cooperation of several italian space industries /9/ /10/ /11/. The earth stations have been set up and made available for the experiment by Telespazio /12/, including the equipment for controlling the satellite in orbit /13/. Only the small station at Spino d'Adda /8/ is directly set up by the CSTS. All the above stations have been built by STS /15/, apart the control station. Telespazio performed also detailed system studies and parameters design concerning the SHF experiment and gave technical and administrative assistance to the managerial staff at SAS for the definition of the technical requirements and for the control of the industrial activities concerning the satellite. The computing center of CNR (CNUCE) in Pisa supported the activities of SAS and Telespazio concerning orbital parameters determination and control /14/. The Ministero delle Poste e delle Telecomunicazioni supported the programme since the beginning, did some supervisory work (also in respect to Telespazio which is its concessionary agency for space communications) and participates with CNR in the definition of applicative experiments of communications.

Fig. 2 shows the satellite, which is spin-stabilized and has a despun antenna pointing to the Earth for the experiment. The characteristics of the antenna are shown in Fig. 3. The satellite cilinder has a diameter of $\sim$1,5 m and a height of

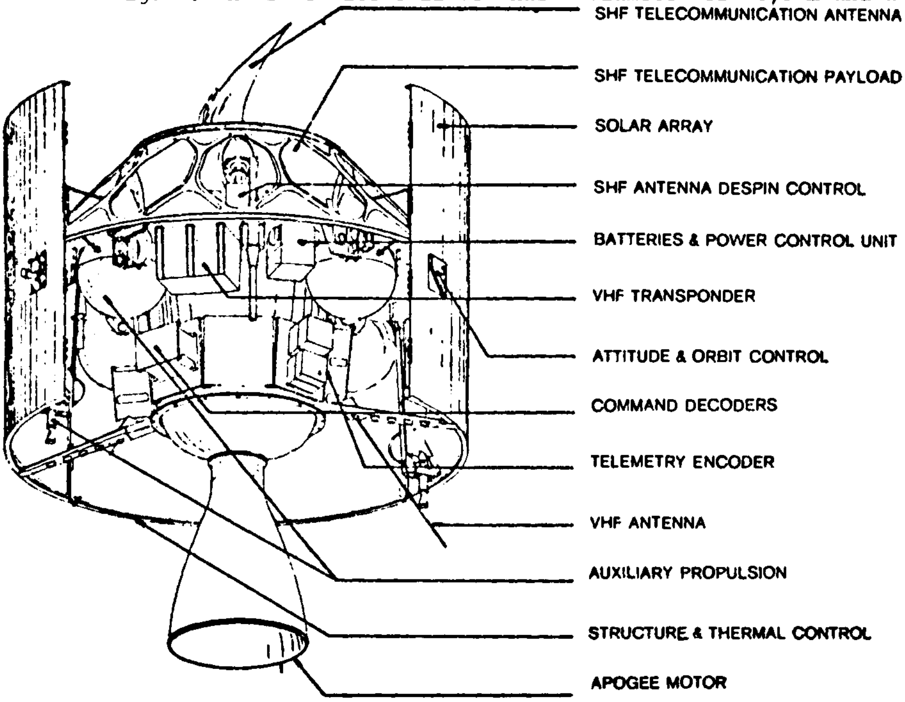

Fig. 2

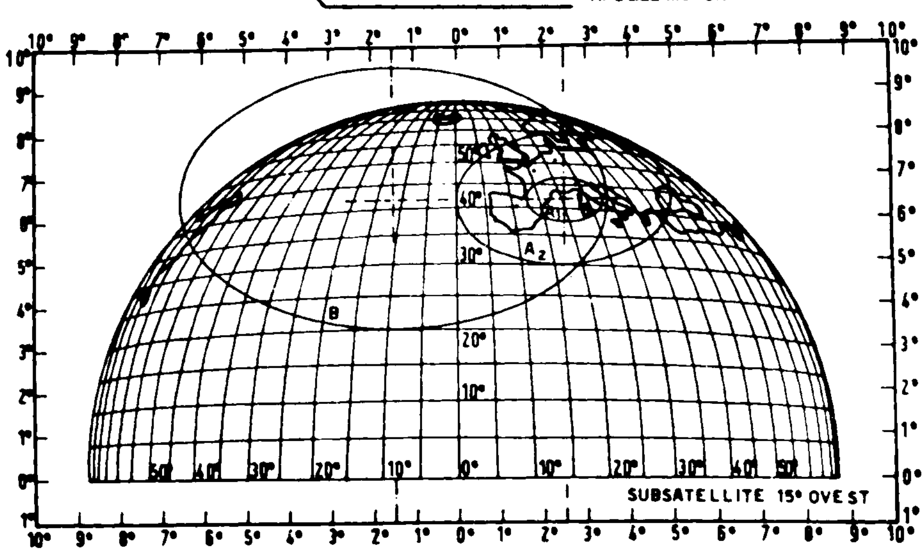

Fig. 3

$\sim$ 1 m. The overall height, including the antenna and the apogee motor is about 2 m. The mass in orbit is about 200 kg, of which about 30 are for the experiment. The electric power generated by the solar cells $\sim$ 150W at the beginning of life and will decrease to $\sim$ 120W after two years; the power absorbed by the experiment is $\sim$ 70W. The radiated microwave power is 10W maximum.

The satellite reached its geostationary position at 15°W on September 7; it was then oriented with the axis parallel to the Earth's axis; the antenna was despun and the transponder was switched on and tested with its redundancies. After September 10, system tests for propagation and communicationexperiments were performed and the experiments gradually initiated allotting an average of 6 ÷ 10% of the total time to communication experiments and the rest to propagation experiments.

A special issue of Alta Frequenza (April 1978) reported all the activities carried out for the development and construction of the satellite and of the earth equipment. Reference to this publication is largely made in the following.

2. Performances and Control of the Spacecraft in Orbit.

The performances of the spacecraft have been completely satisfactory, since the firing of the apogee motor; we must notice that on one hand the NASA launcher put the satellite in a nearly nominal transfer orbit; on the other hand the apogee motor behaved also very near to nominal so that the hydrazine consumtion for putting the satellite on station was very low, as evidenced later in figure 4.

A VHF antenna and equipment provide from Fucino for telemetry and control. In figure 4, data concerning the control of the satellite position are reported, namely the longitude of the satellite and the orbit inclination from the beginning of the life in orbit. Concerning for example the longitude, the natural forces applied to the satellite in its geostationary position tend to move the satellite westward; each time the satellite exceeds a given westward shift from the nominal position,

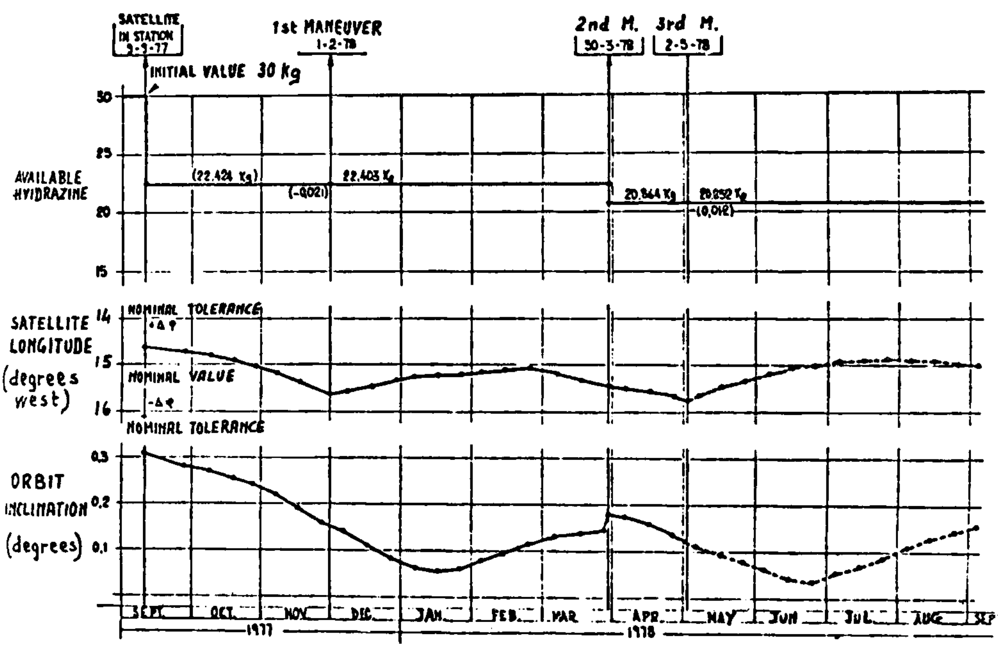

Fig. 4

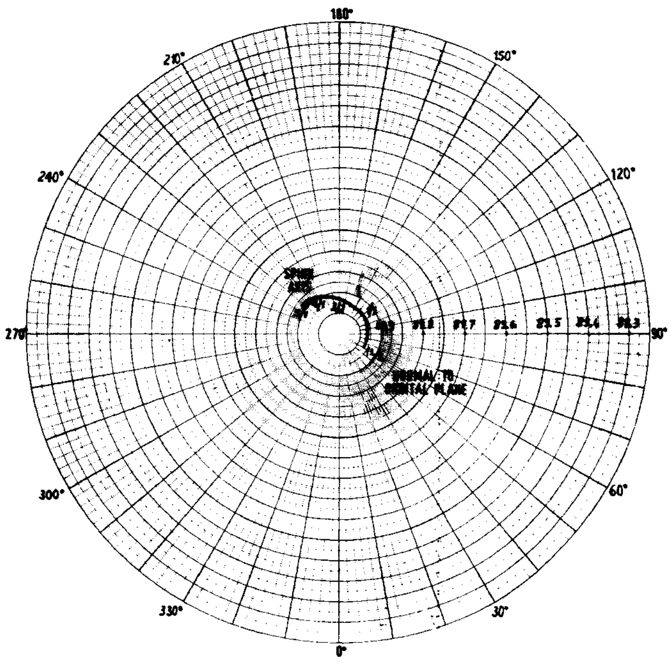

Fig. 5

an opposite radial velocity is impressed to it on command by the auxiliary propulsion. In the same fig. 4 the hydrazine consumption due to the operation of the auxiliary propulsion is given: it is easily seen that, after the initial positioning on station, this consumption has been very low so that the available hydrazine does not appear a limiting factor for the two-years nominal life of the satellite.

Figure 5 reports the attitude data, i.e. the inclination of the satellite axis in respect to the nominal position, parallel to the earth axis.

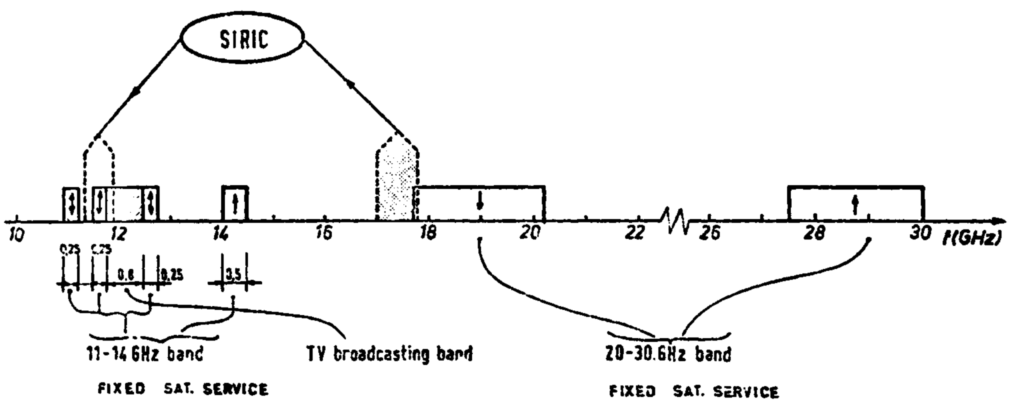

Fig. 6

3. Characteristics of the SHF Experiment

It is well known that frequencies below 10 GHz, although very suited for earth-to space communications due to their propagation almost as in free space, are not able to face the increasing traffic to be carried via satellite. It is thus necessary to shift to higher frequencies. As well known, frequencies above 10 GHz are affected, in their propagation through the atmosphere, by precipitations, mainly rain. The SIRIO SHF expriment was proposed just to investigate these precipitation effects.

Although the proposal of the experiment was made well in advance in respect to the world Administrative Conference for Space Communication (Geneva 1971) which produced the frequency assignments to satellite communications in the spectrum above 10 GHz, it is of interest to compare "a posteriori" the latter assignments with the frequency bands experimented by SIRIO (fig. 6). It is easily seen that the frequency band experimented on the SIRIO down-link (centered at 11.6 GHz) concerns the 12 GHz band for direct television broadcasting and the descending portion of the 11-14 GHz band for point-to-point communications; on the other hand, the frequency band experimented on the up-link (17 ÷ 18 GHz) is at the limit of the descending portion of the 20-30 GHz band for high-traffic systems of the future /20/.

Having included in the programme both propagation and communication experiments, an on-board transponder was needed; however, to avoid complications, a configuration of the propagation experiment was adopted able to allow all measurements be performed at earth.

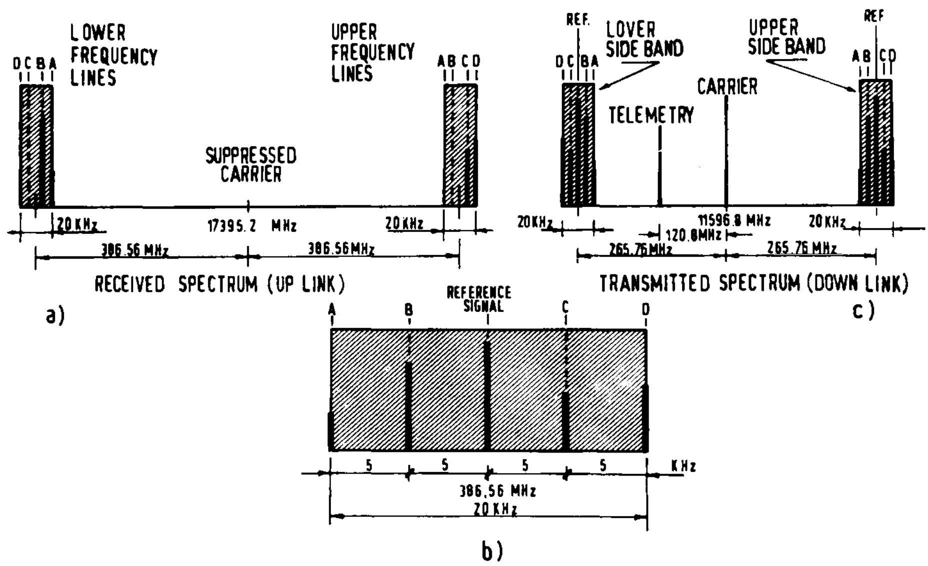

Fig. 7

Figure 7 shows the spectra at the satellite in the propagation experiment. Up to four frequencies can be received from the Earth (fig. 7a) arranged in two pairs of sidelines with respect o a (suppressed) carrier at 17.4 GHz: these sidelines are precisely located 386.660 and 386.665 MHz apart from the carrier. The satellite transponder converts the frequency of the above signal, using a local oscillator whose frequency differs by only 5 kHz from the virtual carrier, so that an intermediate-frequency signal is obtained having the spectrum of fig. 7b. The latter is composed by the four lines corresponding to the ones received from Earth, to which a fifth line, generated on board and amplitude-calibrated, is added, to be used as reference for the maplitude measurements of the other four oscillations. In this spectrum the distance between the lines is only 5 kHz so that the signal is confined in a bandwidth of only 20 kHz and can be properly filtered. This filtering is very important in order to allow the measurements over a high attenuation range, still assuring that the signal retransmitted to Earth is essentially composed by the useful signal with only a limited amount of noise. After filtering and frequency conversions, the spectrum of fig. 7 is centered at a final intermediate frequency of 265 MHz and thereafter amplitude modulates a carrier at 11.6 GHz: the output spectrum of fig. 7c is thus obtained. This time, in addition to the sidebands, the carrier is transmitted with a calibrated amplitude. From the above description clearly appears that a high precision is needed for up-link frequencies: indeed all the system has been conceived with the assumption that all the frequencies be coherent and derived from the master oscillator on the satellite, i.e., at earth, from the received carrier /12/.

The system configurated as above allows the following measurements:

a) On the down path (only-receiving equipment, 11-12 GHz):
   - a.1) absolute attenuation, measuring the level of the received carrier;
   - a.2) differential attenuation on a frequency interval of 530 MHz, measuring the relative level of the reference signal in the two sidebands;
   - a.3) phase distorsion on a frequency interval of 530 MHz, comparing the phases of the sidebands with the phase of the carrier;
   - a.4) space diversity efficiency, receiving the carrier with more than one installation at Earth in a certain location;
   - a.5) cross-polar discrimination, receiving the carrier with two equipment in the same location one with the correct polarization and one with the orthogonal polarization.

b) On the up path (adding to the receiving equipment a transmitting equipment at 17-18 GHz):
   - b.1) Absolute attenuation, comparing in a side-band of the received signal the level of the transmitted line with the level of the reference line. Actually, the power transmitted of each station is automatically controlled in order to mantain the received level of its own line at a value comparable with the level of the reference line, thus allowing path attenuation measurements to be mainly performed through the continuous transmitted-power monitoring readings (at least for what concerns the slow variations).
   - b.2) Differential attenuation, on a frequency interval of 770 MHz, transmitting two sidelines from the same station and comparing their received level;
   - b.3) Space diversity efficiency, transmitting two different lines by two transmitters at a suitable distance in the same location.

An analysis of the accuracy obtainable in the above measurements is given in /12/.

Concerning the communication experiments, the spectra of figure 8 show that the frequency allocation of the communication band is different with respect to the propagation bands, to allow different filtering and amplification; in particular at the transmission from the satellite, one of the sidebands of the communication signal is eliminated by a rejection filter.

The maximum transponder bandwidth for the communication experiments has been fixed at 32 MHz (bandwidth at -1 dB) in order to allow the transmission of television signals by wideband frequency-modulation. A narrower transmission bandwidth has been also provided for communication experiments, in order to allow experiments with low-level signals, making thus possible the use of small earth terminals and/ or acceptable high rain attenuations: this bandwidth has been fixed at 1.5 MHz (bandwidth at -1 dB).

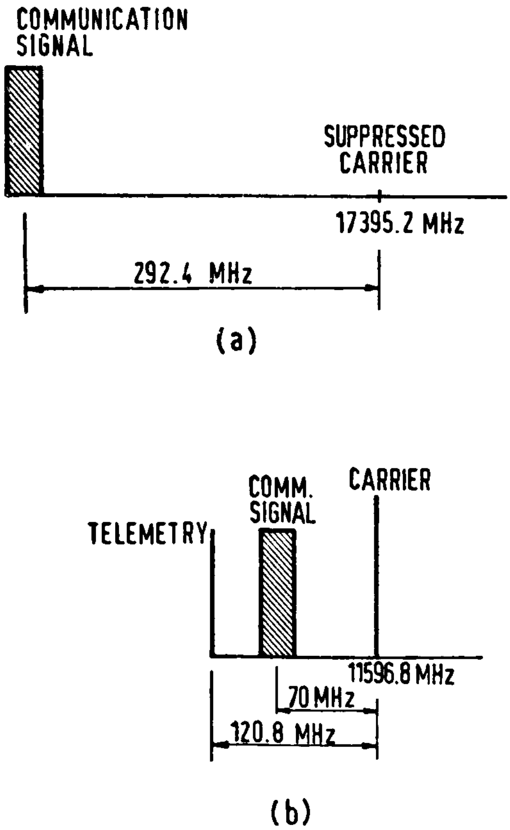

Fig. 8

In conclusion the transponder has been provided with three modes of operation, switchable on command by earth; a) propagation mode; b) narrowband communication mode; c) broadband communication mode.

4. Implementation of the SHF Experiment in Italy.

Two large Earth stations have been provided in Italy in the framework of the SIRIO programme: these two stations are located in Fucino (center Italy) and in Lario (northern Italy) and have been designed to perform the propagation and the communication experiments. These stations /15/ are equipped with a 17 m antenna and an uncooled parametric amplifier from which a G/T of 40.5 dB/K is obtained in clear sky conditions. In transmission, klystrons are used with a saturated power output of 1.5 kW, so that the EIRP is 96 dBW. With such characteristics, the stations are able to satisfy the television transmission requirements, including suitable margins for rain attenuation (see paragraph 5 and /12/). In the propagation experiments, as discussed in /12/, they allow to measure, according to the specifications, attenuations as large as 20 dB at 11-12 GHz and 35 dB at 17-18 GHz, having a fluctuations spectrum up to 1000 Hz. All the propagation measurements listed as a.1), a.2), a.3), a.5), b.1), b.2) in the previous paragraph are performed by these stations using a specific, carefully designed, measuring equipment /17/, the outputs of which are recorded on magnetic tapes to be regularly sent to CSTS for data reduction and interpretation /7/. Due to later definition, measurement a.5) is sistematically available starting from August 1st. In fact this measurement was not included originally in the experiment and it was added only after appropriate improvements of the satellite antenna, performed in March 1976.

Also the noise temperature of the antenna is continuously recorded; this allows to check the correspondence between radiometric data on the noise contribution of the transmission medium and its attenuation.

In addition to the above station, a small receiving-only station with a 4 m antenna has been installed at the end of July in the experimental field of CSTS at Spino d'Adda, near Milano, and will be directly operated by CSTS performing attenuation measurements, noise measurements and cross-polar discrimination measurements at the center frequency of the down-link.

All mentioned stations have associated rain gauges, allowing to record the rainfall rate at points near the station.

At Spino d'Adda full information on the space rainfall distribution in the surrounding area and in particular along the SIRIO path is acquired by a S band meteorological radar.

Concerning communication experiments, they can be performed between Fucino and Lario stations. For the narrowband experiment a modem for 64 kbit/s has been provided which will be used for facsimile and data transmission; experiments with smaller terminals are possible but they have not been included in the programme, at least for the time being.

Concerning broadband operation, a wideband FM television experiment is being performed using a phase-lock demodulator /16/ and a suppressor of the threshold spikes /21/. The two devices together are able to produce a threshold improvement as high as 3 $\div$ 4 dB with a peak-to-peak frequency deviation of 18 MHz. Broadband digital transmission at 8.5, 17 and 34 Mb/s is also being tested in view of application to television transmission. In fact CSTS, in cooperation with the Centro di Studio per la Televisione of CNR has developed a redundancy reduction system capable of transmitting standard monochrome television signals with a bit rate down to 8 Mb/s and with teleconference quality /18/. At present, however, it is not sure that the production of a suitable transmission equipment according to the mentioned laboratory prototype will be made in time to be included in the SIRIO programme.

5. International Participation to the SIRIO Experiment

The following foreign Institutions participate to the SIRIO propagation experiments:

- Appleton Laboratory (U.K.): 2 receiving stations (3 and 1 m antenna diameter).
- Independent Broadcasting Authority (U.K.): 1 receiving station (3 m antenna diameter).
- Netherlands Post Office: 1 receiving station, with transmission capability used up-to-now for a limited period of time, (10 m antenna diameter).
- Technical University of Eindhoven: 1 receiving station (1 m antenna diameter).
- Technical University of Helsinki: 1 receiving station (13.7 m antenna diameter).
- FTZ (German Post Office): 1 receiving station (8.5 m antenna diameter).
- Institut für Rundfunk technik (Münich): 1 receiving station (1.2 m antenna diameter).
- CNET (French Post Office): 1 receiving station (9 m antenna diameter).
- Comsat Laboratories (USA): 1 receiving station (2.4 m antenna diameter).

6. Propagation results

Propagation data have been collected at the Fucino station (center Italy) since September 1977 and at the Lario station (northern Italy) since December 1977. However, the winter semester (October-March) has been characterized (as it is

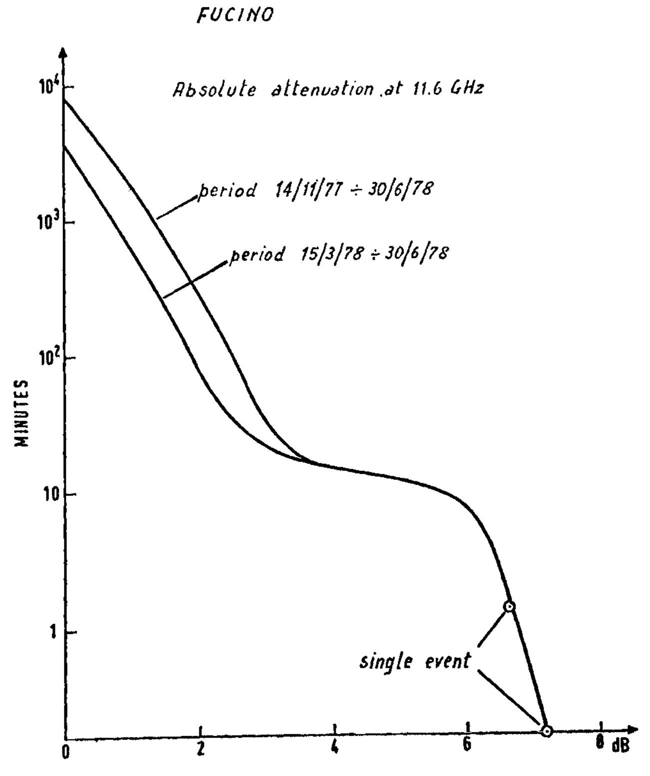

Fig. 9

ñormal) by a substantial lack of intense rain events: in fact from October till March 15 the measured attenuation at 11.6 GHz was restricted to a range of about 3 dB.

A completely different situation took place afterwards, and rain events of high intensity were observed at the two stations during the part of the summer semester already elapsed.

The consequences of this seasonal behaviour are clearly shown in figures 9 and 10, where statistical results, to which we will come back later, are reported. It is easily seen that the interesting tail of the attenuation distribution curves is unaffected by data prior to March 15.

In the following, results concerning the period March 15-June 30, 1978 will be reported, with statistics referred to the same period of time.

The analysis of the data is regularly carried out offline on the digital magnetic tapes provided by the stations; the analysis is done on the basis of single rain events, and on the basis of full periods of time.

Figure 11 reports an example of an event (Fucino, May 27, 1978); the figure is taken from the paper recording which run as backup and quick control in parallel to the digital magnetic recordings.

The recording pens have relative shifts along the time scale which require a correction of the time allocation of the various graphs, as indicated quantitatively, by an arrow on each graph.

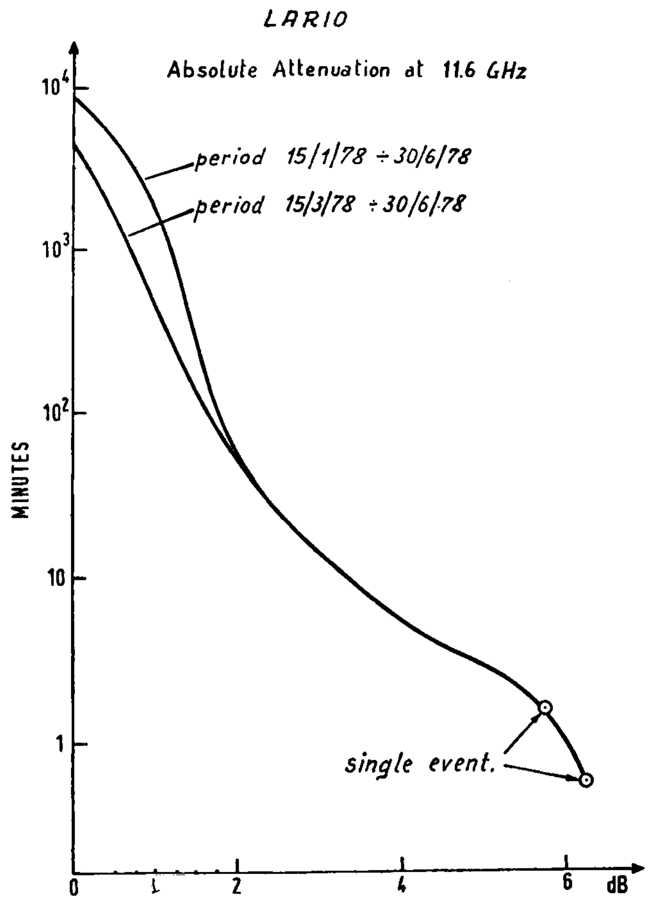

Fig. 10

The traces, originally in colour not reproduced in the figure, correspond to:
AA12 = attenuation at 11.6 GHz;
DFTOT = total measured phase distortion;
ϕSTAZ = phase distortion of the earth equipment;
DFM = D.F. TOT - ϕSTAZ = phase distortion of the propagation medium;
AD12 = differential attenuation between two frequencies at ± 250 MHz in respect to 11.6 GHz;
PTX 17.8 = transmitted power at 17.8 GHz practically coincident with the uplink attenuation (non-linear scale).

On a different paper tape the antenna noise temperature is simultaneously recorded with other data. In figure 11 we can notice that the attenuation at 11.6 reaches 6.9 dB, a so large value that a differential attenuation of .8 dB is noticed over the frequency interval of 500 MHz spanned by the differential attenuation measurements at 11.6 GHz. The corresponding attenuation at 17.8 GHz (as obtained with precision from the digital recordings) is 17.2 dB.

Figure 12 reports the rainfall rate measured by one of the seven raingauges operating under the path toward the satellite at distances ranging from zero to 3 km from the station. Precisely the raingauge considered in figure 12 is the one located at the station. For simplicity the rainrate has been calculated as an average in

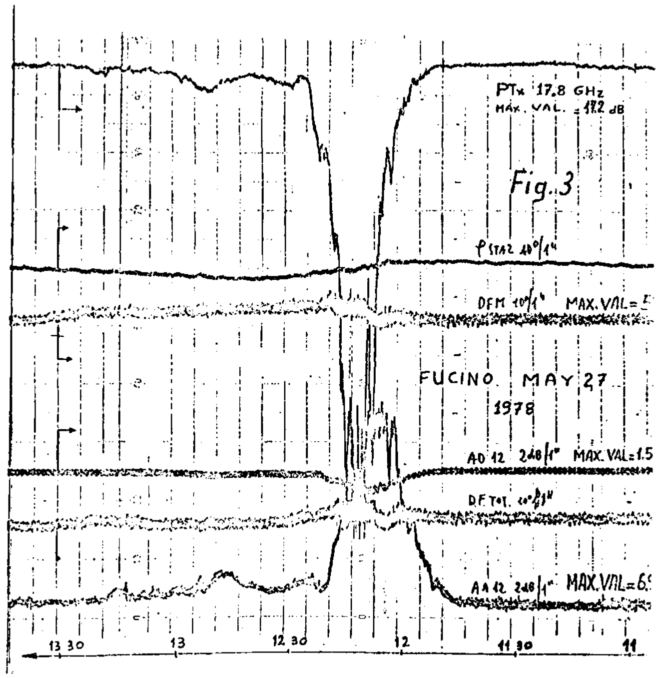
PTx 17.8 GHz
Fig. 3
FUCINO MAY 27 1978
13 30
13
12 30
12
11 30
11

Fig. 11

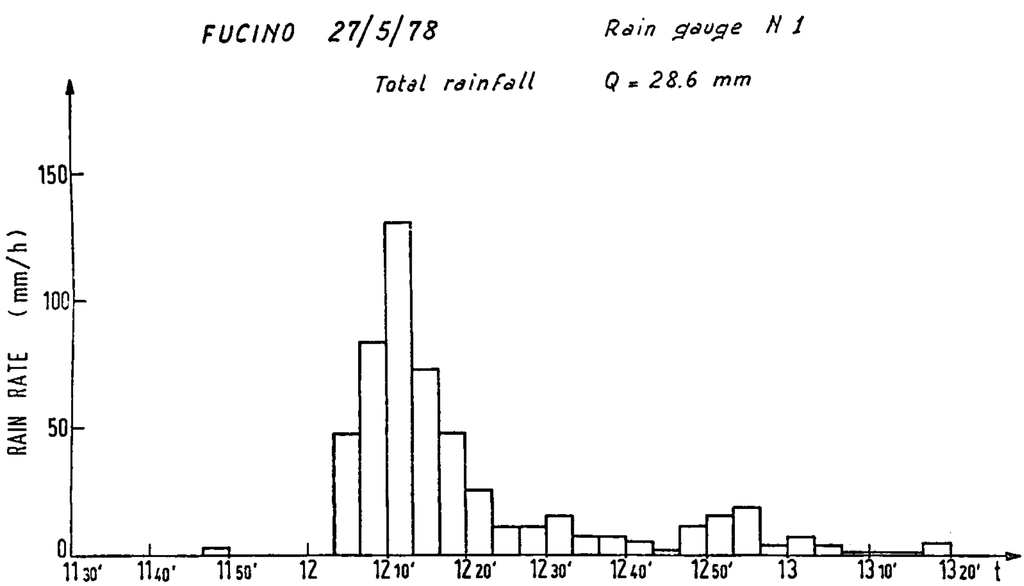
FUCINO 27/5/78
Rain gauge N 1
Total rainfall
Q = 28.6 mm
RAIN RATE (mm/h)
150
100
50
0
11 30'
11 40'
11 50'
12
12 10'
12 20'
12 30'
12 40'
12 50'
13
13 10'
13 20'
t

Fig. 12

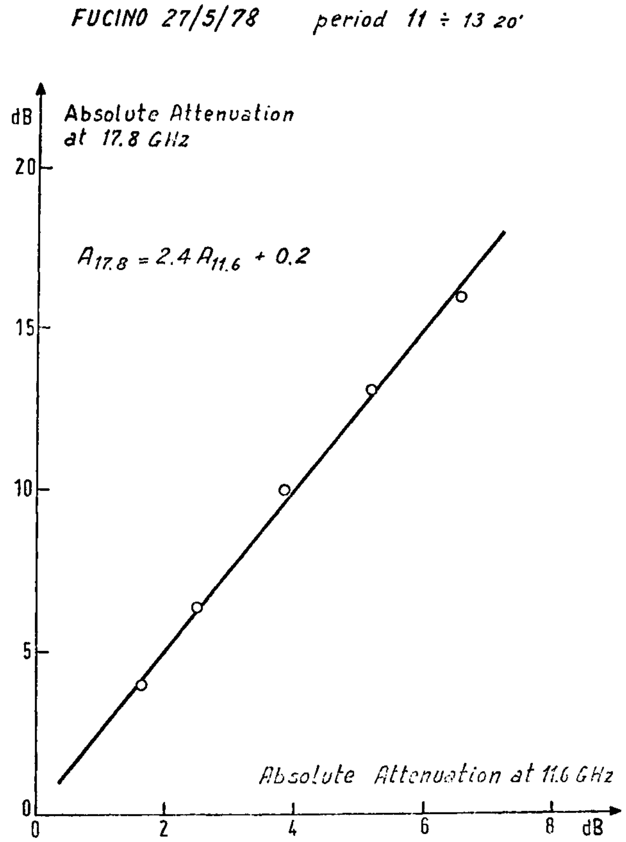

Fig. 13

3 minutes; in spite of this averaging the rainrate reaches 130mm/h, at the same time of the maximum recorded attenuation.

For an event like the one considered in figure 11 the distribution of: the attenuation at 17.8 GHz; the attenuation at 11.6 GHz; the antenna noise temperature at 11.6 GHz, can be calculated. From these distributions, relationships between quantities having the same "probability" levels have been drawn. Figure 13 reports the relationship obtained in this way between the attenuation at 17.8 and the attenuation at 11.6 GHz, together with the appropriate regression line and its equation. For this event, the relationship appears well represented by a proportionality, through a coefficient 2.4.

Another interesting relationship concerns the attenuation measured at 11.6 GHz and the corresponding attenuation calculated from the antenna noise temperature measurements. The study of this relationship requires a little discussion. It is well known that in case of a pure absorber (no scattering phenomena) the following equation holds:

1) $T_{ant} = T_{abs}(1-k\alpha) + T_{cl.sky}k\alpha + T_{ground} = (T_{cl.sky}-T_{abs})k\alpha + (T_{abs}+T_{ground})$.

where
T_{ant} = antenna noise temperature;

T_{abs} = absorber effective temperature,

$\alpha = 10^{-\frac{Atten}{10}}$ = reciprocal of the measured power loss ratio,

$T_{cl.sky}$ = clear sky effective noise temperature,

k = system calibration factor, so that $k\alpha$ is the reciprocal of the actual power loss ratio,

T_{ground} = ground "effective temperature". Which includes also a calibration factor.

Taking attenuation (Atten) data and antenna noise temperature (T_{ant}) data, the system parameters $T_{cl.sky}$, K, T_{ground} have been determined to satisfy at the best equation (1) in the assumption T_{abs}=290°K. (o)

The procedure for such a determination has been the following: -the regression line between the α, T_{ant} points having the same "probability" level is first determined; - the slope of this line gives

2) slope = $(T_{cl.sky} - T_{abs})k$,

the intercept with = 0 gives

3) intercept = $T_{abs} + T_{ground}$

- using a number of "clear sky" observations just before and after the event the following independent condition is obtained (for $k\ \alpha$=1).

4) T_{ant}(in clear sky) = $T_{cl.sky} + T_{ground}$

FUCINO 27/5/78 period 11÷13 20'

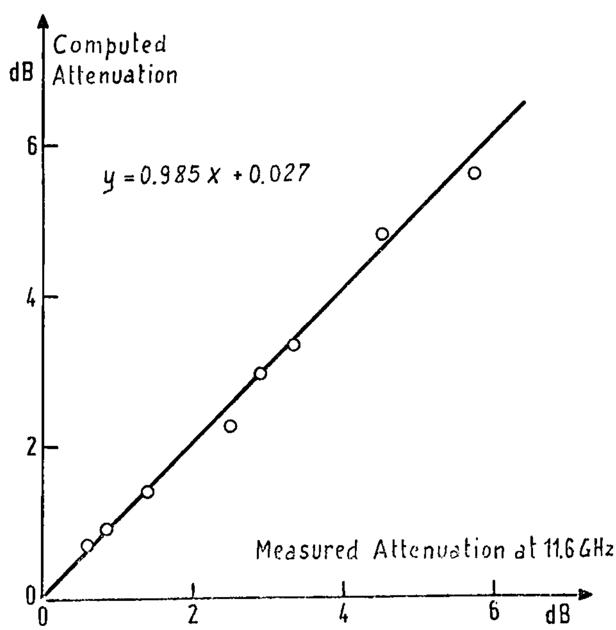

Fig. 14

(o) The correspondence between these values determined for a best fit and the physical parameters of the system is a matter for futher investigation.

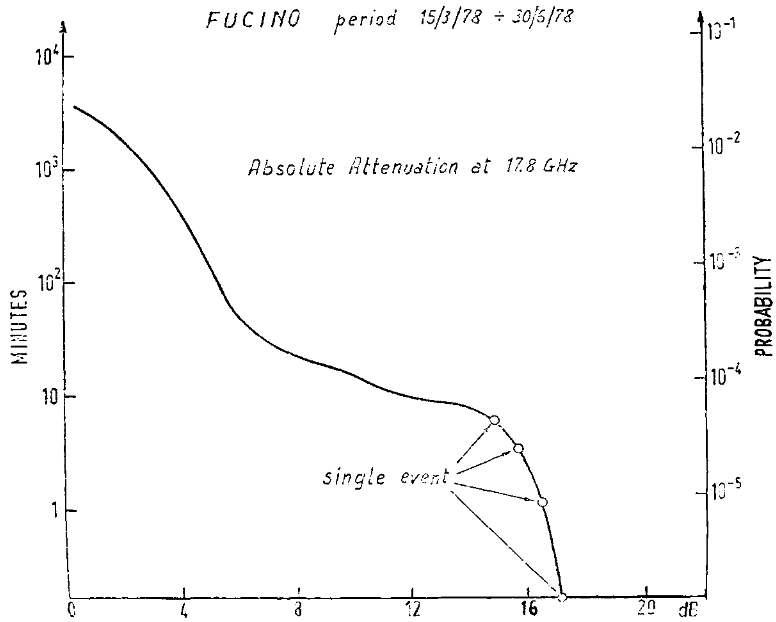

Fig. 15

Using equations (2), (3), (4) the mentioned system parameters are derived. For the event previously considered the following values result:

K = 0.4 dB ; $T_{cl.sky} + T_{ground} = 60^{O}K$;

$T_{abs} + T_{ground} = 324^{O}K$ which for example correspond to

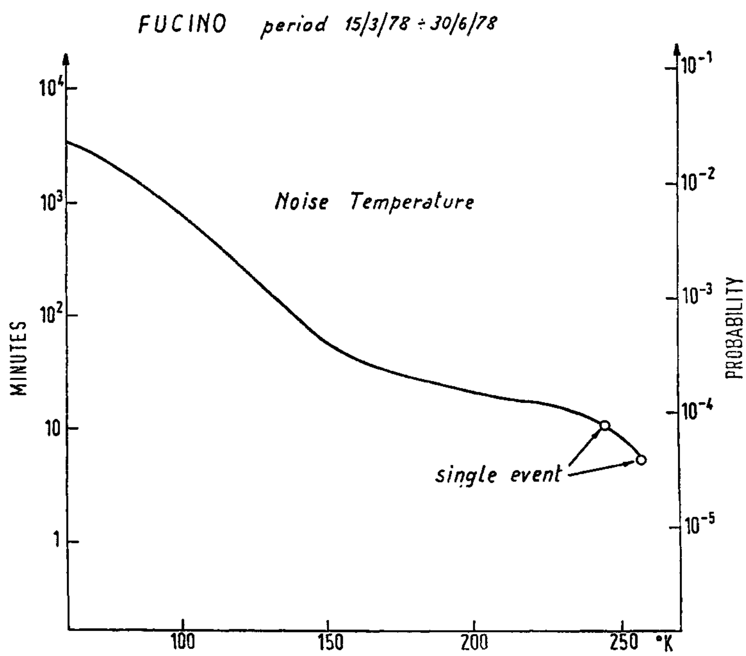

Fig. 16

$$T_{abs} = 290^{o}K$$

5) $T_{cl.sky} = 26^{o}K$

$$T_{ground} = 34^{o}K$$

Using these values, the attenuation, calculated through (1) from the T_{ant} measurements, is reported in figure 14 as a function of the measured attenuation having the same probability level. The agreement between the two values of attenuation is very good in the full range.

Using the same parameters, the computation has been performed also for the instantaneous values, obtaining a very good agreement between measured and calculated attenuation.

Figures 15, 9 and 16 give the cumulative distributions obtained at Fucino for: attenuation at 17.8 GHz; attenuation at 11.6 GHz; antenna noise temperature. From these graphs, relationships between data at the same probability level have been again derived. Figure 17 shows the relationship between the two attenuations: the proportionality coefficient is 2.2. Figure 18 shows the relationship between the measured attenuation and the attenuation calculated from the antenna noise data: in this case the proper parameter values resulted to be:

$K = 0.8$ dB; $T_{cl.sky} + T_{ground} = 60^{o}K$;

$T_{abs} + T_{ground} = 332^{o}K$ which for example correspond to

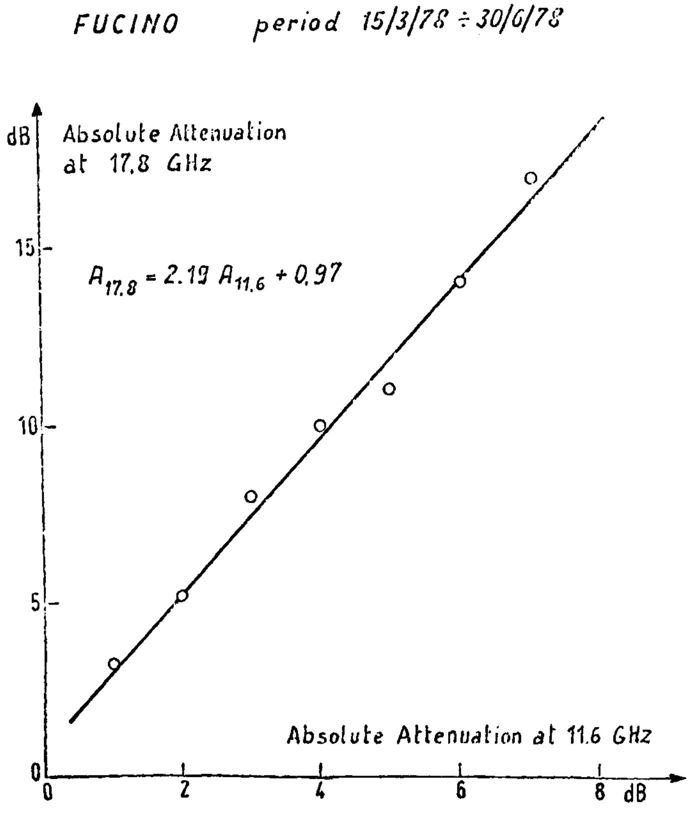

Fig. 17

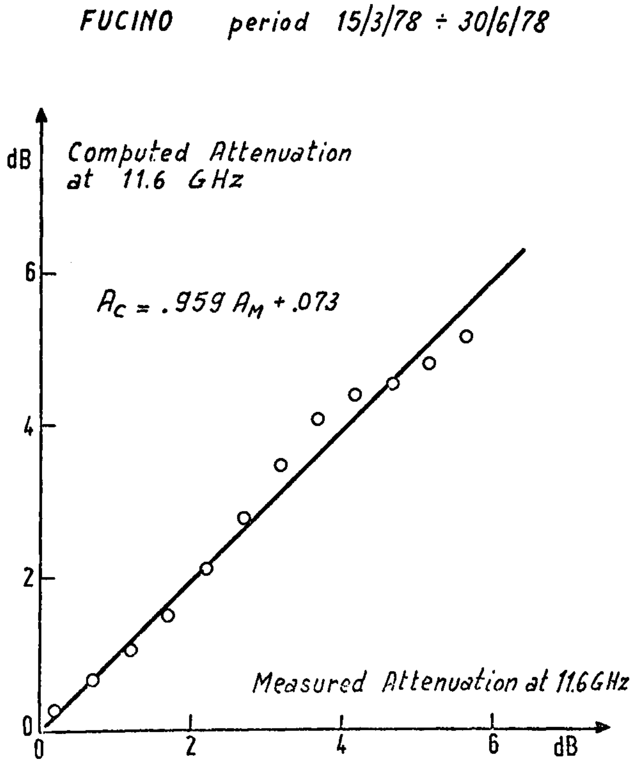
FUCINO period 15/3/78 ÷ 30/6/78
dB
Computed Attenuation at 11.6 GHz
$A_C = .959\ A_M + .073$
Measured Attenuation at 11.6 GHz
0
2
4
6
dB

Fig. 18

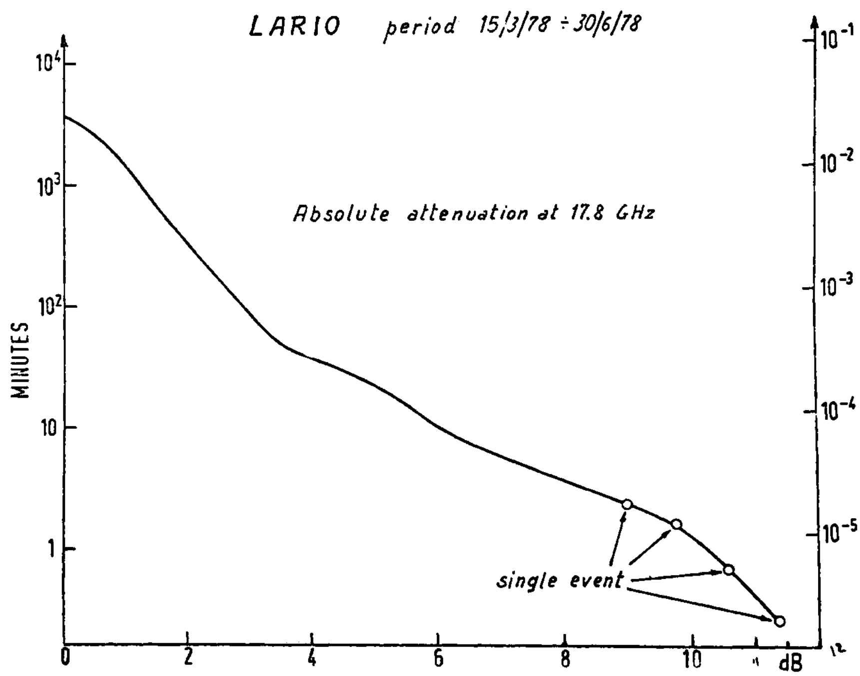
LARIO period 15/3/78 ÷ 30/6/78
Absolute attenuation at 17.8 GHz
MINUTES
PROBABILITY
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
single event
0
2
4
6
8
10
dB

Fig. 19

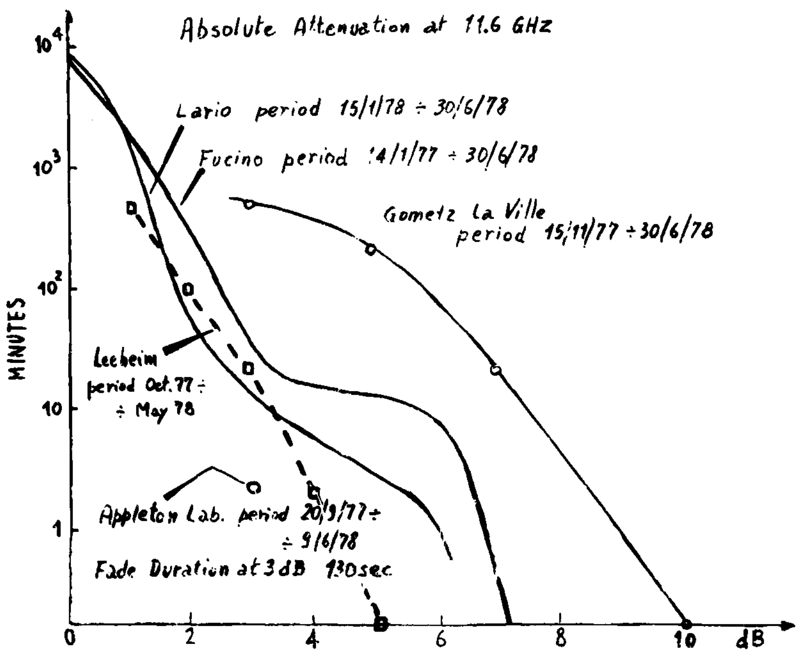

Fig. 20

6) $T_{abs} = 290^{\circ}K$
$T_{cl.sky} = 18^{\circ}K$
$T_{ground} = 42^{\circ}K$

Figure 19 and figure 10 give the cumulative distributions obtained at Lario by the attenuations at 17.8 and 11.6 GHz. Concerning the ratio between the two attenuations a value 1.7 has been obtained; concerning parameters for computing the attenuation from the antenna noise data, the following values were obtained:

$K = 0.5$ dB; $T_{cl.sky} + T_{ground} = 40^{\circ}K$;

$T_{abs} + T_{ground} = 310^{\circ}K$ which for example correspond to

7) $T_{abs} = 290^{\circ}K$
$T_{cl.sky} = 20^{\circ}K$
$T_{ground} = 20^{\circ}K$

All reported data are still very limited in amount but they are going to be completed in a couple of months for what concerns the summer semester of 1978. A complete report on the first year of the SIRIO experiment will be prepared within the end of 1978.

As a conclusion, figure 20 reports the attenuation distributions, obtained at 11.6 GHz for the full period after SIRIO launch not only at Fucino and Lario, but also at Gometz la Ville (CNET) and at Slough (Appleton Laboratory). The contributions of these data from Mr Ramat (CNET) and Mr. Mackenzie (Appleton Lab.) is gratefully acknowledged, together with the contributions from all experimenters which will produce at due time and extended ensemble of propagation results.

7. Acknowledgments

The SIRIO programme is the result of the joint effort of several italian industries and institutions. From our position of experimenters we want to express our appreciation to all who contributed in setting up such a complex system.

Concerning this paper, the contribution of M.Macchia, SIRIO Project Manager at SAS, is acknowledged together with the contributions of the Telespazio team responsible for the experiment development and operation: L. Bruno, S. Tirrò, E. Saggese, L.A. Ciavoli Cortelli, M. Fornari, G. Possenti and A. Marzoli.

For what concerns the propagation data processing and interpretation the excellent work of M. Mauri and G. Macchiarella of CSTS is gratefully acknowledged.

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CTS/HERMES — EXPERIMENTS TO EXPLORE THE APPLICATIONS OF ADVANCED 14/12 GHz COMMUNICATIONS SATELLITES

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ABSTRACT

Since January 1976, Canada and the U.S.A. have shared the use of the experimental Communications Technology Satellite (CTS), called Hermes, to explore the services that may be provided in the future using the 14/12 GHz frequency bands allocated for satellite communications. In Canada, 36 different communications experiments have been carried out during the period 1976 through 1978. These have included experiments in satellite television broadcasting, telemedicine, tele-education, community communications, administration and communications technology.

The operation of the Hermes satellite and its communications capability are described. Some of the major social experiments that have been carried out in Canada using Hermes are summarized and discussed. Conclusions reached as a result of the experimentation regarding the implementation of new services are presented.

KEYWORDS

CTS, Hermes, Satellite Communications, Communications Experiments, 14/12 GHz, Small Earth Stations, Tele-education, Telemedicine.

INTRODUCTION

The experimental Communications Technology Satellite (CTS) shown in an artist's sketch in Fig. 1 was developed under an agreement for a joint program signed on 20 April 1971 between the Canadian Department of Communications (DOC) and the United States National Aeronautics and Space Administration (NASA). Once launched, the satellite was named Hermes.

The principle objectives of the program were to:

(1) Develop and flight-test a high power travelling-wave-tube amplifier (TWTA) having greater than 50% efficiency with a saturated power output of 200 Watts at 12 GHz.

(2) Develop and flight-test a lightweight extendible solar array with an initial power output greater than 1 kW.

(3) Develop and flight-test a 3-axis stabilization system to maintain accurate antenna boresight positioning on a spacecraft with flexible appendanges.

(4) Conduct satellite communications experiments using the 12 and 14 GHz bands and low-cost transportable ground terminals.

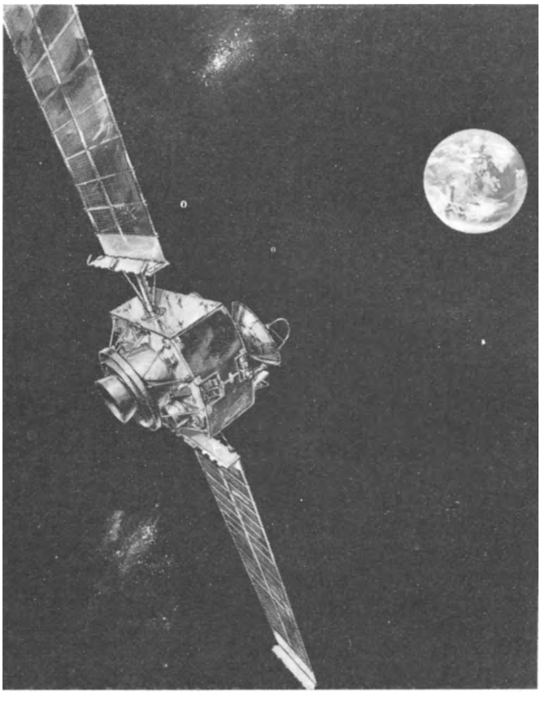

Fig. 1. Artist's sketch of Hermes.

Under the agreement, Canada undertook to design, build and operate the spacecraft, while the United States undertook to provide the launch vehicle, the high-power TWTA, spacecraft environmental test support and launch and operational support to place the spacecraft in the geostationary satellite orbit. Both countries agreed to carry out an experimental program in communications. NASA's Lewis Research Center (LeRC) and DOC's Communications Research Centre (CRC) were designated as the responsible agencies. In May 1972, an agreement was signed between Canada and the European Space Research Organization (ESRO), now the European Space Agency (ESA), under which ESRO agreed to provide 20 Watt SHF TWTA's, a SHF parametric amplifier and to develop an extendible solar blanket and associated solar cells. The satellite was designed and built in Canada.

The satellite was launched on 17 January 1976 using a Thor Delta 2914 launch vehicle, for a planned two year mission in space. Following two years of successful operation, the mission was extended for a third year of operations. A fourth year (1979) of operations is now contemplated. Hermes is the first satellite to operate in the 14/12 GHz bands. An e.i.r.p. of 59 dBw is produced, which is a significantly greater than that provided by previous communications satellites, and is representative of levels that may be used by future broadcasting satellites.

NASA provided the launch vehicle and supported the launch operations to place the satellite in the geostationary satellite orbit at 116°W longitude. Control of the satellite was turned over to CRC on 29 January 1976. Since then, the satellite has been controlled from the DOC Spacecraft Ground Control Centre (SGCC) located at CRC near Ottawa. Backup command and telemetry receiving capability for this station is provided by NASA Satellite Tracking and Data Network (STDN) stations.

In preparation for the Hermes mission, NASA and DOC invited agencies and organizations in the U.S. and Canada respectively to submit proposals for communications experiments. Use of the satellite was allocated to approved experimenters, with each country sharing the satellite on an alternate-day basis. The program in the U.S.A. has been described by Donoughe (1977). The conduct of the experiments has been considerably facilitated in Canada by our present policy of not implementing terrestrial services in the particular frequency band at 14 and 12 GHz. Therefore, as there has been no need to coordinate ground terminal locations with terrestrial services, the experimental ground terminals have been located adjacent to the users premises; in school yards, on university campuses, near or on public buildings, on the roofs of hospitals or high rise buildings and on metropolitan parking lots, thus eliminating the need for terrestrial back-haul.

HERMES SATELLITE

The satellite configuration in orbit is shown in Fig. 2. The satellite is stabilized in three axes with a momentum wheel providing gyroscopic stiffness along the pitch (N-S) axis. An on-board attitude control system maintains the orientation of the front face of the satellite towards the center of the earth to within $\pm 0.1°$ in pitch and roll and $\pm 1.1°$ in yaw. The extended arrays rotate to track the sun at all times to provide electrical power of over 1 kW to the satellite.

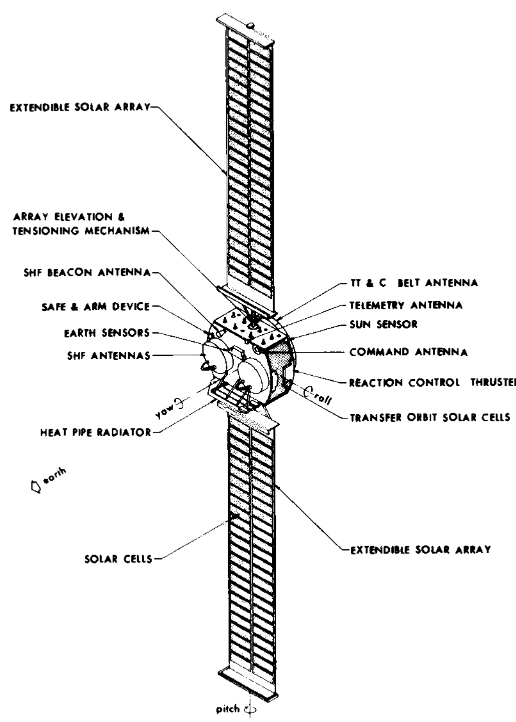

Fig. 2. Engineering sketch of Hermes.

Two SHF communications antennas are located on the front face of the satellite. These antennas, which have a beamwidth of 2.5°, can be independently steered to any point in the western hemisphere to an overall accuracy of ±0.2° (design value). The slew rate of the antennas about the N-S and E-W axes is 0.06°/second and, typically, repositioning of both antennas can be accomplished within five minutes. One antenna is connected to the experimental 200 Watt TWTA and the other to a 20 Watt TWTA. Variable conductance heat pipes and a radiator remove heat generated by the 200W Transmitter Experiment Package (TEP). The performance in space of the satellite subsystems has been described by Raine (1978).

Figure 3 shows a timeline of the major events in the mission beginning with the launch on 17 January 1976 and initiation of on orbit experiment operations in February. These major events are described in more detail elsewhere by Davies (1977). The satellite has been continuously available for experimentation since launch with minor exceptions. During the first eclipse season just after launch, an experiments bus relay malfunctioned and caused the failure of a power conditioner. To reduce the risk of failure of the redundant conditioner, all communications experiments were suspended during the spring and the following fall eclipse seasons (approximately 40 days each). By 1977, sufficient experience had been gained that experiment operations were continued successfully through subsequent eclipse seasons except for the eclipse operations of up to 1.5 hours/day.

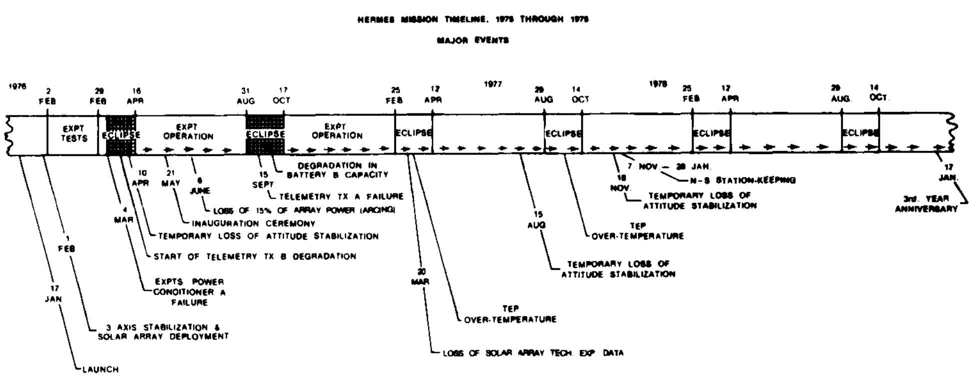

Fig. 3. Timeline showing major events, 1976 through 1978

A number of technology experiments to evaluate the effects of solar pressure and to determine structural resonance frequencies and damping factors in orbit have been conducted. The performance of the 14/12 GHz transponder and the 200W TWTA are evaluated regularly. No change in performance has been detected. Although not included in the mission as originally defined, a nominal launch and modest fuel requirement for on-orbit operations (1.4 pounds of hydrazine per year) left sufficient fuel to permit consideration of North-South station-keeping operations late in 1977. Approximately 19 pounds of hydrazine were used to reduce the orbit inclination from about 0.7° to nearly 0° in the period December 1977 through January 1978. The orbit inclination has now increased again to 0.7° and is increasing at a rate of 0.75°/year, as it will continue to do for the balance of the operational life of the satellite.

A number of malfunctions and anomalies have occurred as indicated on the timeline. Of greatest concern at this time is the continued degradation of one of the telemetry transmitters. As other priorities permit, NASA STDN stations now routinely receive telemetry and forward the demodulated data in real time to CRC. Operations are continued during periods for which telemetry data is unavailable based on previous experience and observation of the status of the SHF communications signals.

The communications subsystem, shown in Fig. 4, consists of the two SHF communications antennas, redundant low-noise receivers, frequency translation circuits, two 20 Watt TWTA's and the experimental 200 Watt TWTA. Figure 4 also shows the frequency plan for signal reception by the satellite (up-link) and transmission by the satellite (down-link).

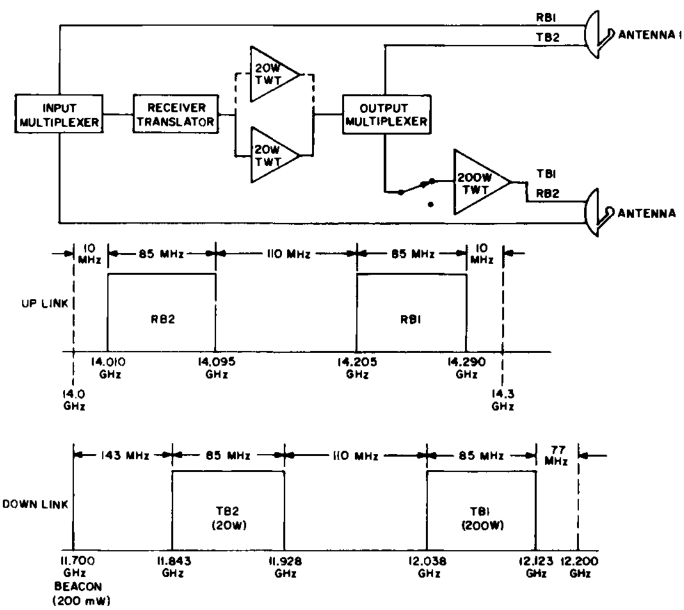

Fig. 4. Block diagram of the SHF transponder with the corresponding frequency plan.

Figure 5 illustrates the coverage provided at four arbitrary positions of either of the antenna beams. The inner contours illustrate the coverage when allowance is made for the estimated pointing errors of the satellite antennas.

EXPERIMENTAL COMMUNICATIONS SYSTEM

A typical communications operating configuration is illustrated in Fig. 6. A comparatively large earth terminal transmits TV signals to Hermes via the antenna used for the 20 Watt beam. Hermes relays these signals via the antenna used for the 200 Watt beam to small ground terminals located anywhere in a second area. Terminals in the 200 Watt beam that are equipped to transmit, can return voice or data signals to the large terminal in the first beam. Using a two-hop link, interconnected through the large terminal, small terminals can communicate by voice with each other. Alternatively, a larger terminal can be located in the second beam to permit two-way video exchanges.

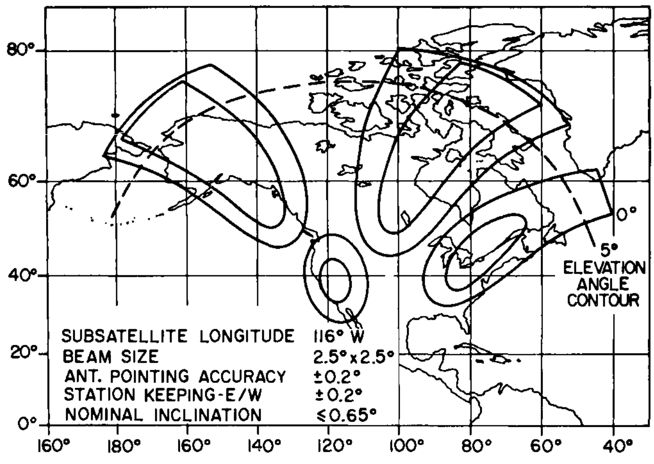

Fig. 5. Typical antenna coverage patterns (3 dB contours).

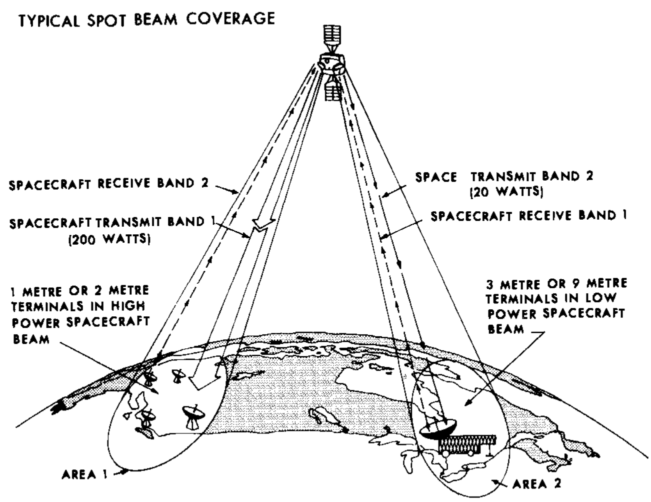

Fig. 6. Typical communications systems configurations.

The Hermes transponder and ground terminals are capable of supporting TV or radio broadcast, educational TV with a voice or data return channel, TV origination from remote locations, two-way TV for teleconferencing, telephone (two-way voice) and digital communications, including experimental time-division multiple-access (TDMA) signals.

In Canada, the required ground terminals were acquired by DOC, and are loaned to approved experimenters. There are five different types of terminals as described by Huck (1975) in a total of 24. Table 1 provides technical details of the terminals.

TABLE 1 Hermes Ground Terminals

Terminal	Qty.	Ant. Diam. (m)	G/T (dB/K)	Tx. Type & Power (Watts)	Ant. Control
9m (Ottawa)	1	9.1	33	TWT (200)	Auto-track
3m	2	3.0	23	Klystron (1250)	Step-track
2m	8	2.1	16	TWT (20)	Manual
1m	10	0.8	5	TWT (20)	Fixed
TVRO	3	0.6-1.2	6-12	N/A	Fixed

Figure 7 shows the largest terminal, with a 9m antenna, located at CRC near Ottawa. It is the only terminal that is not transportable. It is capable of transmitting TV, data and telephone voice communications. In the foreground, the smallest terminal, with a 1m antenna, can be seen. It is capable of receiving and transmitting a telephone channel.

Fig. 7. 9m and 1m Terminals.

Figure 8 shows one of the two transportable TV transmit terminals which have the same communications capability as the fixed 9m terminal. These can be moved by road, rail or barge and one can be dismantled for air transport. The terminal is equipped with a 1.2 kW klystron power amplifier for transmission and a parametric amplifier for reception. These terminals were developed for DOC by a Canadian firm, SED Systems of Saskatoon.

A 2m terminal which has a capability to receive TV and to transmit and to receive a telephone channel is shown in Fig. 9. It is equipped with a tunnel diode amplifier for reception and a 20W TWT for transmission. The terminal consists of the antenna and two outdoor electronic units plus three indoor units. Typically, it is mounted on a wooden base weighted down with concrete blocks or stones. The terminal can be erected or disassembled by two men in about 8 hours. When packaged for shipment, the terminal weighs 409 kg. Eight of these terminals were developed in Canada for DOC by SPAR Technology Ltd.

Fig. 8. 3m terminal.

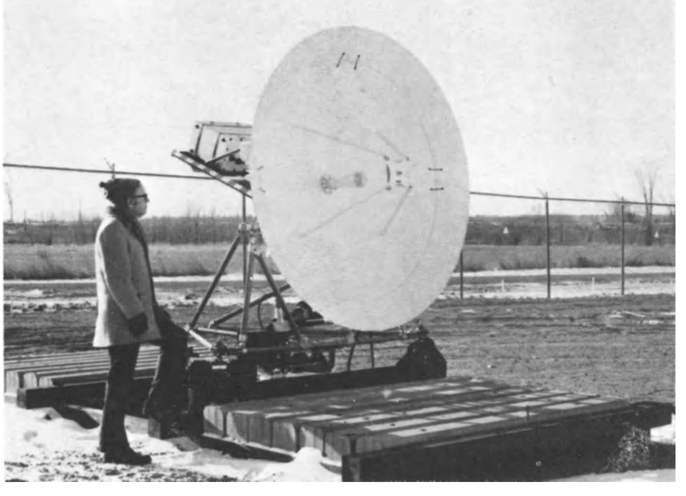

Fig. 9. 2m terminal.

A 1m telephony terminal with a capability to transmit and receive a telephone channel is shown in the foreground of Fig. 7. This terminal also is equipped with a 20W TWT for transmission and a tunnel diode amplifier for reception. The terminal consists of the antenna and two outdoor electronic units plus two indoor units. When packaged for shipment, the terminal weighs 273 kg. Ten of these terminals were developed for DOC by SPAR Technology Ltd.

All the above terminals are capable of transmitting and receiving a high quality 15 kHz sound program channel as well as the normally used 3.1 kHz telephony channels. Single-channel-per-carrier (SCPC) techniques are used for the telephony transmission in a double-hop configuration through the 9m, or one of the 3m terminals. Provision is made in the latter terminals for switching of the telephone channels. All signal transmissions are by means of analog FM, although one technical experiment investigated high-speed digital and TDMA techniques at data rates of up to 65 Mb/s.

To demonstrate the potential of a satellite such as Hermes for TV broadcasting, several TV receive-only (TVRO) terminals were developed by CRC. Figure 10 shows one of these with a 60 cm antenna which is capable of receiving a good quality TV signal when located near the center of the 200W beam. The same figure shows the outdoor electronic unit at the focus of the antenna and the indoor electronic unit on the top of the 19" TV set. This terminal utilizes an image-enhanced mixer to provide a noise figure of 6 dB. It has been demonstrated both outdoors and while receiving signals through a window when located within an office building. These terminals are sufficiently small that they may be carried as personal baggage on aircraft. They have been assembled and put into operation to receive a signal from Hermes in less than 30 minutes.

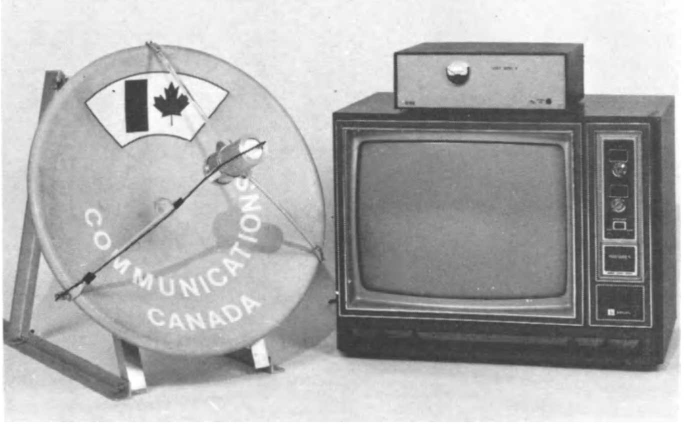

Fig. 10. Developmental TVRO terminal.

CANADIAN COMMUNICATIONS EXPERIMENT

DOC invited government and private agencies and organizations to propose communications experiments. All proposals were submitted to an independent Evaluation Committee which made recommendations to the Minister of DOC concerning their acceptability. Forty-eight proposals for experiments were approved for implementation in the period 1976 through 1978. At the end of 1978, after three years of operation, the 36 experiments as listed in Table 2, as well as many demonstrations, will have been carried out.

The experiments are approximately equally divided between those with technical objectives and those with social objectives. The objectives of the 15 technical experiments are to evaluate terminal performance (3 experiments), to test data modems (6), to test multiple access techniques (2), to make scientific observations (3) and to measure propagation factors (1). The objectives of the 21 social experiments are to test the use of satellite communications for tele-education (7), telemedicine (3), community-to-community communications (5), TV/radio broadcasting (2) and provision of administrative communications (4). These social experiments explore new applications of telecommunications for delivery of social services and have attracted wide interest.

TABLE 2 Canadian Hermes Communications Experiments

No.	Experimenter	Subject	Category	Status*
F-1-1	Communications Research Centre	Propagation	T	U
-2	Communications Research Centre	TDMA	T	C
-3	Communications Research Centre	FDMA	T	C
-4	Communications Research Centre	High Rate Data	T	C
-5	Communications Research Centre	Terminal Evaluation	T	U
3F-1-6	CRC/NASA/SOMSAT	Digital TV	T	P
F-2-1	Canadian Broadcasting Corp.	Urban Reception	T	C
-2	Canadian Broadcasting Corp.	Radio Broadcast	S	C
-3	Canadian Broadcasting Corp.	TV (Olympics) Broadcast	S	C
F-3	Public Service Commission	Tele-education	S	C
3F-4	Kash Connection	Telemedicine	S	C
3F-5-1	National Research Council	Time Transfer	T	U
-2	NRC/NASA/DOC	SRMS	S	C
P-1	Memorial University	Telemedicine	S	C
P-2-3	Quebec-University of Quebec	Tele-education	S	C
-4	-James Bay Development	Remote Camp Comm.	S	C
-5	-Hydro Quebec	Clock Synchronization	T	C
P-3	Government of Ontario	Government Admin.	S	C
3P-3	Government of Ontario (ext.)	Government Admin.	S	C
3P-4-1	Ont. Educational Comm. Auth.	Summer Academy	S	C
3P-4-1	Ont. Educational Comm. Auth.	Teleconferencing	S	C
P-5	Government of Manitoba	Computer Comm.	T	C
P-6	B.C. Distance Education	Tele-education	S	C
U-1	Carleton University	Tele-education	S	C
U-3	University of Toronto	Radio Interferometry	T	C
3U-3	University of Toronto (ext.)	Radio Interferometry	T	U
U-4	McMaster University	Digital Modems	T	C
U-6	University of Western Ontario	Telemedicine	S	C
U-7	Waterloo University	Data Communications	T	C
U-9	Regina University	Community Interaction	S	C
3U-10	University of Montreal	Nursing Education	S	U
3U-11	Université du Québec (ext.)	Intercommunity Comm.	S	P
I-1	Bell/Telesat	Terminal Evaluation	T	C
E-2	Alberta Native Comm. Society	Community Interaction	S	C
3E-4	Taqramuit Nipingat	Community Comm.	S	U
3E-5	Wa Wa Ta	Community Comm.	S	U

* As of 30 September 1978

Number:
F - Federal Government
P - Provincial Government
U - Universities
I - Industries
E - Other Organizations
3 - Third Year Experiment

Category:
T - Technical (15)
S - Social (21)

Status:
C - Completed (27)
U - Underway (7)
P - Planning (2)

The experimenters are allocated use of the satellite transponder and a number of ground terminals for an agreed period of time. Figure 11 shows the schedule for the operational phase of each experiment over the three years of operation and gives the allocation of ground terminals and the Canadian satellite time utilized.

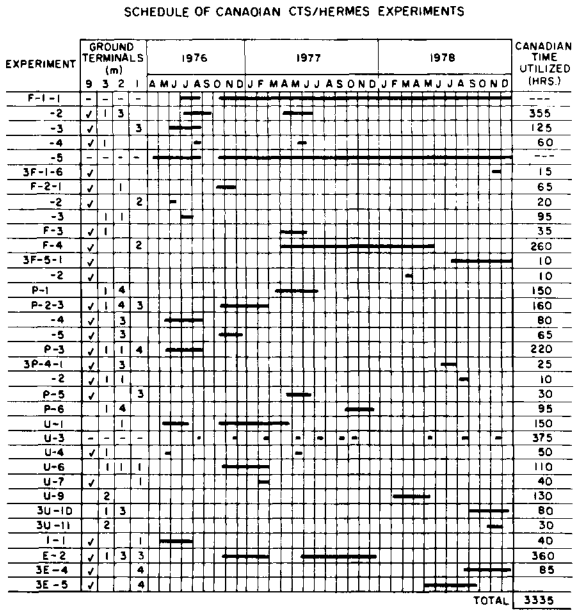

Fig. 11. Schedule of operational phases of experiments.

As can be seen from this figure, several experiments have been operational at the same time. Each experiment has the use of the satellite for several hours per day, every other day. A typical schedule of operations in April 1977 is shown in Fig. 12. At the end of each scheduled period during the day, the corresponding experimental network is shut down and another experimental network in another part of the country is activated within the half hour allocated for satellite antenna steering and ground terminal readiness checks. A wide variety of signal types such as TV, voice, data or high speed digital data have been employed each day.

The ground terminals owned by DOC are shared among the approved experimenters. Figure 13 shows the places where ground terminals have been located through to the end of 1978. The map shows the location of the fixed Ottawa terminal and the 15, 20 and 40 locations respectively where the 3m transportable television terminals, the 2m TV terminals and the 1m telephony terminals have been installed.

Prior to the commencement of each experiment, ground terminals are shipped to selected locations, installed, checked out with the satellite and experimenter equipment and turned over to the experimenter for operations. Typically, these activities, for a given experiment, are carried out by 1-2 technicians and are completed in 2 to 3 weeks. The 3m terminals are installed and operated by DOC contract personnel. The 2m and 1m terminals are usually installed and tested by DOC contract personnel, but are operated by the experimenter. However, several experimenters successfully undertook installation and checkout in order to gain greater experience. During the experiments, all maintenance is performed by DOC contract personnel usually on the basis of complete replacement of one of the electronic sub-units. At the end of each experiment, the ground terminals are dismantled and prepared for shipment to the locations for the next experiment.

A Symposium was held in Ottawa at the end of 1977 to exchange information on the experiments that were completed during the planned two year mission. These experiments are described in the Symposium Record (I. Paghis, 1977). To provide information on the kinds of services that have been investigated in the experiments that have been conducted, some of the major experiments are described in the following sections.

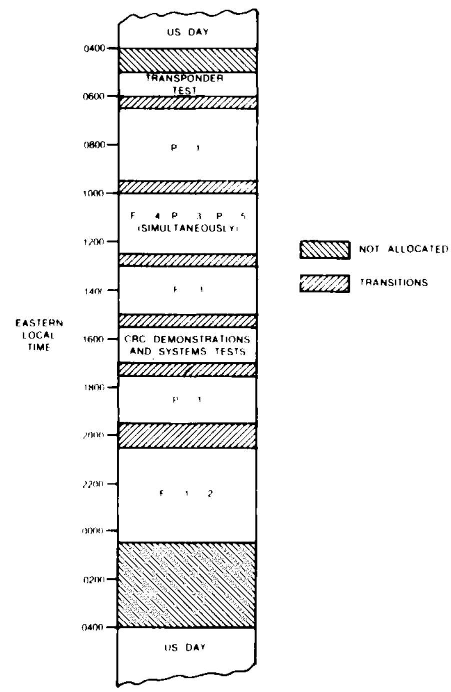

Fig. 12. Typical Daily Schedule for April 1977.

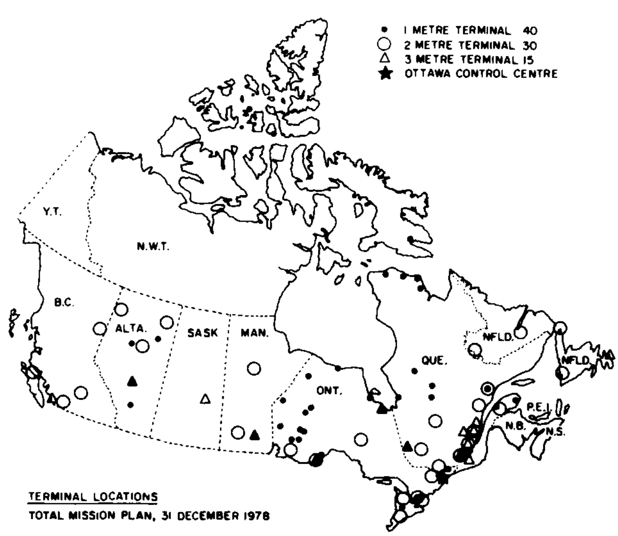

Fig. 13. Terminal Locations, 1976 through 1978.

Telemedicine

An experiment (U-6) to assess the use of telecommunications to provide consultative services to an isolated northern district hospital, was conducted between Moose Factory General Hospital (MFGH), which serves Indian and Eskimo communities on the shores of James Bay and Hudson Bay, and the Health Sciences Center (HSC) at the University of Western Ontario in London in southern Ontario. The latter is one of several universities which provide consultation to the MFGH. A 3m terminal was located adjacent to the hospital, a 2m interactive television terminal was located on a balcony of the HSC and a 1m telephony terminal was located adjacent to a nursing station at Kashechewan, a small Indian community on James Bay. As there is no road access to the communities on James Bay, the 3m terminal was driven by road and transported by rail and barge to Moose Factory where it was installed beside the hospital. The 1m terminal was transported by air to Kashechewan.

The 3m terminal was connected by cable to a consultation room in the 125 bed hospital where a TV camera and control equipment was installed. The TV camera was remotely controlled by consulting doctors in London in sourthern Canada who viewed the activities in this room on a TV monitor. TV cameras installed in an operating room and in a case room could also be used by doctors in London to participate in medical activities.

The 2m terminal in London was connected by cable to the indoor units and to a TV monitor and audio equipment. A consulting doctor in London sat before the monitor and was able to participate actively in a medical transaction taking place at MFGH. A voice link to the nursing station at Kashechewan using the 1m terminal enabled nurses to seek advice from MFGH and arrange for medical treatment. Doctors in London could advise if called upon. The experiment, which was carried out from October 1976 through February 1977, showed that doctors in London could participate actively and effectively in the diagnosis and treatment of cases at MFGH. The voice link to Kashechewan gave the nurses there dependable voice communications for advice and immediate support in case of emergencies.

In the most easterly portion of Canada, a 3m terminal, installed at Memorial University in St. John's, Nfld., was used to transmit medical education programs to doctors and health professionals in four participating hospitals at Stephenville, St. Anthony, Goose Bay and Labrador City (Experiment P-1). The necessary 2m terminals were located on the roofs of these hospitals to provide for TV reception and voice interaction. During the experiment, which was conducted between April and mid June 1977, doctors and other health staff gathered in a video room in each of the hospitals to participate in a medical discussion among the five sites, led by staff from Memorial University. During the period of the experiment, the satellite system was also used to test tele-consultation, transmission of medical data and the value of slow-scan TV to augment the audio return channel. A major side-effect of the experiment was the development of a spirit of collaboration among the participating hospitals which had not resulted from other methods of communication.

Tele-Education

In Quebec, the scattered campuses of the University of Quebec were integrated into a tele-university by using the 3m terminal to transmit courses to students at four other campuses (Experiment P-2-3). During the period of the experiment, which started in mid-October 1976 and continued until March 1977, campuses at Quebec City, Montreal, Trois Rivières, Hull, Rouyn, Rimouski, Chandler and 7 other centers participated in short courses, tests of teleconferencing, transmission of documents, library access, cultural exchange, and teacher training exercises. A variety of originating locations and scenarios for system implementation were tested by changing the allocation of 3m and 2m terminals among the various campuses. Considerable experience in teleconferencing was obtained which provided data on which decisions were made for expansion of the existing terrestrial telecommunications network linking the major urban campuses.

In British Columbia, a 3m terminal was used to transmit educational programs from Vancouver to 2m terminals at cable TV head-ends in Chilliwack, Kelowna and Campbell River (Experiment P-6). Another 2m terminal was located at a community college in Dawson Creek and a TVRO terminal was located at a lumber camp at Pitt Lake. For a period of two months, between mid-October and mid-December 1977, a variety of topics was discussed among the communities. Distribution of the program to the communities via cable enabled many people to participate in the discussion of program material on topics as diverse as lumbering, Indian culture, earth physics and job training. The experiment provided valuable information to aid the planning of distant education activities in B.C., where mountainous terrain greatly increases the cost of terrestrial communications services.

In an experiment to illustrate and test the sharing of expertise by distant universities, Carleton University in Ottawa and Stanford University near San Francisco exchanged courses during a full academic year (September 1976 through May 1977). A particular feature of this experiment (U-1) was the use of a unique digital video-compression technique which made it possible to send video images at a data rate as low as 8 Mbps and made possible the use of a 2m terminal at Carleton to receive and transmit video signals.

In the period April to mid June 1977, while the 3m terminal was in St. John's, Nfld., for a telemedicine experiment, the Public Service Commission (Experiment F-3) tested the use of a duplex video link to conduct management training courses for public servants. The use of such links could make skilled lecturers more available and avoid the need to remove groups of people from their normal place of work for several weeks at a time.

The Ontario Educational Communications Authority (OECA) used 2m terminals in the communities of Fort Francis, Chapleau and Owen Sound in Ontario during the period June through August 1978 to extend the OECA network in Ontario to the cable systems in the three communities (Experiment 3P-4-1). This provided OECA with experience in the use of satellite links.

In the period September through December 1978, the University of Montreal are using a 3m terminal at Montreal and 2m terminals at Rimouski, Hauterive and Sept Iles in Quebec to conduct courses in nursing for students at the three locations to compare the effectiveness of such teaching with the extension courses normally held at these locations (Experiment 3U-10).

Community Communications

In Alberta, a 3m terminal at Edmonton was used by the Alberta Native Communications Society to transmit adult education, community interest and school programs to three native communities at Wabasca-Desmarais, Fort Chipewyan and Assumption in northern Alberta (Experiment E-2). The adults and school children in each community participated in the programs by means of the telephone return channel in the 2m terminals. The exchanges covered many aspects of native community life such as housing, health, roads, job opportunities, legal aid, Indian councils, and fire-arms control in accordance with the needs expressed by the communities. Several government departments participated to provide the native people with information and to enable them to interact effectively with their representatives in Edmonton. The experiment took place in two phases; from October 1976 to February 1977 and from August to December 1977.

The two 3m terminals were installed at Zenon Park (population 400), Saskatchewan, and Baie St. Paul (population 4,000), Quebec, to permit two French-speaking communities to exchange information on their respective activities (Experiment U-9). Zenon Park is located in an English-speaking milieu and there are few other opportunities for an exchange with French-speaking residents of the province of Quebec. The experiment, which was conducted between February and May 1978, included discussions of agriculture, recreation, schooling and government. The experiment illustrated the freedom of exchange that is feasible with flexible communications links.

In an experiment conducted in 1978, the Wa Wa Ta native communications association of northern Ontario used 1m terminals to tie together radio stations in the communities of Sioux Lookout, Fort Hope, Trout Lake and Sandy Lake (Experiment 3E-5). During the period May through September 1978, the radio stations each originated a one-half hour program in sequence in the Cree language to inform and to entertain members of the other communities. In a similar experiment, the Taqramuit Nipingat, an Inuit communications society, will use 1m terminals in Sugluk, Payne Bay, Wakeham and Koartuk to tie together radio stations in these communities on the shores of Hudson Strait (Experiment 3E-4). Other communities with earth stations operating in the Telesat Canada ANIK-A system will also be connected to this network. The experiments will explore the usefulness of communications for the maintenance of cultural association among these communities.

Administrative Services

The Government of Ontario have tested the use of several 1m terminals during the period May to September 1976 and April to September 1977 to provide flexible communications for various government services in difficult locations in northwestern Ontario (Experiments P-3 and 3P-3). In addition, duplex video links between Toronto and Thunder Bay (via a 3m terminal in Thunder Bay and the 9m terminal in Ottawa with terrestrial microwave links to Toronto), were used in July 1977 and July through August 1978 to test the use of video teleconferencing between administrative centers of the provincial government.

Communications Technology

The largest technological experiment was carried out by CRC to test a novel synchronization system for a TDMA system. The experiment demonstrated a technique by means of which an earth station could join a TDMA network with an accuracy of a few ns without itself having to make ranging measurements to the satellite. The technique is particularly applicable to satellite systems using narrow beams.

In another experiment, CRC evaluated a number of TVRO terminals as reported by Halayko (1978). Many demonstrations have been carried out with these terminals to illustrate the simplicity of installation and the high quality of the TV picture. Two terminals taken to Lima, Peru, in May 1978, were installed in one-half day to demonstrate satellite broadcast direct-to-home colour TV at an international seminar.

ANALYSIS OF THE RESULTS OF EXPERIMENTATION

The many social experiments have demonstrated that the necessary communications technology is now available to link effectively individuals and organizations in any part of the country.

Perhaps more importantly, the experimental satellite links made potential users aware that terrestrial and satellite facilities are available to them now or could be in the future to meet service delivery needs that they have identified. However, operational implementation of many of the concepts embodied in the experiments is constrained by the present lack of flexibility regarding access to satellite transponders and ground terminals. These factors are now under review by the Canadian Government.

Other barriers to service delivery by satellite are inherent in the traditional organizational institutional, cultural, and professional structures (see for example Rockoff (1978)). In some of these experiments, the barriers were successfully overcome. In one experiment, for example, a number of colleges and universities in B.C. cooperated to produce programming for five more isolated communities.

The experiments further illustrated that although many of the groups do not have a requirement for full-time use of a satellite transponder, there are no technical or operational barriers to prevent time-sharing the use of one transponder among many geographically widely spaced groups. Although considerable flexibility in the time and duration of access to a transponder might be desired for some applications, it was found during the experiments that the experimenters always controlled their requirements to match the allocated time periods. A pre-emption to accommodate an emergency situation was exercised in Canada on only two occasions and by the U.S.A., of Canadian time, on only one occassion during three years, indicating that rigid definition of access is possible.

The high power of the Hermes satellite and the frequency band of operation made it feasible to use small ground terminals which could be installed in physically suitable locations without the need to coordinate these with terrestrial systems. Hence it was possible to install complex video or other communications links in a matter of weeks without regard to difficulty of terrain or geographical separation. Once installed, it was shown that the relatively complicated ground terminals could be operated by staff who did not have specialist technical training. It was also demonstrated that one technician with an assistant could routinely install and check out a ground terminal in either urban or difficult remote locations. The quality of the video reception and the voice links using Hermes in the remote locations was spectacular, taking into account the normal difficulty of access in these areas and the quality of the existing communications.

The implementation of the experiments demonstrated that effective transfer of communications technology was necessary in the development of new services. It was found, particularly with respect to the social services applications, as documented by Jelly (1978), that multi-disciplinary approaches to solving problems were necessary. As a result of the experiments, an improved awareness of the potential of telecommunications developed and the satellite program emerged as a catalyst that stimulated numerous spin-off benefits and development activities in other areas.

For example, as reported by Dumas (1978), an experiment by the University of Quebec resulted in a decision to install a broadband terrestrial video network which has interconnected most of the participants since September 1977. The experiments in video tele-education and teleconferencing realized in this project accelerated the institutionalization of this mode of communications at the University of Quebec. Other activities in intergroup communications, community interaction and tele-documentation are developing at the university, and have benefitted in large part from the awareness developed in the Hermes experiments of the possibilities technology can offer.

CONCLUSION

The extensive program of Canadian experiments will be completed at the end of 1978. Most of the available ground terminals are then to be refurbished for communications pilot projects to be conducted in 1979 through 1980 with the 14/12 GHz transponders on the ANIK-B satellite. However, it is planned to implement one or two projects in the first 6 months of 1979 to demonstrate and investigate the feasibility of direct broadcasting in Canada since many of the parameters of Hermes are similar to those of the high power satellites that may be available in the future. TVRO terminals with antenna diameters of 0.6 to 1.2m will be used. In 1979, time will also be allocated during the latter half of the year to carry out technological tests of the satellite.

Several of the larger Hermes experiments in social services are the bases of pilot projects to be conducted in the ANIK-B Program as described by Davies (1978). The objective of the pilot projects will be to test, over a longer period of time, the configuration of the new telecommunications services and to evaluate the reality of the perceived need. These pilot projects should facilitate a transition from experimental to operational services.

ACKNOWLEDGEMENT

The experiments described in this paper have involved the efforts of a large team of people including planning, design, operational, evaluation and management groups. The success of the program has also depended heavily on the participation and active cooperation of the outside agencies who have carried out the experiments. The efforts of these groups is gratefully acknowledged. The work of H.R. Raine and J.D.R. Boulding of CRC in maintaining the operation and availability for experiments of the Hermes satellite are also particularly acknowledged.

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THE INDONESIAN PALAPA SYSTEM AND ITS EXPANSION

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ABSTRACT

Indonesia consisting of more than 6000 inhabited islands requires a good communications system established within a short time and within economic bounds. To integrate with the existing terrestrial system a domestic satellite communications system has been adopted to give :

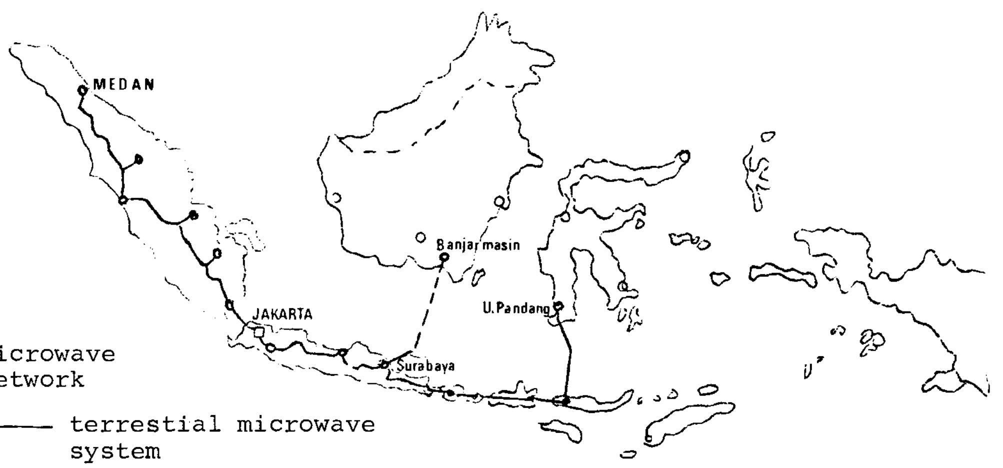
1. A diversity of the existing terrestrial system and to establish a broadband and reliable communications system in areas which cannot be or are very hard to be reached by the terrestrial system.

2. A short time construction implementation.

The domestic satellite communications system in operation initially with 40 ground stations located at population centres, will be expanded with an additional 10 small stations at the end of this year. Thirty four (34) of them are equipped with TV receiver equipment, having the capability to receive and locally rebroadcast television and radio programmes from Jakarta or other locations, enhancing educational and cultural programmes and the integration of the nation. During the first year of operation, the availability of the system was not yet satisfying, but during the second year an availability of more than 99.8% was reached. It is expected that in 1982 a second generation of Palapa satellites have to be launched; Palapa-3 and -4; each having of 24 to 28 transponders. Palapa-1 and -2 is expected to be fully occupied by that time.

INTRODUCTION

The Domestic Satellite Communications System (SKSD) which began its operation on August 16, 1976 uses two satellites, Palapa-1 and -2 which has 12 transponder each. They are synchronous orbit satellites located at 83°E and 77°E launched on July 1976 and March 1977 respectively. The Palapa antenna beam coverage patters was designed to cover both Indonesia and neighboring ASIAN countries with an EIRP ranging from approximately 31 to 34 dBW. Based on a predicted traffic matrix, the Palapa system is initially equipped with 2124 FDM/FM channels, 266 SCPC channels are used on a preassigned basis for telegraphy and the rest are for demand assigned. These SCPC channels have 60 kHz spacing. Especially in Sumatra, Java and Bali, the 4 GHz frequency band has been used for the terrestrial micro wave system. Earth stations are located remote from telephone exchanges, to avoid interference. They are connected to the telephone exchange with 3 types of tail links e.g. 7 GHz microwave links or coaxial systems or multipair cables whichever is suitable depending on its distance and capacity.



Microwave network

—— terrestial microwave system

- - - troposcatter system

EXISTING MICROWAVE TERRESTIAL NETWORK IN INDONESIA

1. INITIAL SYSTEM

1.1. Ground Segment

The 40 earth stations using 10 m antennas are located at 26 province capitals and 14 district capitals, as shown in Figure 1.1. The Master Control Station (MCS), located at Cibinong near Jakarta, has a 9.7 m antenna diameter for Telemetry, Tracking and Command with monopulse tracking capability and full 360° control of polarization angle, besides a 10 m antenna for communication. Main traffic stations (MTS); 18 in total; have both FDM/FM carriers and SCPC for voice communication and television down link capability. TV uplink facility is only provided at Jakarta and Surabaya Stations. Light Traffic Stations (LTS); 21 in total; have only SCPC for voice communication, and a TV down link capability. Small Terminals (ST) will have 2 Demand Assignment (DA) voice channels and 1 SCPC channel for telegraphy. These 10 ST's are now being installed and expected to be in operation by the end of this year. Table 1.3. shows The Station Parameter.

1.2. Demand Assignment System

The Single Channel Per Carrier (SCPC) operates on a frequency division multiple access (FDMA) mode with an initial 60 KHz carrier spacing. Companders are used to improve voice quality and at the same time enable future conversion to 30 KHz carrier spacing. If a voice activation factor of 0.40 to 0.35 is assumed a multiplication factor of 2.5 to 3.0 is obtained. A greater multiplication factor is obtained when the DA network is applied. Hence the present transponder having 60 KHz carrier spacing or 500 voice frequency channels can handle approximately 800 to 1,500 SCPC modems in the DA mode, depending on the traffic density. When the future configuration of 30 KHz carrier spacing will be applied, one transponder can handle approximately 1,500 to 3,000 SCPC modems. The voice frequency (VF) input in the transmit direction as band limited between 300-3400 Hz. The Master Communication Equipment (MCE) acting as the DA central device consists of DLMs (Data Link Modems), register equipments and associated SCPC modems, and a redundant Master Control Computer (MCC). The MCC consists of 2 (two) PDP_11/35 computers, one operational and one on hot standby, having memory capacity of 64,000 words each. The DLM is basically a SCPC modem which is dedicated to data transmission between the DARC (Demand Assigned Remote Controller) and the MCC. The 4 DLMs each having a capacity to accommodate up to 30 remote slaves, provide data interchange between the MCC and up to 120 DARC units at any locations.

1.3. Space Segment

The two satellites Palapa-1 and -2 of HS 333D type, have a design life time of 7 years and an expected one 8 to 9 years. The space craft antenna pointing error is better than $\pm 0.1^\circ$. A solar cell system producing 300W is provided and minimum of 10 transponders are retained during eclipse seasons. Palapa has twelve of five watt transponders with a 40 MHz, using 6 GHz for receiving and 4 GHz for transmitting.

1.4. System Performance

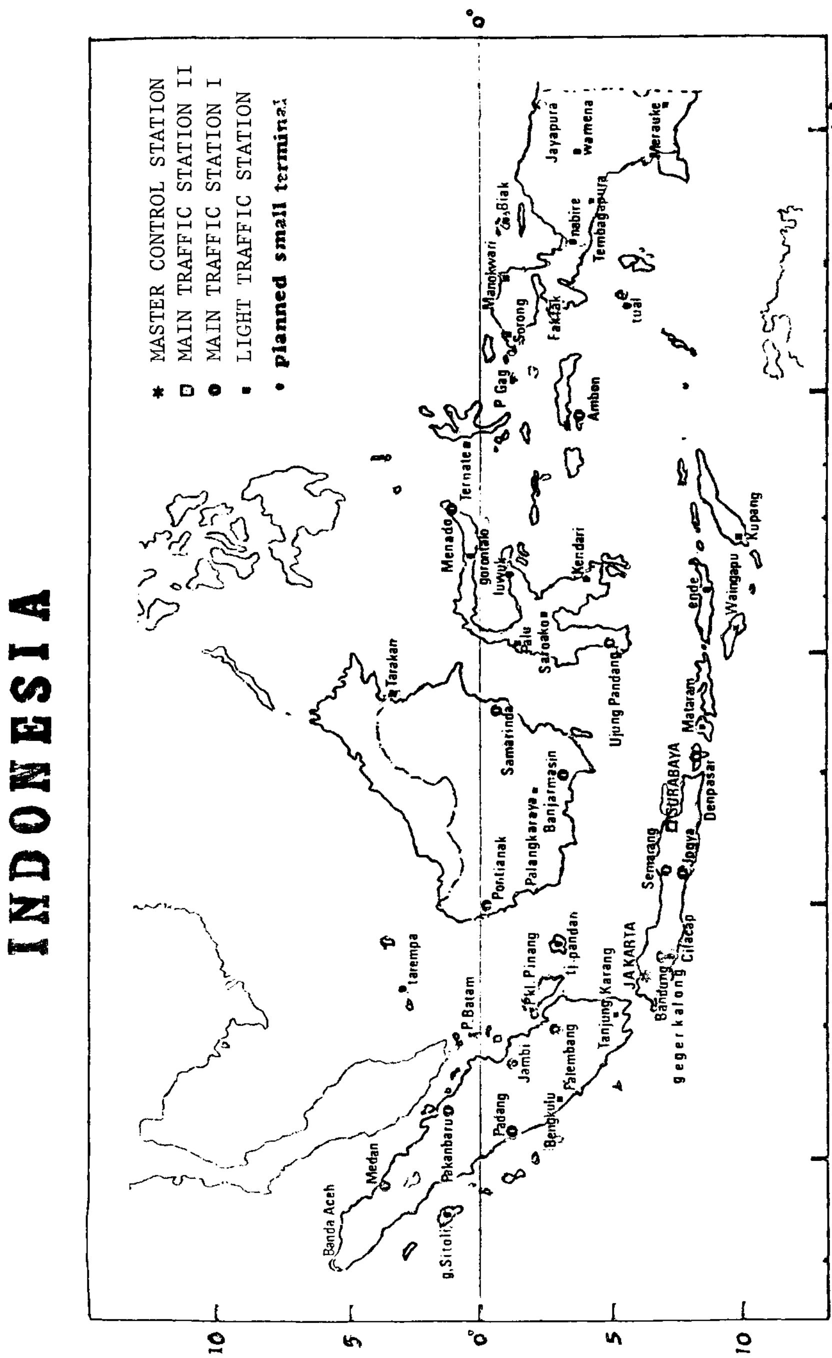
Engineering data shows that all ground station G/T values are better than 29.5 dB/°K, and an average of 30.2 dB/°K is obtained. The minimum EIRP per carrier which each ground station has to transmit is based on ground station locations which should be in accordance with the Palapa G/T contour shown in Figure 1.4. for Palapa I EIRP contours and Figure 1.5 for Palapa I G/T contours. The received system noise temperature of the satellite is 1500°K. In determining the noise performance of the system rain attenuation, especially ionospheric scintillation has been taken into account, and a 6 dB fading margin above threshold was adopted to comply to CCIR Rcc 353-2 where the total noise is not to exceed 50,000 pWOp (S/N = 43 dB).

1.5. System Availability

System failure is due to several factors such as system design (with or without redundancy), equipment quality, spare availability and distribution, operation & maintenance and personnel skill and discipline. Table 1.6 shows the failure contribution percentages of each subsystem during one year from May 1977 to May 1978. (Mean value). No system failure is contributed by the satellite since January 1977. Table 1.7. shows the source of failure contribution from May 1977 to May 1978 (mean value). Monthly system availability curve on Figure 1.8. shows that the monthly availability is improving and meets the performance mentioned on Study Group 4 CCIR 1977 (99.8 % of the time).

1.6. Traffic Data

As shown on table 1.2. the total installed channels are 2,389 channels consisting of 2,124 FDM/FM and 265 SCPC. Number of active channels are 950 FDM/FM and 261 SCPC channels.



FORTY OPERATIONAL and
TEN PLANNED GROUND STATIONS

TABLE 1-2. ALLOCATION OF VOICE AND TV CHANNELS

	LOCATION	PA - channel	DA - channel	TV - channel Receive	TV - channel Transmit
1.	Jakarta	600	24	TV	TV
2.	Banda Aceh	24	4	TV	-
3.	M o d a n	180	8	TV	-
4.	Pakanbaru	60	7	TV	-
5.	Padang	84	7	TV	-
6.	J a m b i	12	7	TV	-
7.	Palembang	60	13	TV	-
8.	Samarang	144	6	TV	-
9.	Surabaya	360	15	TV	TV
10.	Bandung	120	3	TV	-
11.	Yogyakarta	108	2	TV	-
12.	Denpasar	72	6	TV	-
13.	Pontianak	24	9	TV	-
14.	Banjarmasin	36	10	TV	-
15.	Samarinda	36	6	TV	-
16.	Ujung Pandang	108	11	TV	-
17.	M a n a d o	36	6	TV	-
18.	A m b o n	36	10	TV	-
19.	Jayapura	24	9	TV	-
20.	Bengkulu	-	6	TV	-
21.	Kupang	-	5	TV	-
22.	Palangkaraya	-	5	TV	-
23.	Tarakan	-	5	TV	-
24.	Kendari	-	5	TV	-
25.	P a l u	-	5	TV	-
26.	Ternate	-	5	-	-
27.	Sorong	-	5	TV	-
28.	Fak-fak	-	5	-	-
29.	Manokwari	-	5	-	-
30.	B i a k	-	5	TV	-
31.	Morauke	-	5	-	-
32.	Tombagapura	-	5	TV	-
33.	P. Gag	-	5	TV	-
34.	Tanjungkarang	-	6	TV	-
35.	Mataram	-	6	TV	-
36.	Pangkalpinang	-	6	TV	-
37.	B a t a m	-	6	TV	-
38.	Saroako	-	2	TV	-
39.	Cilacap	-	3	-	-
40.	Waingapu	-	2	-	-
		2124	265		
	T o t a l :	2389 channels (1195 circuits)			

Table 1:3 STATION PARAMETER

	INITIAL SYSTEM PARAMETER	STATION			
No.	ITEM	MASTER CONTROL	MAIN TRAFFIC	LIGHT TRAFFIC	SMALL TERMINAL
1	Total Number	1	18	21	10 (will be installed by the end of '78)
2	Antenna Diameter	9.7 m for TT&C 10 m for communications	10 m for communications	10 m for communications	4.5 m for communications
3	Antenna Operation	stop track	manual tracking	manual tracking	hand crank
4	Channel Facility	TT&C and support launch and transfer orbit FDM/FM, SCPC, TV	FDM/FM, SCPC, TV received only except Surabaya	SCPC, TV receive	SCPC
5	H P A	3 KW redundant	600 W or 400 W redundant	400 W non redundant	100 W non redundant
6	L N A	approx 60°K uncooled redundant	60° - 85°K uncooled redundant	85° - 110°K uncooled redundant	G a As F E T 160'K non redundant
7	G / T	29 dB/°K	29 dB/°K	29 dB/°K	22 dB/°K
8	Power	diesel genset redundant with UPS	diesel genset redundant with UPS	diesel genset redundant with UPS	diesel genset redundant without UPS

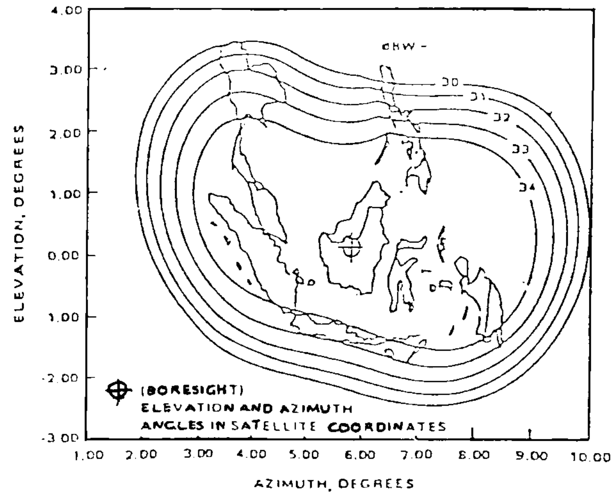


Fig. 1.4 PALAPA EIRP CONTOURS

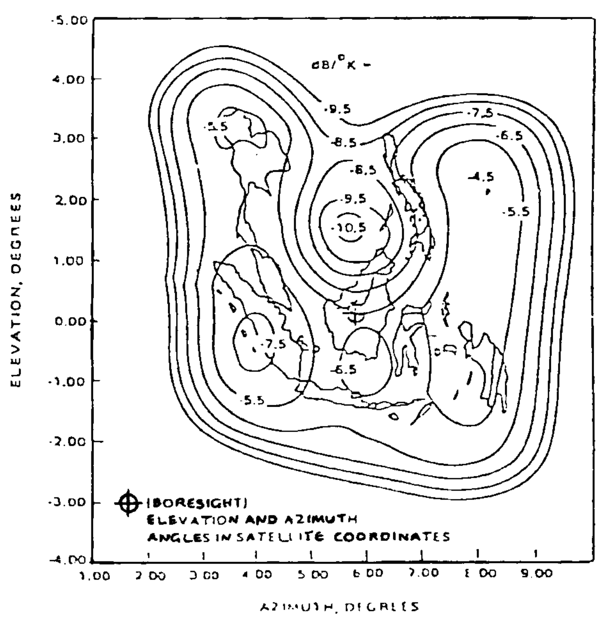


Fig. 1.5 PALAPA G CONTOURS

FAILURE CONTRIBUTION PERCENTAGE

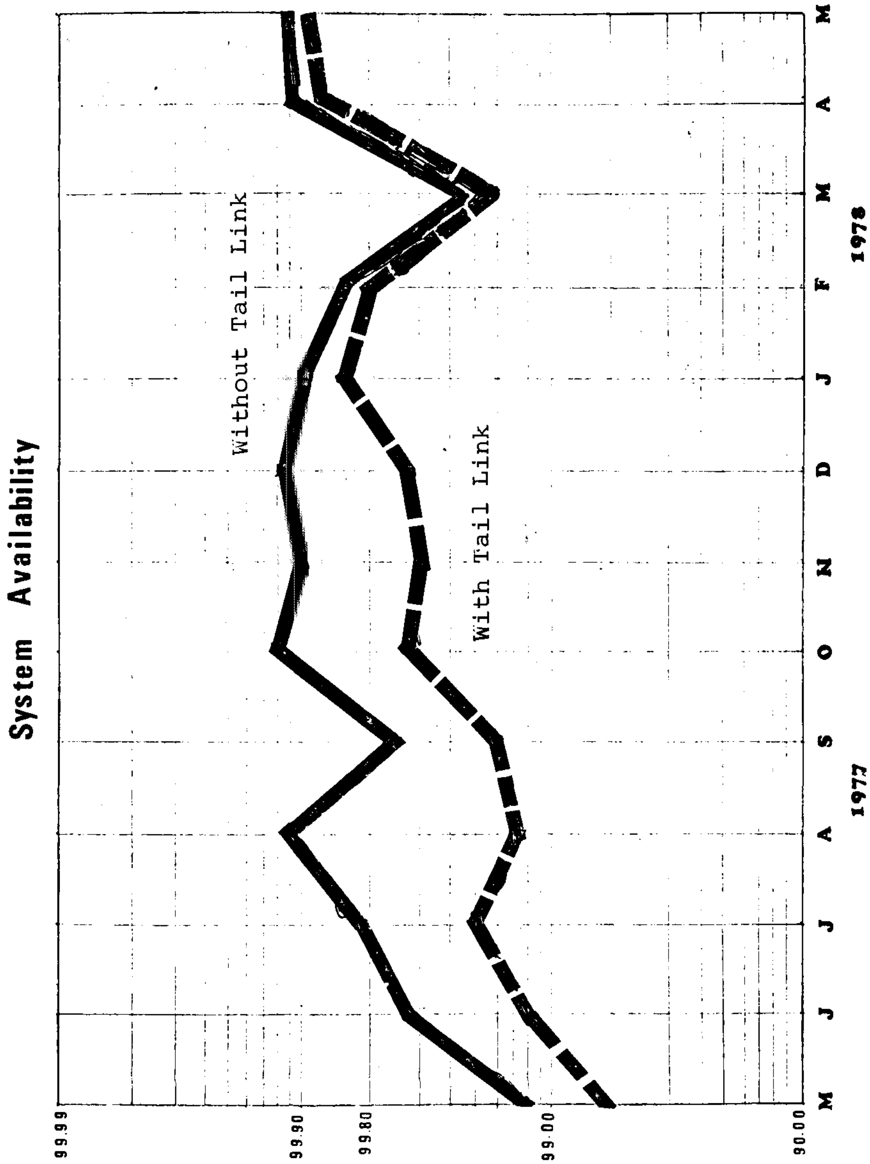
TABLE 1.6

NR	SUBSYSTEM	PERCENTAGE
1	Air Condition	0.005
2	GCE Down	0.385
3	UPS	0.388
4	Echo Suppressor	0.668
5	LNA	0.728
6	ES Multiplexer	2.003
7	GCE Up	2.141
8	Antenna	2.611
9	City Multiplexer	2.773
10	Generator Set	3.406
11	ES Tall Link	5.377
12	Commercial Power	5.645
13	Others	6.742
14	Matching Unit	9.862
15	City Tall Link	10.950
16	HPA	11.053
17	Telephone Exchange	17.375
18	SCPC - DA	17.888

SOURCE OF FAILURE CONTRIBUTION

TABLE 1.7

1.	Switching	0.341
2.	Sun Outage	0.509
3.	Human Error	0.511
4.	Maintenance	2.288
5.	Testing	3.081
6.	Waiting Parts	3.898
7.	Unknown	3.924
8.	Weather	4.750
9.	Others	3.648
10.	Equipments	72.250


System Availability
Without Tail Link
With Tail Link
99.99
99.90
99.80
99.00
90.00
M
J
J
A
S
O
N
D
J
F
M
A
M
1977
1978

The distribution of active channels are as follows:

FDM/FM channels,

16.4 % used for simplified SLDD (Subscriber Long Distance Dialing).
23.3 % used for point to point link (e.g. leased channels, telegraphy, operator to operator dialing and manual services).
49.1 % still unassigned channels or spare.
SCPC channels
9.6 % operator to operator dialing via DA system.
1.4 % pre assignment channels for telegraphy and leased channels especially to light traffic stations.
0.2 % spare channels.

As the trunk exchanges are still being constructed, a simplified SLDD and manual services is taking place and traffic generated by these facilities can be summarized as follows: The average daily calls in 1977 were 7,195 and in 1978 (up to May) was 14,234 with the average call duration of 5 minutes.

2. SYSTEM DEVELOPMENT

After the system had been in operation for one year traffic to some directions became very dense and required additional channels. The increasing demands were great and far beyond our prediction. To give additional channels for certain directions or links the following actions are being taken : activate the spare DA modems, re-allocate the DA modems and reallocate FDM/FM channels with minimum equipment purchased. The reallocation of DA modems is easier than the reallocation of FDM/FM modems. One of the parameters which was used in reallocating the DA modems was grade of service of 3 % using Erlang C formula as the DA channels are used for operator to operator dialing circuits.

Due to the limitation of spare modem and spare tail link capacity, the reallocation of DA modem give little relief to the number of blocked calls as traffic increased rapidly.

Reallocation of FDM/FM modem is a more difficult job and requires extensive study and preparation in avoiding the interruption of the system. Principally the ultimate capacity of each link was expanded by reducing the number of carriers in each transponder and putting the spare transponder in operation.

The objective of this FDM/FM modem reallocation is to accommodate simplified SLDD plan among several places like Samarinda, Monado, Ujungpandang and Ambon (Eastern part of Indonesia) to Jakarta.

Further extension has also been planned by forming a new traffic matrix. By considering several factors as the number of population, GNP, the number and capacity of existing telephone traffic demands, a SLDD traffic matrix for up to 1919/1980 was predicted with the total channel of approximately 5550 FDM/FM and 1150 SCPC channels.

To handle other traffic such as operator to operator dialing, leased channels, telegraphy etc, 20 % capacity above SLDD channel requirements, will be provided.

2.1. FDM/FM Channels Expansion

To increase the efficiency, flexibility and simplicity of the system any expansion plan must work toward standardizing the system within economic bounds.

To reach this objective FDM/FM channels will be grouped in a supergroup or supergroup as:

Group A + n x Supergroup (where n is an integer) or 12 + n x 60 channels.

It means that the minimum of ultimate capacity of a station RF carrier is 72 channels.

By doing so, based on ultimate channel capacity of each station, those MTS can be grouped as follows:

Channels Capacity	Number of Station
912 + 612	1
672	1
252	1
192	5
96	3
72	6
36	2

By standardizing these RF carrier sizes, transponder capacity is expected to be utilized more efficient for multicarrier FDM/FM.

2.2. SCPC Channel Expansion

On the initial system, SCPC channels were only used for operator to operator dialing via DA system and for point to point telegraph channels, so the increasing demand was not so great.

However in the second phase where DA system will be used for handling the SLDD connections, SCPC channels required are so great that more than one transponder SCPC channels might be required.

If it is so, the DA computer programme must be changed. The DA system is planned for handling SLDD calls amongst small cities or small trunk exchanges where the traffic generated is small (not more than 5 E). To shorten the digit cycle from an approximately 1300 ms to 800 ms, semi-compelled MFC signaling will be used.

Several possibilities of trunk connections can be applied in DA system e.g.: manual both-way, auto MFC to auto MFC, auto decadic to auto decadic and manual to auto decadic.

The existing DA system which working with one transponder is capable to handle traffics up to 450 E.

To handle traffic more than 450 E, some solution have been studied e.g. :

1. Using second computer with the same program to handle traffic via two transponders.
2. Using new computer with new computer programmes.
3. Rerouting the traffic so that traffic via DA system not more than one transponder SCPC.

For 17 stations where microwave tail link is applied SCPC expansion is more costly than FDM/FM channel expansion.

This is one of the reasons that one transponder SCPC-DA system operation is preferable. In this case, maximum SCPC modems utilized for DA system are approximately 1500 each and the expected total blockage is 0.1 %.

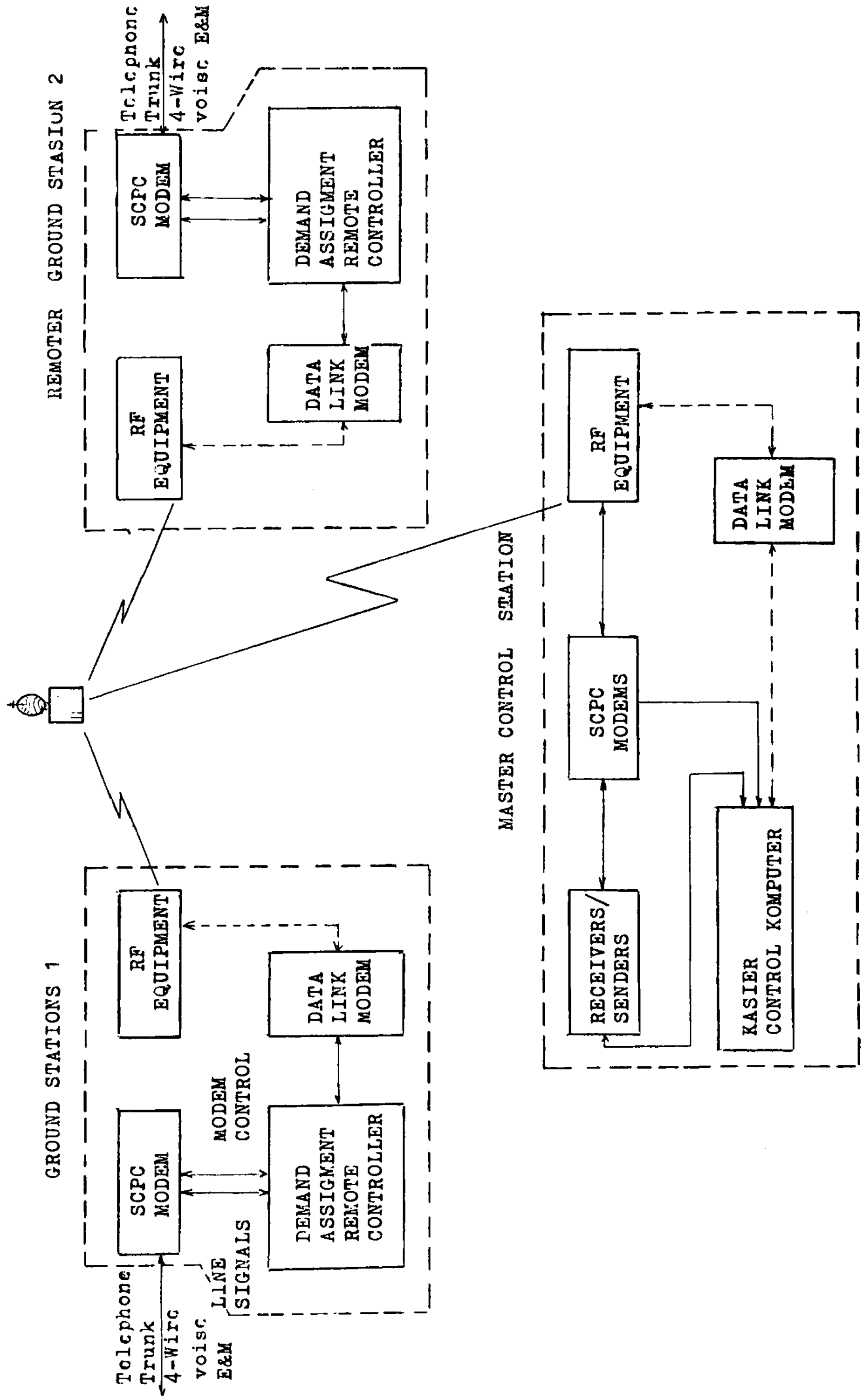


Figure 2. DEMAND ASSIGMEND SYSTEM

3. SECOND GENERATION OF PALAPA SYSTEM

3.1. Traffic Forecast

An annual trunk traffic growth of 15 % has been projected for designing the second generation Palapa System. Before finalizing the system definition or the new Palapa, it is necessary to review the projected traffic periodically. It is predicted that the total transponder required are as follows:

Year	Used by: Indonesia	Used by: ASEAN members	Total Transponder
1983	15	9	24
1989	26	13	39

It is estimated that, by 1983, Palapa-1 and -2 will be fully loaded and Palapa-3 with the capacity of 24 transponders should be launched.

3.2. System Configuration and System Concept

According to the estimation, Palapa-3 can carry the traffic of Palapa-1 and -2 as they approach their life end. Palapa-4 will provide a back up to accommodate a traffic growth, and be launched soon after Palapa-3 launch date. The policy on spare usage dictates the launch of Palapa-5 at a later date as appropriate. Palapa-5 can also accommodate traffic growth if the growth rate is higher than the 15 % anticipated.

Transponders of Palapa-1 and -2 are expected to remain operational one to two years after the launch of Palapa-3. This will provide a smooth transition to Palapa-3.

Concurrent with the above concept, ground segment techniques for increasing the system capacity are being explored. Compandors, Smaller SCPC spacing (22.5 kHz) and 1/2 transponder for television (17.5 MHz), may make the system more efficient and give more channels per transponder.

3.3. Spacecraft Concept

3.3.1. The Design Approach

The advent of Space Transportation System (STS) largely eliminates the constraint of mass, volume, weight and power.

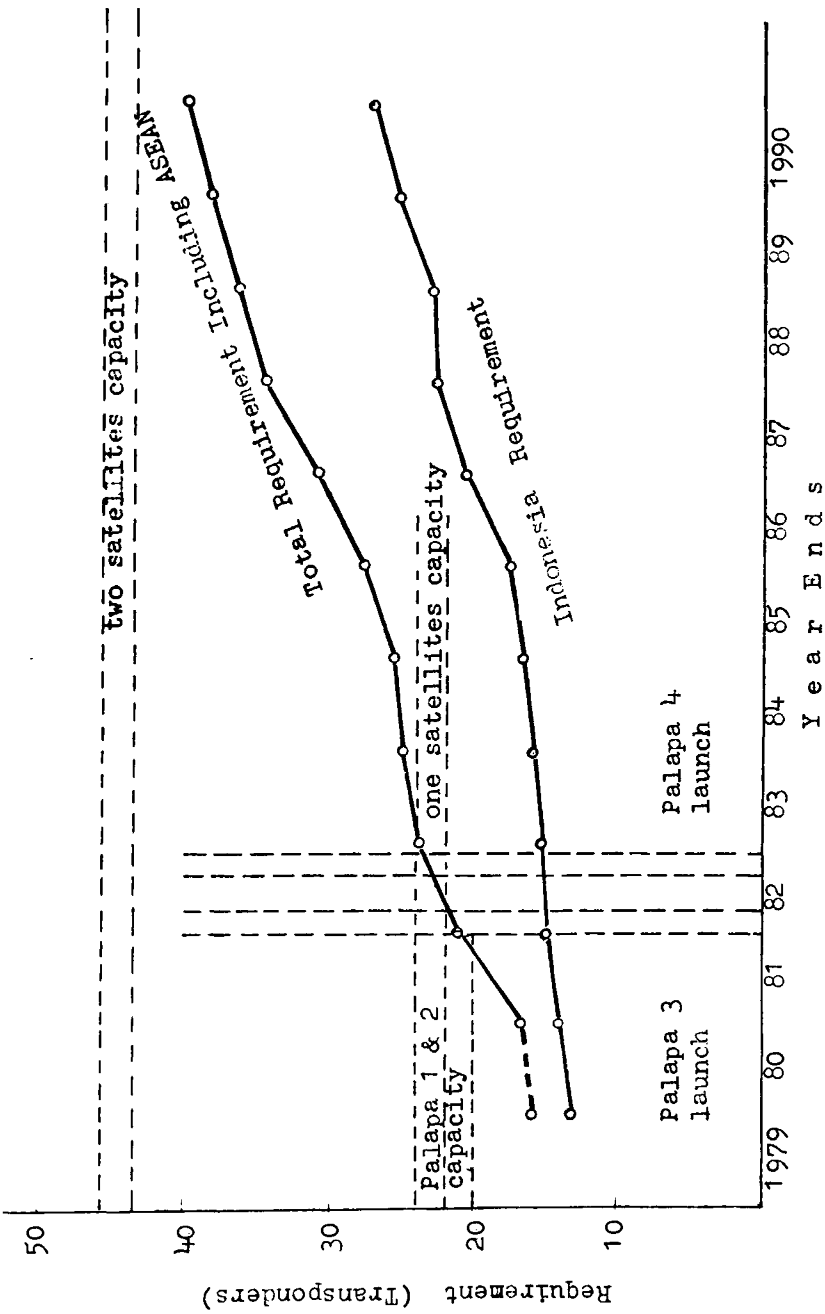
Palapa-3 launch date plan can take advantage of the STS launch being well developed after 1980. Also without the constraint on mass and power it is possible to increase satellite capacity at reasonable cost. However, Indonesia considers also a possible alternate launch vehicle. The baseline approach will be STS launch optimized, with expendable launch vehicle as a back up.

3.3.2. Frequency Reuse

To achieve an economical system having the capacity predicted by the traffic estimates, frequency reuse is necessary. The technique has been successfully implemented with Satcom and Constar and Intelsat IVA satellites, achieving - spacecraft polarization isolation of 33 dB - ground station polarization isolation of 30 dB.

Sufficient data for rain depolarization for tropical areas is not available at this time.

Dual polarization mode (which requires antenna feed system modification) is planned



TRAFFIC PROJECTION VIA PALAPA SYSTEM

for implementation only after the traffic has reached a certain level of growth. In the first operational phase. Experiments are planned to determine the polarization factor.

In any case, ASEAN countries other than Indonesia do not require ground stations modifications, provided that isolation provision is sufficient to reject cross polarization elements.

3.3.3. The Frequency Band

Utilization of the standard band i.e.: 6 GHz band (uplink) and 4 GHz band (downlink) with 500 MHz bandwidth is proffered due to technological and cost considerations. Large bandwidths require new designs of frequency sensitive components and subsystems both for spacecraft and ground stations. In case of insufficient capacity to handle the traffic growth, a 575 MHz bandwidth will be considered, with the frequency bands are as follows :

Uplink	:	5925 - 6425 MHz (500 MHz band), or
		5850 - 6425 MHz (575 MHz band),
Downlink	:	3700 - 4200 MHz (500 MHz band), or
		3625 - 4200 MHz (575 MHz band).

3.3.4. Other Spacecraft Parameter

A single beam, ASEAN coverage, spacecraft antenna will be preferred, due to considerations of cost and flexibility in handling services. Higher satellite EIRP is planned (around 10 watts TWT) to obtain higher capacity, combined with more sensitive receivers and increase of transponder usable bandwidth. Minimum 7 years life time design is planned for the second generation of Palapa series.

3.3.5. Orbital Location

Consideration on orbital locations to achieve an economical efficient system, minimum ground station modifications and smooth intersystem coordinations directed us to choose the arc between 108°E and 118°E as most suitable. The individual locations planned are :

Palapa 3 : 118° East longitude.
Palapa 4 : 113° East longitude.
Palapa 5 : 108° East longitude.

Due to the new satellite positions there might be two major problems which will cause system interruption, e.g. :

- Modification of existing antenna feed polarization as consequence of using frequency reuse.
- 19 of the existing ground station antennas should be reoriented toward East as consequence of the new Palapa position.

4. CONCLUSION.

1. The Palapa system is a suitable system for Indonesian archipelago and gives a high reliability meeting the CCIR standard.
2. Construction of the system has been implemented within a relatively short period (18 months).
3. The SCPC/DA system is very flexible and an economical system especially for adding channels or reallocation of existing modems in small quantities and provide telephone switching facilities with high efficiency in using channels.
4. Traffic estimation has a significant impact to the final system concept. A good traffic forecast is necessary in the process of finding the best system

in the term of economy, engineering, and operation. Coordination to all users are required, periodically.

5. The operating transponders of Palapa-1 and -2 will provide an efficient transition to Palapa-3 operation.

PRESENT STATUS AND FUTURE PLANS OF JAPANESE CS AND BSE PROGRAMS

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ABSTRACT

The Japanese CS and BSE spacecraft were launched successfully from the United States Eastern Test Range on Dec. 15, 1977 and Apr. 8, 1978 JST, respectively, and placed at their predetermined orbital positions of 135 deg. and 110 deg. E..
CS, a spin stabilized spacecraft, has two C-band and six K-band transponders using in common a horn-reflector type mechanical despun antenna. BSE, a three-axis stabilized spacecraft, has two sets of 14/12 GHz transponders, with a shaped beam paraboloidal antenna for TV broadcasting.
Initial performance checks of both spacecraft on-orbit have been completed, and regular experiments started in both programs.
The experiments will be conducted for three years in order to obtain technical data necessary for establishing future operational domestic satellite communication and broadcasting systems.

I. INTRODUCTION

The Ministry of Posts and Telecommunications (MOPT) has made the experimental satellite programs of CS and BSE in 1972 for the purposes of acquiring technical knowledge and operational experience necessary for establishing future operational domestic satellite communication and broadcasting systems. Under the charge of National Space Development Agency of Japan (NASDA), both spacecraft have been developed and launched from the United States Eastern Test Range successfully on Dec. 15, 1977 and Apr. 8, 1978 JST respectively and placed at their predetermined geostationary orbit positions of 135 deg. and 110 deg. East.
The CS is a spin-stabilized spacecraft weighing about 340 kg in orbit, and has two C-band (6/4 GHz) and six K-band (30/20 GHz) transponders. A common horn-reflector type mechanical despun antenna is used, giving radiation patterns to cover Japanese territory. After the initial spacecraft performance check, regular experiments are now being conducted by Radio Research Laboratories (RRL) of the Ministry, in cooperation with Nippon Telegraph and Telephone Public Corporation (NTT).
The BSE is a three-axis stabilized spacecraft weighing about 350 kg in orbit. It has two sets of Ku-band (14/12 GHz) transponders with 100 watt output power, and a uniquely shaped beam paraboloidal antenna for colour TV broadcasting.

After the initial spacecraft performance check, regular experiments in the BSE program are also being conducted by RRL in cooperation with Japan Broadcasting Corporation (NHK). The experiments of both programs will be continued for about three years.
The Ministry has recently announced that operational domestic communication and broadcasting satellites will be launched in 1983 and 1984 respectively. The experimental results of the present CS and BSE programs will be reflected in the system configurations of these operational systems.

II. LAUNCH AND INITIAL CHECK OF CS PERFORMANCE

CS was launched by No.137 Delta 2914 rocket on Dec. 15, 1977 JST from the Eastern Test Range of USA, and put into transfer orbit at 24 minutes 54 seconds after the lift-off, after separation from the third-stage of the rocket. These operations were carried out with the support of NASA. Executing a series of maneuvers such as attitude correction, AM firing in the transfer orbit, and orbit and attitude controls in the drift orbit, CS attained its final geostationary position of 135 deg. E on Dec. 24. The history of the CS spacecraft development and maneuvers conducted during the period of lift-off to final orbit position acquisition are shown in Fig. 1 and Table 1 respectively.

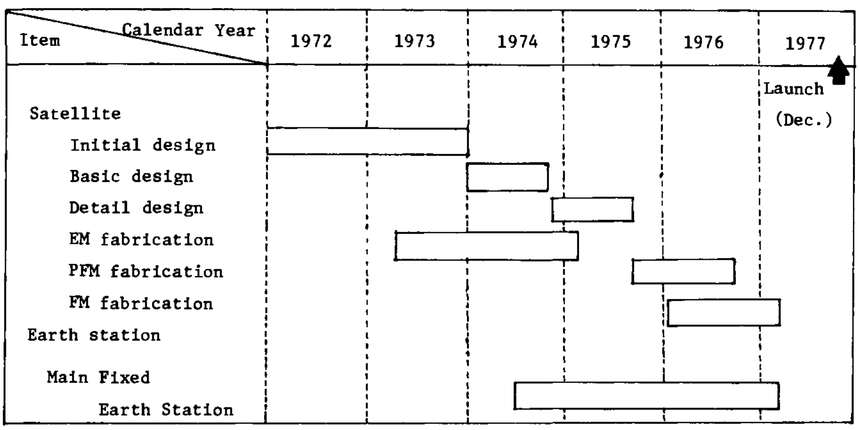


Fig. 1 Histories of the CS Spacecraft Development

Table 1 Histories of the CS Maneuvers from Lift-off to Orbit Injection

Transfer orbit		Drift orbit	
Coarse attitude cont	18^h20^m, Dec.15	Coarse attitude cont.	20^h30^m, Dec.16
Fine attitude cont.	8^h40^m, Dec.16	Fine attitude cont.	11^h30^m, Dec.17
Toutch-up	11^h55^m, Dec.16	#1 orbit cont.	3^h53^m, Dec.18
AMF	12^h25^m, Dec.16	#2 ditto	16^h00^m, Dec.19
		#3 ditto	15^h56^m, Dec.21
		#4 ditto	3^h35^m, Dec.23
		#5 ditto	3^h58^m, Dec.24
Injection into drift orbit at 138.8°E, Drift rate -0.9°/rev.		Final orbit position	134.9°E
		Orbit inclination	0.1°

The general characteristics of the CS spacecraft are also shown in Table 2.
The CS is named SAKURA which is Japanese for cherry blossom. The CS is kept within the accuracy of ± 0.1 deg. in both of orbit position and attitude. The on-orbit initial performance check of the spacecraft was conducted by NASDA in co-operation with RRL. All subsystems of the spacecraft bus and mission equipments have been examined in detail during the drift and stationary orbit phases with telemetry data reduction and satellite transponder loop-back test methods. The test results are summarized in Table 3 and 4. It was verified that all subsystems except for two of the K-band transponders were working well.
Functions of both S- and C-bands TT&C are normal, the solar-arry generating power is estimated as 513 watts and 448 watts in autumnal equinox and solstice repectively at the end of three years of the design life. The antenna beam pointing is kept within the accuracy of ± 0.3 deg.. The temperatures at various parts of the spacecraft are retained within the pre-estimated range, and thermal control by electric heaters is working normally. The efficiency of the second propulsion subsystem is better than 90 %. The antenna patterns measured by E-W off-set beam scanning method revealed themselves to be very close to those of pre-launch measurement, though only one-dimensional patterns were measured at the Main Fixed Earth Station of RRL in this phase. The antenna gains at the beam center were measured to be as high as 40 dB and 30 dB in K-band and C-band respectively, and it is expected that the main-land is covered within the K-band 35 dB antenna gain contour and the whole Japan territory including surrounding remote islands is covered within the C-band 27 dB contour.
The transponder characteristics such as output power, local oscillator frequency, amplitude response, delay characteristics, input-output characteristics, spurious response and power consumption were measured with satisfactory results.
Unfortunately, however, the sixth K-band transponder (F6) lost its output radiation on Feb. 15, and some spurious emission occurred in the second K-band transponder (F2) on March 15. The causes of these defects are now under investigation.

Table 2 General Characteristics of the CS Spacecraft

Physical config.	Cylindrical Diameter 2.18m Height (including antenna) 3.84m
Weight	At launch 675.8Kg On orbit 340 Kg
Attitude control	Spin-stabilization 90±9 rpm
Communication subsystem	Antenna Mechanical despun type (Shaped beam in K-band) Antenna gain C-band higher than 25dB K-band higher than 33dB Transponder K-band (30/20GHz) 6sets F_1 to F_6 C-band (6/4GHz) 2sets G_1 and G_2 Transponder characteristics (NF / Output / Bandwidth) K-band: 13dB / 34dBm / 200MHz C-band: 9 / 34.5 / 200
Electrical power subsystem	Solar cell array 420W at EOL Storage battery 20AH Ni-Cad
Ant. pointing	Accuracy within ±0.3°
Station keeping	E-W within ±0.1° N-S within ±0.1°
Life-time	3 years

Table 3
Results of Initial Check-up
(Bus equipments)

Item	Requirements	Results
TT&C subsystem		
(1) Telemetry xmtr		
S-band output	0.7 to 2.4W	#1 1.4W #2 1.5W
C-band output	>25mW	#1 51.3W #2 45.7mW
(2) TLM sig. modulation	0.8 rad ± 10%	#1 0.85rad, #2 0.83rad
(3) RNG sig. modulation	0.56 rad ± 20%	#1 0.6rad, #2 0.65rad
(4) S-band rcvr threshold	≤ -127dBm	#1 -134.4dBm #2 -135.1dBm
(5) Commnad sensitivity	≤ -110dBm	#1 -120.0dBm #2 -119.2dBm
Electrical power subsystem		
(1) Solar cell array generating power	at 3 years EOL ≥475W A.equinox ≥422W Solstice	at 3 years EOL (estimate) ≥513W A.equinox ≥448W Solstice
(2) Voltage stability	29.4 ± 0.2V	29.30 to 29.31V
Antenna & attitude control subsystem		
(1) Spin rate	90 ± 9rpm	92.9rpm
(2) Ant. bias function	+4° to -4°	+4° to -4°
(3) Ant. pointing	≤± 0.3°	≤± 0.3°
Thermal control subsystem		
(1) Heaters		normal
(2) Temperature		normal
Propulsion subsystem		
(1) Canted thruster efficiency	100 ± 10%	#1 94.6% #2 97.7%
(2) Radial thruster efficiency	100 ± 10%	#1 90.9% #2 92.7%
(3) AKM	error of $\Delta V \leq 1\%$	0.2%

III. GROUND TERMINALS AND EXPERIMENTAL ITEMS IN THE CS PROGRAM

Various kinds of ground terminals have been prepared by RRL and NTT for the experiments. The Main Fixed Earth Station (MFES) was constructed at Kashima by RRL for communication experiments in K- and C-bands and TT&C operations in C-band. RRL is also preparing small terminals for K-band light traffic communication using a SCPC system, and for field strength measurement in propagation studies. NTT has installed a Fixed Earth Station (FES) at Yokosuka for K- and C-band communication and C-band TT&C experiments and C-band and K-band vehicle mounted type Small Transportable Earth stations (STES) for emergency communications. And it is also preparing a simple type Fixed Earth Station at Sendai for K-band communication and Transportable Earth Stations (TES) for C-band communication in the remote islands.
With these earth terminals, various kinds of communications experiments are to be conducted, such as multiple access in PCM-TDMA, SCPC-FDMA and SSRA, TV transmissions in FM or PCM-PSK, communication circuit set-up to remote islands or for emergency usage, and so forth. The basic experimental items have been decided as follows.

1. Measurements of on-board mission equipment characteristics
2. Experiments on signal transmission through satellite communication system
3. Measurements and evaluation of radio wave propagation characteristics
4. Experiments on satellite communication system operation
5. Experiments on satellite operation and control

The most remarkable point of the CS system is the introduction of the frequency band of 30/20 GHz for communications overcoming many technical difficulties, especially in propagation effects. The above experimental items are purely technical oriented, and some applications or social oriented experiments will be conducted in the latter half of the three year period.

Table 4
Results of Initial Check-up
(Mission equipments)

Item	Requirements	Results
K-band transponders		
Output power	≥ 34.0 dBm	34.3 dBm to 35.2 dBm
Input-output charact.	≤ 1.0 dBm	≤ 0.8 dB
Freq. conversion	9800,000 ± 157 KHz	9799,820 to 9800,050 KHz
Freq. response	for f_0 ± 70 MHz ≥ - 2.0 dB	for f_0 ± 70 MHz ≥ - 0.6 dB
Delay charact.	for f_0 ± 70 MHz ———	for f_0 ± 70 MHz + 2.8 nS worst case
Spurious	< - 40 dB	negligible
Power Consumption	———	40W to 30W
C-band transponder		
Output power	≥ 34.5 dBm	≥ 35.01 dBm
Input-output charact.	≤ 1.0 dBm	0.0 dBm
Freq. conversion	2225,000 ± 35.6 KHz	2224,998 KHz
Freq. response	for f_0 ± 70 MHz ≥ - 2.0 dB	for f_0 ± 70 MHz ≥ - 0.2 dB
Delay charact.	for f_0 ± 70 MHz ———	for f_0 ± 70 MHz + 2.7 nS worst case
Spurious	< - 40 dB	negligible
Power consumption	———	27W (G_1), 35W (G_2)
Antenna		
K-band	for Main-land ≥ 35 dB	for Main-land ≥ 35 dB (estimated)
C-band	for Japan territary ≥ 25 dB	for Japan territory ≥ 27 dB (estimated)

IV. INTERIM REPORT ON THE CS EXPERIMENTAL RESULTS

Beginning May 15, regular communication experiments have been conducted only for two months, and only interim tests results can be reported here.
In this experimental period, only Kashima MFES, Yokosuka FES, and C- and K-band vehicle mounted type STESs have participated. Mainly the MFES test results will be described here.

1. FDM-FM and FM-TV Transmission Characteristics

Basic FDM-FM voice transmission characteristic, such as cross-talk noise, S/N vs ground transmitter power and degradation of S/N due to rain attenuation in K-band have been measured in a satellite loop-back configuration. S/N and DG.DP characteristics of the FM-TV signal transmission have been measured also at the MFES. One sample of the cross-talk modulation characteristic measured by a noise loading test metohd is shown in Fig. 2. In K-band, about 3 dB spin modulation appears, and the averaged values in C/N and S/N were obtained. An emphasis circuit of CCIR REC. 275-2 was applied, but improvement in the higher frequency range is not sufficient for the CS system. It was verified that the main cause of the cross-talk modulation did not lie on the satellite transponder characteristics but on the ground receiver BPF characteristic by referring to

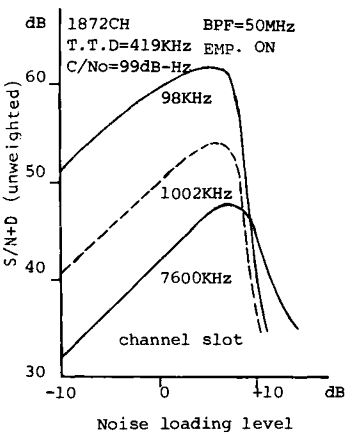


Fig. 2 Noise Loading Characteristics

the measured frequency response and delay characteristics of the FM signal transmission route.
The F1 transponder can be operated in both modes of AGC-on and -off. Fig. 3 shows the C/No and S/N characteristics when gound transmitter power was changed. Better C/No and S/N can be obtained in the AGC-on mode, and poorer S/N values by 0.5 to 2.5 dB were obtained compared with the theoretical estimates assuming noise is purely Gaussian. Fig. 4 is a sample of the S/N variation on a light rainy day. Received beacon signal level at 20 GHz is also shown for reference. It shows that degradation of S/N due to rainfall attenuation is serious because C/N degrades in both up- and down-links. In the TV signal transmission via satellite, the usual maximum frequency deviation is 15 to 30 MHz, but much larger frequency deviation can be used in the CS experiments because of wider transponder bandwidth. S/N vs C/N characteristics are shown in Fig. 5. It was verified that threshold C/N values of the TV transmissions were 15 dB and 12 dB in the cases of 50 MHz and 20 MHz p-p frequency deviation respectively. DG and DP characteristics were measured as shown in Table 5. The amplitude and delay characteristics are good and there is

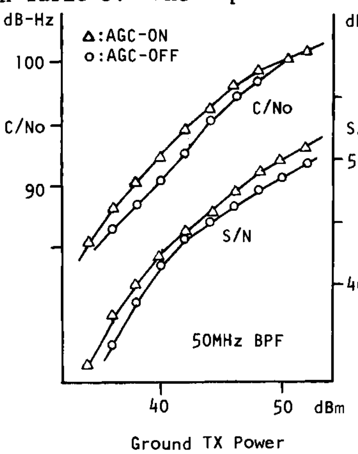


Fig. 3 S/N,C/No vs Ground TX Power

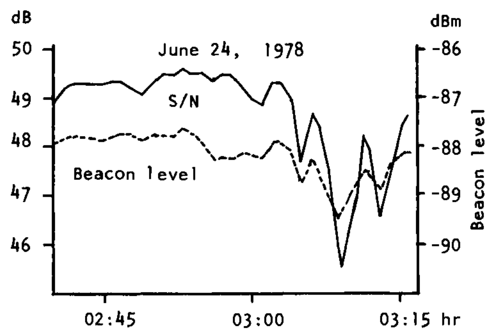


Fig. 4 S/N Variation on Rainy Day

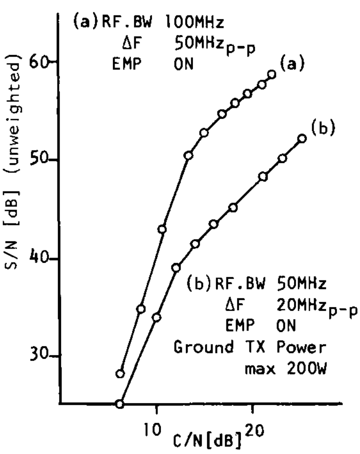


Fig. 5 C/N vs S/N Characteristics (TV)

Table 5 DG.DP Characteristics

RF BW (MHz)	50		50		100	
ΔF (MHzp-p)	20		36		50	
Emphasis	ON	OFF	ON	OFF	ON	OFF
DG (%)	0.5 (0.2)	3.0 (1.8)	0.5 (0.5)	7.0 (7.0)	0.5 (0.5)	2.0 (1.0)
DP (deg)	1.0 (0.8)	2.0 (2.0)	1.5 (1.0)	6.0 (6.0)	1.0 (0.5)	2.0 (1.0)

( ) : values in modem loop-back

little waveform distortion. Investigation must be made for obtaining optimum frequency deviation and suitable emphasis characteristics for the CS system, considering required rain attenuation margins. Also, experiments of more than two channel color TV transmission through a wide bandwidth transponder will be conducted.

2. PCM-PSK Voice and TV Transmission Characteristics

First, basic PSK signal transmission characteristics through the CS K- and C-band transponders were investigated using the PSK Test Equipment which can process PSK signals with various transmission parameters in bit rate, modulation phase, dispersal, mark ratio, and so forth.

Fig.6 shows BER vs C/No characteristics of the Gl transponder link. 97 dB-Hz is obtained for a ground transmitter output power of 54 dBm. This results in up-link margins of 12 and 16 dB for obtaining 10^{-4} BER in 64 Mbs- and 32 Mbs-4 phase PSK signal transmissions respectively. In the tests of PSK signals transmission through the CS K-band transponders, following results were obtained.

(a) Roll-off spectrum shaping; BER is improved by about 0.5 dB for the rather poor link condition worse than 10^{-5} in BER.

(b) Number of modulation phases; In the signal transmissions of 32 Mbs, higher Eb/No is required by 0.5 dB in 4 phase modulation case compared with the 2 phase modulation case for getting same BER value.

(c) Transmission rate; In the PSK signal transmission with 4 phase modulation, higher Eb/No by about 1 dB and by 2.5 dB is required in 64 Mbs and 96 Mbs transmission rate respectively compared with 32 Mbs in order to get same BER (10^{-4})

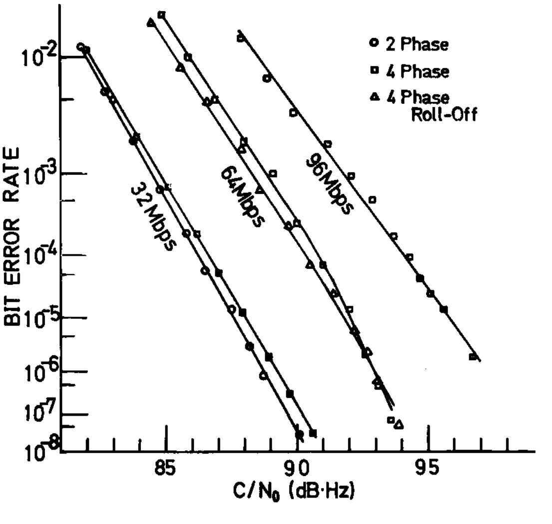
(d) AGC function of the satellite transponder; Fl transponder can be operated in either AGC-on or -off mode by ground command control.
It was found that BER characteristics in AGC-on mode is better by 0.5 dB compared with the AGC-off mode.

(e) Baseband characteristics; In PCM telephone transmission, S/N is improved along with increased C/N up to 10^{-4} in BER, and unweighted S/N of 42 dB is obtained. However, S/N can not be improved more because of quantization noise. In the PCM-TV signal transmission, unweighted S/N of 50 dB is obtained in the condition of BER of 10^{-4}. DG and DP characteristics were measured as 2.0 % and 1.0 deg. respectively.

3. Performance of PCM-TDMA System

The PCM-TDMA system developed in RRL is a system clock incoherent type and has suitable functions for K-band multiple access communications such as diversity station switchover, considering potential instability of transmission path

Fig. 6 BER vs C/No Characteristics



conditions due to rainfall attenuation. The main parameters of the system are shown in Table 6. Measurements were made of such items as BER vs C/N, overdrive effects of the transponder TWT for TDMA burst signals application in AGC-on mode, initial acquisition process and so forth.

Table 6 System Parameters of RRL PCM-TDMA

Transmission rate	65.536 Mbps
Transmission capacity	960 telephone channels
Frame length	500 μ sec
Frame structure	three steps superframes, 2^{10}, 2^{14}, 2^{17}, bits
Modem	two phase DPSK, Delay det.
System clock	non-coherent among bursts
Initial acquisition	low level PN codes
Baseband interface	30 channels PCM Codecs
Rainfall protection	Error rate monitoring Switchover of reference station diversity station

It was verified that all functions were working normally. The overdrive effects depend on the duty factor of the TDMA signals, and the leading portion of received burst signals is suppressed for several tens of microseconds. Optimum operating drive level of the TWT and proper time-constant of the AGC circuit were investigated in detail. Performance of low level initial acquisition using PN code worked quite well, and 100 % success of initial acquisition was attained until the level of PN code was reduced to 39 dB below the normal signal level.

4. Propagation Characteristics

Experiments on radio wave propagation especially on rainfall attenuation effects in K-band are quite important for getting required link margins in the operational satellite communication system in Japan. Measurements of the field strength of the 20 GHz beacon signal started in January, 1978.

Fortunately, the propagation experiments of ETS-II satellite program, which has 1.7, 12 and 34.5 GHz beacon signals, have been conducted at Kashima simultaneously up to May 8. Detailed statistical analysis is now being carried out, and only one sample of the data is shown in Fig. 7, which is the accumulated probability distribution of rainfall attenuation in April, 1978.

At Kashima MFES, other kinds of propagation studies such as noise temperature increases, cross-polarization discrimination, diversity effects and so forth are also being conducted with the aid of various kinds of meteorological aids including weather radar.

5. Other Experiments

In parallel with the RRL experiments, NTT is also conducting various kinds of experiments such as satellite RF links characteristics with their various earth stations, diversity effects between Yokosuka FES and a small terminal for field strength measurement located about 21 km away from Yokosuka, PCM-TDMA system performances of system clock coherent type, link setting between Yokosuka FES and C-band and K-band vehicle mounted type STRS and so forth. Useful data are being accumulated. More detailed experimental results of RRL and NTT will be presented at future conferences.

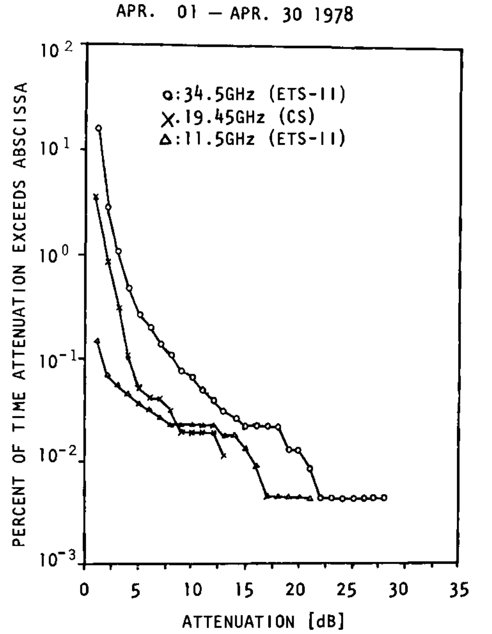


Fig. 7 Accumulated Probability Distribution Functions of Rainfall Attenuation

V. LAUNCH AND INITIAL CHECK-UP OF BSE PERFORMANCES.

BSE was launched by No. 140 Delta 2914 rocket on April 8, 1978 JST from the Eastern Test Range of the USA, and put into a transfer orbit at 23 minutes 54 seconds after the lift-off.
Executing a series of maneuvers, such as attitude correction, AM firing in the transfer orbit, and shifting sequences into the zero-momentum three axis attitude control which is peculiar to the BSE in the drift orbit, BSE succeeded in attaining its final geostationary position of 110 deg.E on April 26.
The history of the BSE spacecraft development is shown in Fig. 8 and maneuvers conducted during the period of AM firing to final orbit position acquistion are shown in Table 7. The general characteristics of the BSE spacecraft are also shown in Table 8.
The BSE is named YURI which is Japanese for lily. The BSE is held within the accuracy of ± 0.1 deg. and ± 0.2 deg. in orbit position and antenna beam pointing respectively. The on-orbit initial performance check of the spacecraft was conducted by NASDA in cooperation with RRL. All subsystems of the spacecraft bus and mission equipments were examined in detail during the drift and stationary orbit phases by telemetry data reduction and satellite loop-back test methods. The test results are summarized in Table 9 and 10. It was verified that all subsystems were in good operational condition. Functions of both S- and K-bands TT&C are normal. Results of attitude control tests with the mono-pulse sensor were good. The solar array drive mechanism works satisfactorily, keeping within ± 1.0 deg. of the sun direction. The solar array is estimated to generate more than 1 kw. The temperatures at various parts of the spacecraft are all in reasonable range.
The antenna beam pointing is kept within ± 0.2 deg. in both roll and pitch axes.
Operating condition of mission equipments were tested with commands and telemetry signals. It was verified that both transmitting and receiving parts could be switched normally, and all components were in normal operating condition with regard to voltage, current, RF input/output level, operating temperatures, etc.
Color TV channels maintained constant output power of 100 watts for satellite input receiving levels of -56.7 to -70.7 dBm.
RF characteristics such as in-band amplitude/frequency, delay distortion, spurious components, third order modulation product at simultaneous 2 channels transmission of color TV signals, were tested with satisfactory results.
Baseband characteristics of the overall system consisting of the BSE main station and BSE communication transponders were examined with respect to C/N, linear and nonlinear distortion, S/N, and amplitude/delay frequency characteristics with adequate results to guarantee BSE experiments for the satellite lifetime of 3 years.

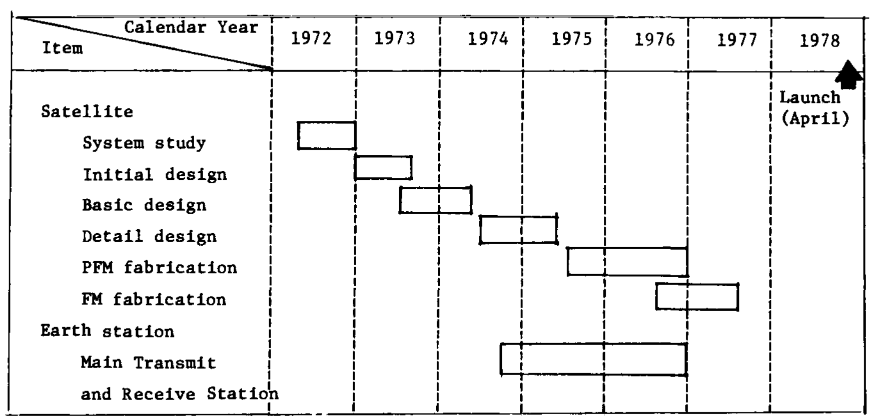


Fig. 8 BSE Schedule of Development

Table 7 Main Events of Three Axis Acquisition

Event	Executing time
AMF	9^h33^m, April 9
S band TT&C black-out	~ 17^h52^m, "
Earth sensor calibration	19^h32^m, "
Earth orient precession	0^h30^m, April 10
#1 Despin (59.4 → 36.8rpm)	4^h35^m, "
Calibration despin (36.8 → 34.5rpm)	5^h52^m, "
#2 Despin (34.5 → 1.44rpm)	6^h45^m, "
Earth acquisition	7^h25^m, "
#3 Despin (1.44 → 0.08rpm)	7^h34^m, "
Solar array panels deployment	7^h35^m, "
Solar array panels rotation drive	11^h19^m, "
Yaw axis acquisition	12^h23^m, "
Wheel acquisition	13^h16^m, "
#1 Pitch axis unloading	17^h05^m, "

VI GROUND STATIONS AND EXPERIMENTAL ITEMS IN BSE PROGRAM

Various kinds of ground stations have been prepared by RRL and NHK for the BSE experiments. The Main Transmit and Receive Station (MTRS) was constructed at Kashima by RRL for broadcasting experiments and TT&C operations in Ku-band.
NHK has installed Transportable Transmit and Receive Stations (TTRS, Type A and B), Receive Only Stations (ROS, Type A, B and C), and Simple Receive Stations (SRS) for broadcasting experiments in Ku-band.
Using these earth stations, various kinds of BSE broadcasting experiments are to be conducted for about three years by RRL with close cooperation of NHK.
BSE experimental items can be summarized into three categories as follows.

1. Experiments on basic technologies concerning service area, transmission systems, propagation, frequency sharing, characteristics of spacecraft and ground facilities.
2. Experiments on control of satellite and broadcasting system including access to the spacecraft by multiple ground stations.
3. Experiments on TV reception including assessment and improvement of reception techniques.

Though the standard transmission parameters are those given in Table 11, various kinds of tests will also be conducted. These are tests of multi-channel sound, multiplexed TV signal, Y/C separated video transmission signals, digitized TV signal, multiple still pictures, and others. Experiments of broadcasting of standard time and frequency accompanying the TV signal will also be conducted.

Table 8 General Characteristics of the BSE Spacecraft

Physical config.	Width 132cm Length 119cm Height 309cm Solar array panel (Deployed) Total length 893cm Width 148cm
Weight	At launch 665Kg On orbit 352Kg
Attitude control	Zero-momentum wheels and hydrazine thrusters in all three axes
Communication subsystem	Antenna Center-feed shaped-beam parabalic antenna Antenna gain Mainland : higher than 37 dB Remote islands : higher than 28 dB Transponder Ku-band (14/12GHz) Simultaneous two-channel TV broadcasting Bandwidth A ch (A_1, A_2) : 50MHz B ch (B_1, B_2, B_3) : 80MHz Output : 100W/ch
Electrical power subsystem	Solar cell array 1000W at BOL 780W at EOL
Ant. pointing	Accuracy within±0.2°
Station keeping	E-W within ±0.1° N-S within ±0.1°
Life-time	3 years

After the initial check of satellite performance, regular broadcasting experiments started on July 20. Any detailed experimental results have not yet been obtained due to the short experimental period, but BSE broadcasting color TV has been received by many SRS's distributed in the Japanese main islands, giving fairly good quality of received pictures.

VII. FUTURE PLANS OF CS / BSE PROGRAMS AND THEIR FOLLOW-ON SATELLITES

In the CS program, not all kinds of ground terminals have been available at this time, as some are still now under preparation. They are SCPC terminals for use at Kashima MFES and Yamagawa Radio Wave Observatory, K-band field strength measuring terminals for use at Wakkanai and Yamagawa Radio Wave Observatories, and SSRA communication terminal equipments of RRL.
NTT is also completing construction of Sendai FES, C-band TES for use in Hachijo Island, and K-band vehicle mounted type STES for TV transmission. Work on these

Table 9 Results of Initial Check-up (Bus Equipment)

Item	Requirements	Results
TT&C subsystem		
(1) Telemetry xmtr		
S-band output	≥ 29.3 dBm	# 1 ≥ 31.7 dBm # 2 ≥ 31.5 dBm
K-band output	≥ 0 dBm	# 1 10.0 dBm # 2 10.3 dBm
(2) TLM Sig. modulation	1.25 rad	normal
(3) RNG Sig. modulation	0.5 ∿ 1.5 rad	normal
Electrical power subsystem		
(1) Solar cell array	at 3 years EOL	
generating power	≥ 785 W	719.8 W max (measured) about 1 kW (estimate)
(2) Voltage stability	28 V ± 1 %	27.8 ∿ 28.0 V
Antenna & attitude control subsystem		
(1) Ant. pointing	≤ ± 0.2°	0.16° max (Pitch axis) 0.13° max (Roll axis)
(2) Attitude control by sensors conbination	Two sensors out of ES, SSA, MP	normal
Thermal control subsystem		
(1) Heaters		normal
(2) Temperature		normal
Propulsion subsystem		
(1) Orbital position control	E-W within ± 0.1° N-S within ± 0.1°	possible
(2) Fuel quantity	with margin for 3 years	adequate

stations or equipments will be finished toward the end of this year at which time they will be used for designated experiments.
Almost all of the technology oriented experiments listed in Chapter III will be conducted throughout the whole experimental period, and some applications or social oriented experiments, such as satellite computer networks, data-facsimile or still picture transmission in a MCPC system, voice or data traffic connection between satellite and terrestrial communication networks in a more operational framework, and others will be conducted in parallel, in the latter half experimental period. Of course, satellite performance degradation tests and radio wave propagation experiments will be continued for the full experimental period.
The Ministry has made a proposal to the Space Activities Commission this year that an operational communication satellite, CS-2, should be launched in 1982 fiscal year with an on-orbit spare satellite. According to the proposal, the CS-2 and its spare satellite will be similar to the present CS satellite in respect of their scale and functions. Composition of transponders, communication channel capacity, attitude and station keeping stabilities as well as general shape, weight and DC power will be almost the same as those of the CS. Expected life will be 5 years. They will be launched from Tanegashima Space Center by Japanese N-II type rockets which have a launching capability equivalent to Delta 2914 rocket. Detailed satellite configuration is now under investigation reflecting the results of the CS's development and experiments. Basic and detailed design of the CS-2 will start next fiscal year simultaneously with development of mission transponder engineering models.

In the BSE program, broadcasting experiments have just started on July 20 this year,

Table 10 Results of Initial Check-up (Mission Equipments)

Item	Requirements	Results
Ku-band transponder		
Output power	$\geq$ 100W	100.5 ~ 113.8W
Output circuit loss	2.3dB	(-1.9 ~ 1.6dB)
Freq. response	for 50MHz(chA) within ± 1dB	for 50MHz(chA) within ± 0.5dB
	for 80MHz(chB) within ± 1dB	for 80MHz(chB) within ± 0.65dB
Delay charact.	for 50MHz(chA) and 80MHz(chB) $\leq$ 6ns	for 50MHz(chA) and 80MHz(chB) 4ns worst case
Overall noise figure	$\leq$ 8.0dB	(6.94dB)
Spurious	$\leq$ -50dB	satisfied
Intermodulation	$\leq$ -40dB	< -41.5 ~ -43.0dB
Output level variation	$\leq$ ±1.0dB/day	±0.8dB/day
Output freq. variation	$\leq$ $\pm 5\times10^{-6}$/day	4.4×10^{-7}/day
Ku-band antenna	for Main-land $\geq$ 37dB	for Main-land $\geq$ 37dB(estimated)
	for Japan territory $\geq$ 28dB	for Japan territory $\geq$ 28dB(estimated)

( ) : measured on ground

Table 11 Standard of TV Signal Transmission Parameters in BSE Program

System	NTSC Standard System M (525 lines, 30 frames/sec)
Modulation	FM, Freq. dev. 12 MHz (p-p)
Sound subcarrier	
Frequency	4.5 MHz
Modulation	FM, Freq. dev. 25 kHz (0-p)
Sound/Video ratio	1/6
Emphasis	CCIR Rec. 405-1
Dispersal	22dB (600 kHz p-p) in triangle wave form

and it is expected that the experiments listed in Chapter VI will be performed with satisfactory results. As in the case of CS, near operational or social oriented experiments such as educational TV broadcasting, standard time and frequency signals distribution accompanied with TV, and so forth will be conducted in the latter half experimental period.

The Ministry has also announced that consideration is being given to the launching of an operational broadcasting satellite, BS-2, one year after the CS-2 launching. There are many problems to be solved before deciding on a satellite configuration and functions in order to fit the restrictions made in the last WARC-BS in such points as selection of frequency slots, adoption of circular polarization, required EIRP for individual reception, and so forth. In any case, experimental results of the BSE program will be reflected to the system configuration of both space and ground segments.

Though final national decisions have not yet been made, the Ministry is now making preparatory arrangements for realizing these future operational satellite systems.

VIII. CONCLUSION

Japanese CS and BSE spacecraft have been launched successfully and regular communication and broadcasting experiments are being conducted following predetermined schedules. Except for two sets of K-band transponders of CS, all subsystems of both spacecraft are working normally. Though only interim experimental results of the CS program can be presented this time, it is expected that valuable experiments will be performed for three years. Concepts for an operational communication satellite, CS-2, and broadcasting satellite, BS-2, have been developed and announced by the Ministry of Posts and Telecommunications. The experimental results of the CS and BSE programs will be reflected in the establishment of these operational systems.

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THE TECHNOLOGY OF LARGE MULTI-FUNCTION COMMUNICATION SATELLITES IN THE POST INTELSAT V ERA

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ABSTRACT

In the post Intelsat V era - in the 1990's and into the 21st century - communication satellite systems and technology will arise from a broadening of the user-base of requirements upon which telecommunications is based. By the 1990's, the giant satellites of the Intelsat V variety will be an accomplished fact and both international and domestic satellite communications will be matured systems which will be the fountainheads of new and innovative uses of satellite communications to benefit man and his environment. It is in this era that the giant multi-function satellite will be developed and placed in geosynchronous orbit using either Ariane or using Space Shuttle with EVA (extravehicular activity techniques). In the years following the 1980's, more and more functions will be required of communication satellites and these satellites will become complexes of antennas and communication transponders and switching centers to not only provide for the increasing telephone, television and computer data traffic, which is growing in magnitude with each year, but also to serve new functions and services such as maritime and aeronautical services, meteorology and navigation, business and government networks teleconferencing, library and health services, personal communications and satellite-to-satellite communications. In addition, providing a multiplicity of functions into one satellite will avoid the crowding of the geosynchronous arc with many single function satellites, providing instead multiple complexes of communication transponders at points in this arc which can provide the services required without introducing the interference which could inhibit this valuable natural resource. This paper will review and discuss the present day and new technologies which are required to implement these giant satellites. The various concepts relating to the future giant satellites as published in 1977 will be reviewed relative to the structures, functions, and technology associated with these satellites. These concepts of giant satellites will include the Cuccia (present author) national satellite, the Edelson-Morgan (Comsat) Orbiting Antenna Farm (OAF), the Beckey (U.S. Aerospace) satellite for personal communications wrist-radio, the Morrow (Lincoln Labs) packet-switching system, the Reudink-Yeh (Bell Labs) scan beam satellite, the Jaffe-Fordyce (NASA) switchboard in the sky, the Rosen-Jones (Hughes) giant spinner, and the Koelle (MBB) giant platform. These satellites will be discussed in terms of commonality and modularity of payload and antenna requirements, and the techniques required to construct and launch the giant satellites into geosynchronous orbit including the use of the Space Shuttle to lift a bay full of satellite parts into low earth orbit where the satellite is constructed in space, checked out, and then sent into geosynchronous orbit.

INTRODUCTION

The yearly growth in the number of telephones used in the world is a strong force in the burgeoning growth of the art of satellite communications. However, many types of communications systems are now being developed concurrently to serve an increasing number of user communities, which by the year 2000 can virtually subordinate in relative dominance now enjoyed by commercial domestic and international telephone systems in world telecommunications. These types of communications systems include twisted-pair wire systems, cable, submarine cable, terrestrial radio, fiber optic systems, guided mm-wave systems, and satellite communications. The communication satellite has now come into its own as a major source of interconnecting continents and remote points and now handles more than 60% of all international telephone traffic and is becoming a major source of domestic traffic in areas of the world where other terrestrial systems are either impossible or non-economic. The number of satellites being placed in the geostationary orbital arc are increasing with each succeeding year and as pointed up by W. Morgan (1), this arc is being rapidly filled by closely spaced satellites, as shown in Figures 1A and 1B for the visible geostationary arc above Clarksburg, Md., with ominous implications of interference due to these satellites and saturation of the arc from the standpoint of available locations.

A viable solution to the interference caused by the saturation of the geostationary arc was presented in 1977 by Dr. Burton Edelson, Director of Comsat Laboratories, who, with Walter Morgan, proposed the use of large space stations known as Orbiting Antenna Farms (OAF's) (2), which would combine the functions and operations provided by many satellite systems onto one orbiting platform. The use of OAF's would not only eliminate a major source of interference and orbit saturation, but also increase the effective use of the orbital arc from the standpoint of the various users and frequencies which could be employed as listed in Tables 1 and 2, but also the use of feature of repair and maintenance in orbit as submitted by G. Gordon and W. DeRocher (3), which could also extend the life expectancy of these OAF's well above the 7-year life expectancy now characteristic of communication satellites.

Following the disclosure of the innovative OAF concept, other concepts for large space structures for telecommunications were also disclosed in 1977. This paper is intended to review these various advanced space systems proposed in both the United States and Europe and to develop the growing technological advances which make these space stations a logical consequence and development from communications satellites such as Intelsat V and TDRS now in construction.

THE INTELSAT POSITION ON OAF'S

In the year since the disclosure of the Edelson-Morgan OAF concept, many new concepts have been offered in the art and technology relating to space platforms for telecommunications, including a discussion of a "national" antenna farm by the present author (4) at the IAF-77 Congress in Prague, Czechoslovakia. Publication of NASA's Jaffee-Fordyce giant antenna platform concept (5) has done much to increase interest in the potentiality of OAF types of spacecraft. However, the OAF concept was changed from speculation to recommendation by Dr. Santiago Astrain, Director General of Intelsat in his testimony to the U.S. House of Representatives (6) in May 1978, when he made the following comments: "The proliferation of communications satellite systems, some of which could divert traffic from Intelsat and erode economics of scale, is noted as a problem. Also emphasized is the problem of demands upon the orbital arc and radio frequencies. Finally, the possibility of large space stations for the 1990's, equipped with complex orbital antenna farms and multiple communications packages which might perhaps be operated under the framework of the Intelsat Agreements is noted as an area of productive study for the future. Intelsat would urge the U.S. government to continue an active and aggressive U.S. space program, particularly in the areas of development of new communications satellite technology and of production of reliable and cost-efficient launch vehicles such as that represented by the Space Transportation System. To be even more specific, we would suggest the following satellite technologies that would be of great interest to users of satellite communications, including Intelsat. These include: operation with large antennas in space; multibeam and shaped beam antennas; intersatellite communications links; millimeter wave and laser transmission and propagation; advanced propulsion, stabilization and orientation techniques, including ion engines; on-board satellite switching and signal regeneration; new spectrum/orbit-efficient modulation schemes; large electrical power systems and advanced battery and fuel cell development; fabrication techniques for large structures in space, including orbital antenna farms, modularization techniques and lightweight structural design."

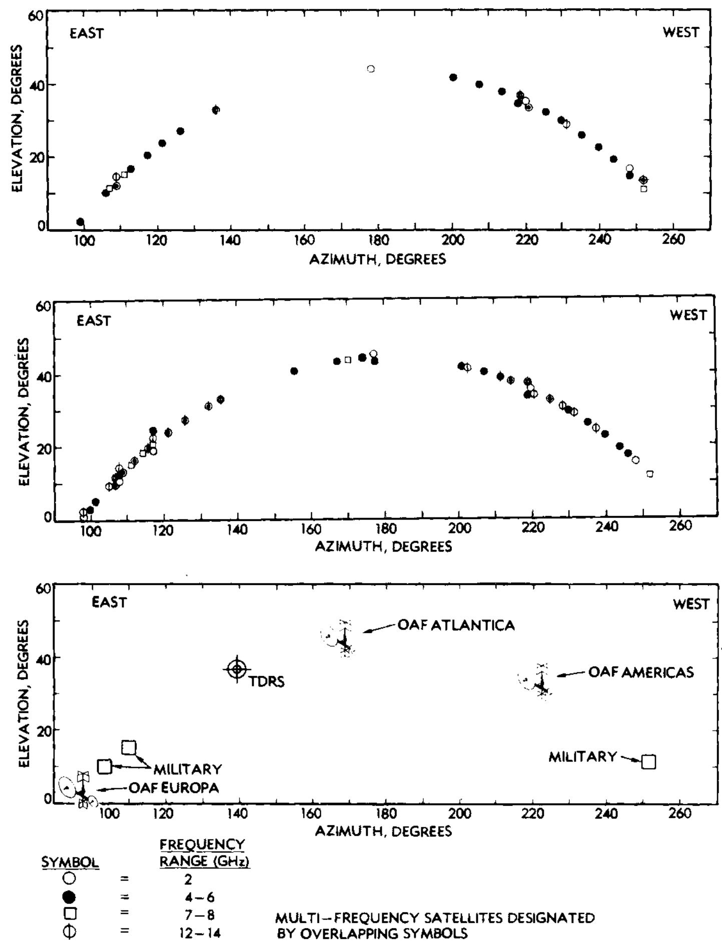

Fig. 1. Actual and Predicted Satellite Density in the Visible Orbital Arc as Seen from Clarksburg, Md. by W. Morgan of Comsat Labs for 1977 (top), 1981 (middle) and the 1990's (bottom) Illustrating the Advantage of the OAF Concept in Reducing the Number of Satellites Crowding the Orbital Arc in this Space

TABLE 1

UP/DOWN LINK FREQUENCIES

Up-Link	Down-Link	Bandwidth
1.537 - 1.541	1.6385 - 1.6425	4 MHz
5.925 - 6.425	3.7 - 4.2	500 MHz
7.925 - 8.425	7.25 - 7.75	500 MHz
14.0 - 0.25	11.7 - 12.0	500 MHz
27.5 - 30.0	17.7 - 20.0	2.5 GHz
30.0 - 31.0	20.2 - 21.2	1.0 GHz

TABLE 2

VARIOUS USERS AND FREQUENCIES DERIVED FROM W. MORGAN

Users/Missions	Up/Down Frequencies
Intercontinental Trunking	6/4 and 14/11 GHz
Regional and Domestic Trunking	6/4, 14/11, and 30/20 GHz
Regional and Domestic Networks	6/4 and 14/11 GHz
Business Networks	6/4 and 14/11 GHz
Electronic Newsprint	6/4 GHz
Maritime Services	1.6/1.5 GHz
Aeronautical Services	1.6/1.5 GHz
Mobile Land Communications	UHF/UHF
TV Broadcast	14/UHF, 14/12 GHz, 6/2.5 and 6/UHF GHz
TV Distribution	6/4 and 14/11 GHz
Educational TV	14/2.5 GHz
Teleconferencing	14/11 GHz and 14/2.5 GHz
Bush Voice	2.5/2.5 GHz
CB/Amateur	24/24 GHz
Intersatellite	55/55 GHz
Standard Time/Frequency	14/0.4 GHz
Disaster Aid	6/4 GHz
Search and Rescue	0.149/0.135 GHz
Navigation	1.6/4.5 GHz
Meteorology	14/1.7 GHz
Earth Exploration	14/8 GHz
Public Service	14/11 and 30/20 GHz
Military	8/7 and 31/21 GHz
Personal Communications (Paging)	1.5 GHz

Modern Giant Satellites

The twenty years since Sputnik has resulted in many large high capacity communication satellites which are now in orbit (Statsionar T, Molnyia, Intelsat IV and IVA, Anik, CTS, Japan CS, etc.). Even larger satellites are being built (Intelsat V, Insat, TDRS, European ECS, Japan ETS-III, etc.). These satellites are of both spinner and spin stabilized types and the satellites now in orbit have provided a dramatic increase in capacity in telephone circuits from240 circuits for Intelsat I in 1975 to 6000 circuits for Intelsat IVA in 1975.

Intelsat V and Insat represent the most modern satcom technology for communication satellites. Intelsat V, now being built by Ford Aerospace & Communications Corp. (FACC), is a high-capacity, commercial communications satellite. Intelsat spacecraft growth is illustrated in Fig. 2. As many as 6 Intelsat V satellites will be operated simultaneously to interconnect more than 300 Intelsat earth terminals. Depending on the operational configuration employed at Intelsat, each satellite will carry up to 12,000 two-way telephone circuits and two color television transmissions. The powerful communications transmitters, sensitive communications receivers, and rf up-converters require nearly 800 watts of electrical power. Consequently, a large solar array area of nearly 20 square meters is required to provide electrical power for the communications and supporting subsystems. The solar array area necessitates a body-stabilized spacecraft configuration with deployable, sun-oriented solar panels. The spacecraft three-axis stabilized design is composed of a box-shaped main body 1.65 x 2.01 x 1.77 meters, containing the electronics and propulsion subsystems, and a truss-type tower holding the antennas. The tower extends from the earth-facing surface of the body. The spacecraft is oriented in space with the 2.01 x 1.77 m side facing north and south. The solar arrays extend from this surface approximately 7.8 m each side of the spacecraft. The antennas are oriented with the large 4 and 6 GHz reflectors on the east and west sides. The total spacecraft power requirement for synchronous orbit conditions is around 1200 watts. The power margin is 125.95 W at end of life

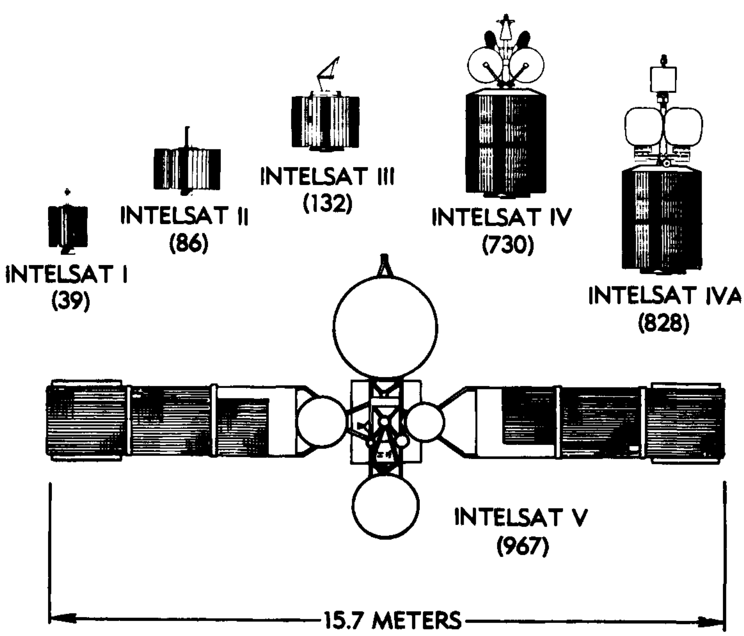

Fig. 2. The Intelsat Series of Satellites

(EOL) autumnal equinox and 172.68 W at end of life (EOL) summer solstice. The total spacecraft mass is around 1880 Kg which indicates a total spacecraft mass margin of 24 Kg. The communications subsystem of Intelsat V provides an rf bandwidth capability of 2137 MHz, which is three times that of its predecessor, Intelsat IV-A. It accomplishes this by means of extensive frequency reuse of 4 and 6 GHz, accomplished with both spatial and polarization isolation, and by introducing 11/14 GHz operation into the Intelsat frequency plan. The frequency reuse scheme is accomplished by a multiplicity of antenna coverages, which allows the spacecraft to transmit right (hemi) and left (zone) circularly polarized signals at 4 GHz to many east and west locations at the same frequencies. This provides a 4:1 frequency reuse factor for these locations.

The Insat, which is being built by FACC for the Government of India is a derivative of Intelsat V, which is a high capacity multi-function satellite whose capacity is quite differently oriented from that of Intelsat V. Insat will provide 12 channels in the 6/4 GHz bands for telecommunications. It will provide 2-channel broadcast satellite services at 3.5/2.6 GHz; a 1-channel data collection service will be provided at 0.402/4 GHz, and this satellite will include a visual and infrared imagery radiometer with a down-link at 4035.4 MHz. This satellite is of the 3-axis body-stabilized type developed for Intelsat V but uses body mounted antennas instead of an "antenna farm" to provide visibility for the imaging system. This satellite is designed for 1981 launch.

LAUNCH VEHICLES FOR MODERN SATCOMS

At present, a wide variety of launch vehicles are available to place communication satellites (satcoms) into geostationary orbit. They include the Atlas-Centaur and the Thor-Delta 2914, 3914 and 3910 series in the United States and the N-rocket in Japan. By 1980, the principal launch vehicle which will be available for large satellites will be the Ariane and the Space Shuttle Orbiter. The Orbiter must be augmented by an auxilliary stage or space transportation system to propel the satellite from a low earth orbit into the geostationary orbit. The Intelsat V has been designed to be compatible with not only Atlas-Centaur, but also with the Space Shuttle Orbiter and the Ariane launch vehicle. Fig. 4 illustrates the Intelsat V launch configurations by K. Reseck and D. Dwyre

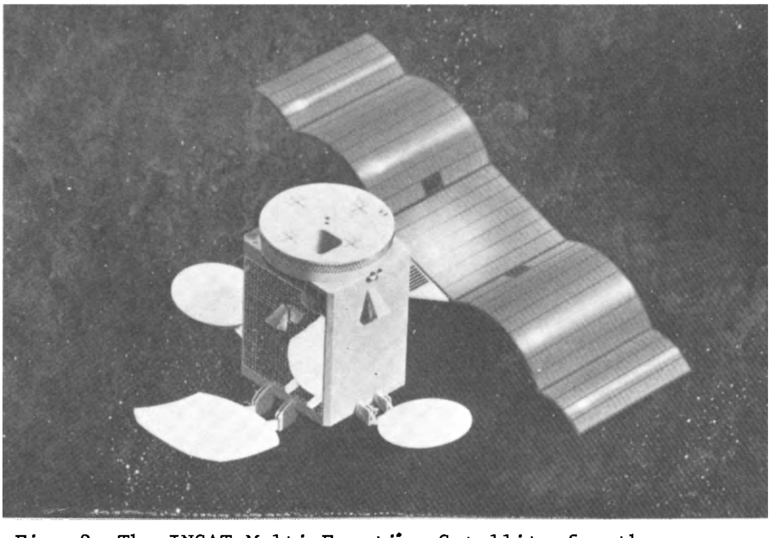

Fig. 3. The INSAT Multi-Function Satellite for the Government of India

(7), relative to both the Space Shuttle and the Atlas-Centaur including the Intelsat V and SSUS (spin stabilized upper stage) combination in F-4 which is a configuration planned for the 18th Shuttle flight. In addition to satellites using space transportation systems such as SSUS, which are launched on an angle from the Orbiter, launch structures for lifting a satellite vertically from the Orbiter bay are under development by Hughes for the SBS and by McDonnell-Douglas (Payload Assist Module - PAM) for Insat, as illustrated in Fig. 5 for SBS by M. Lyons and P. Dougherty (8). At present SBS and Insat, using their respective launch structures, are scheduled for launch on Shuttle flights 8 and 10 for SBS and 13 for Insat-A.

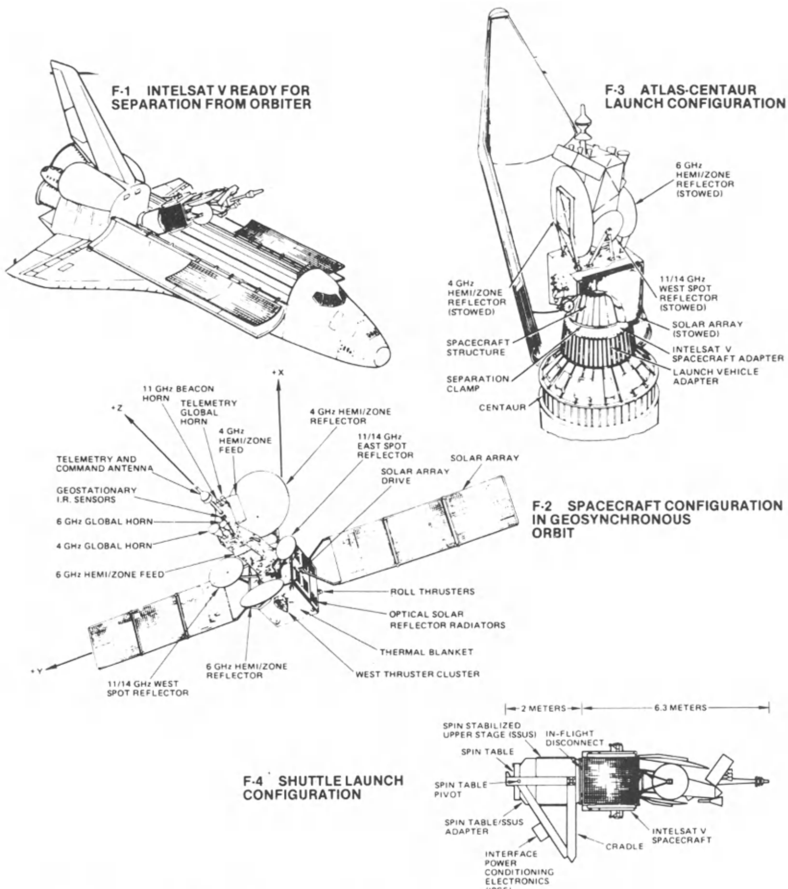

Fig. 4. Intelsat V Launch Configurations

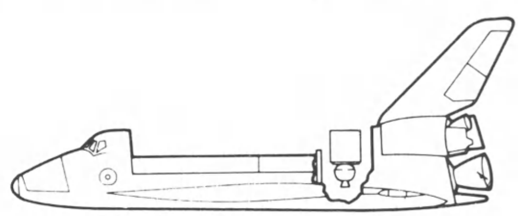

Fig. 5. SBS Payload Transverse Alignment

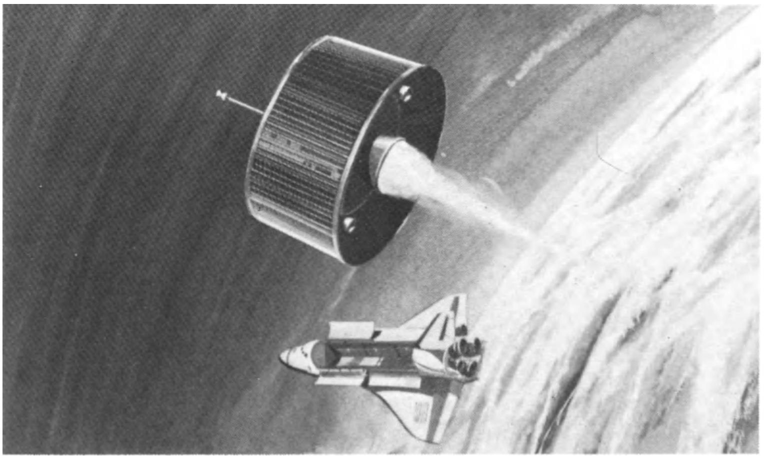

Fig. 6. The Hughes Syncom IV Spin-Stabilized Satellite Concept - Courtesy of C. Richard Jones

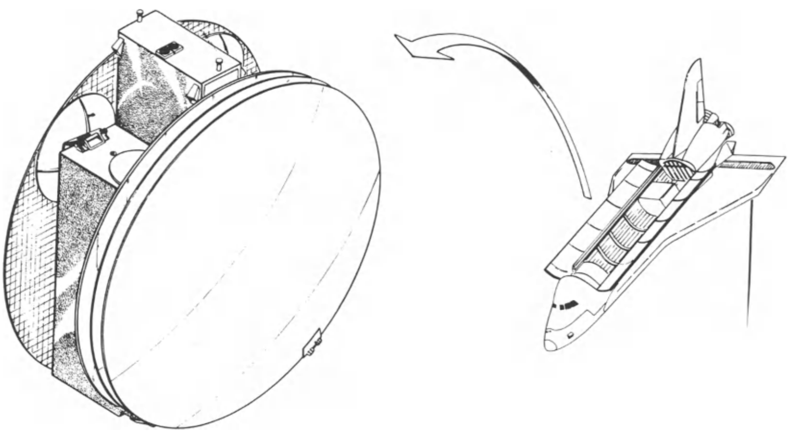

Fig. 7. The Ford Aerospace Currier-6 Three-Axis Stabilized Satellite Concept

OPTIMIZED SATELLITE CONFIGURATIONS FOR THE SHUTTLE ORBITER

The use of the Space Shuttle Orbiter and the various STS systems now in design has produced a "forcing" function in spacecraft design. Heretofore, communication satellites were designed to sit in a booster fairing in which heighth was acceptable as long as spacecraft diameter did not exceed the inner dimension of the fairing; i.e., 9 feet for the Atlas-Centaur and 7 feet for the Delta 2914. The 14-ft. width of the Orbiter bay and general cost factor relating to the use of a prescribed length in the bay (60 ft. long) as a length and weight oriented factor which provides a cost roughly proportional to the length used as a function of a cost of from 30 to 40 million dollars when the entire bay is used. Fig. 6 shows Syncom IV, a spin-stabilized geostationary communication satellite optimized for use in the Orbiter as proposed by H. Rosen and C. R. Jones of Hughes Aircraft Company (9). This satellite uses a large despun earth oriented platform on which communications antennas are mounted. In order to minimize the length of the configuration, the satellite diameter is made as large as practical - 14 feet.

Within this structure is included a solid perigee motor, and two liquid bi-propellant apogee boost motors. Figure 7 shows an optimized short length 3-axis body stabilized satellite as proposed by P. Crill and S. Kulick of FACC, using the full diameter of the Shuttle and round unfurlable solar panels. The perigee and apogee kick motors are included in the satellite structures. The Insat, with its payload assist module (PAM) also gives excellent optimization of Orbiter length, using a cubic box as shown with antennas folded against the spacecraft body at launch and using a solar array which will fold out from the structure. As the technology of using the Space Shuttle and the STS systems is developed, the variety of payload transfer systems for transferring a satellite from the Orbiter to the geostationary orbit can be expected to increase and the art to mature. The design of such transfer systems will materially impact on the cost of placing a spacecraft or platform into final orbit and it can be expected that unique designs will be developed for certain communication satellites. Fig. 8 shows an artist's concept of how two Intelsat V types of spacecraft could be designed to be propelled into transfer orbit by a round transfer assist cluster of perigee and apogee thrust motors.

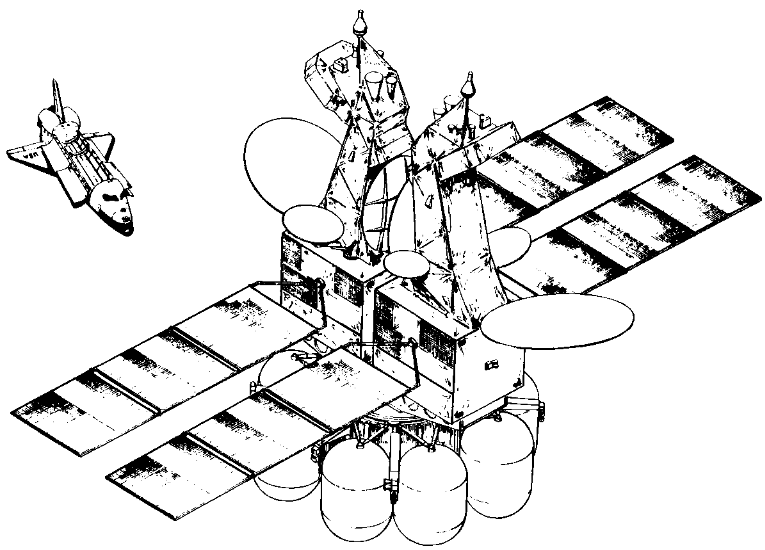

Fig. 8. Concept of a Dual Satellite System Launched by a Common Payload Transfer System from a Shuttle Orbiter

ASSEMBLY OF COMMUNICATION SATELLITES IN SPACE

The use of EVA (Extra Vehicular Activity) in the Space Shuttle era - in addition to the huge size of the Shuttle payload bay - will eventually lead to satellites in which the parts, girders, strutts, antenna sections, feed farm, transponders and computers can be designed in individual packages suitable for remote assembly in space, and once in earth orbit, put together by EVA crews, which will develop EVA experience during the late 1980's. The Extra Vehicular Activity of the Space Shuttle eventually will separate the Shuttle from merely being only an alternative booster. The Shuttle bay has a volume bounded by a length of 60 ft. and a diameter (six-sided) of around 14-15 ft. With a satellite designed to be assembled in space, a closely packed payload can be placed in the Shuttle bay in which a large number of differently shaped subsections can be packed. These can include long girders, antenna sections, feed assemblies already mounted on a feed farm, transponders, computers, and other electrical equipment in modular boxes, six-sided rather than round, as recommended by Walter Morgan, and as long as required with a capability of repair by EVA. Such subsections, carried by one or more Shuttle launches, can then be assembled in space as shown in Figures 9 and 10, checked out in each earth orbit, and then sent into geosynchronous orbit by an STS system. During the EVA era, many new techniques must be developed, however, from the simplest techniques of how to optimally connect waveguides, cables, and wires in space, to the tools and propulsion techniques used by astronauts to perform assemblies of complicated structures in space at some distance from the Space Shuttle Orbiter.

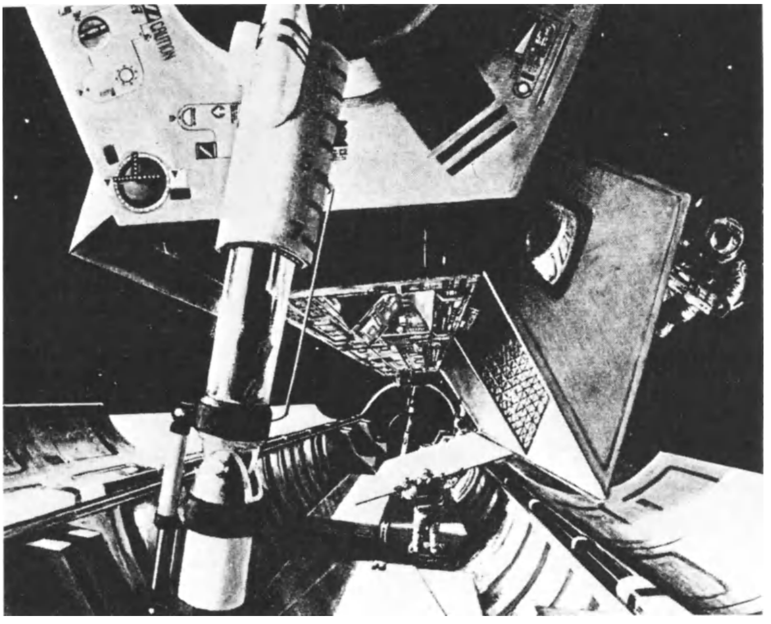

Fig. 9. NASA Conception of Astronauts Performing Assembly Functions in the Orbiter Bay

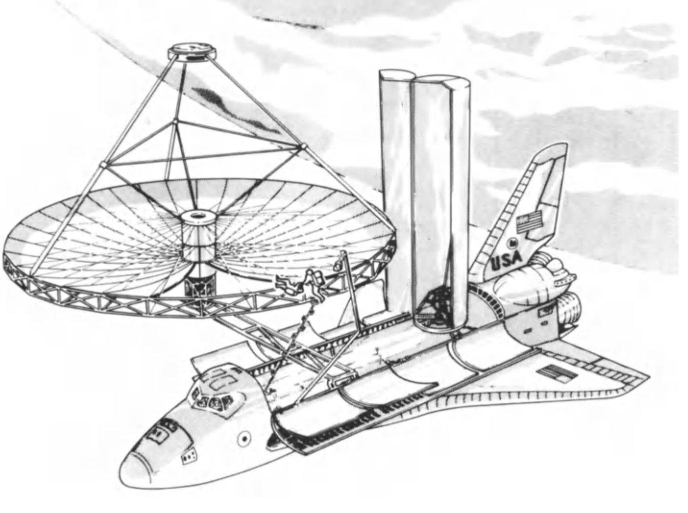

Fig. 10. NASA Conception of Astronauts Assembling a Large Antenna

MISSIONS OF THE LARGE SPACE TELECOMMUNICATION PLATFORMS

The size of the OAF's and large space telecommunication platforms cannot be justified based on a technological desire for size alone. Actually, the present author is in agreement with W. Morgan (10) that space antennas larger than fifty feet in diameter probably are not warranted, particularly for frequencies from 4 to 55 GHz. Actually, size and complexity will be determined by how many missions of Table 2 are to be served and two other principal aspects of the use of these large orbiting antenna farms; i.e., the spatial reuse of frequency by spot beams which makes optimum use of the frequency spectrum and the computer controlled interconnectivity of these spot beams in space.

The technology of spot beams, contoured to fit a particular area on earth is a new antenna technology which has matured only during the last decade and is achieving significant use on Intelsat IV-A and Intelsat V by use of offset multiple-horn reflector systems, and on DSCS-III using lens antennas. As pointed out by C. L. Cuccia, R. Davies, and E. W. Matthews at ICC-77 (11), multiple-horn offset-fed reflector systems using a 37-ft. reflector can be produced at 12 GHz to access 40 major U.S. cities with less than 17-20 dB of co-channel interference between cities. This reflector system will use 3/16 degree beamwidths. The technology for producing spot beams can be continued to produce thousands of beams of much smaller beamwidth as suggested by I. Bekey (12) and a computer controlled switching center in space similar to the U.S. Bell System ESS-4, which can provide on a space platform the interconnectivity now produced at a variety of telecommunication nodes on the ground as described by Hayden Evans (13) in his pacing 1968 paper.

The need for increased capacity in space has been predicted for the Intelsat system by Dr. Harry Van Trees et al (14) and Samuel Fordyce and Leonard Jaffe (5) have called attention that the domestic U.S. market could require 325 transponders or 27 Westar-class domsats by 1985. This far exceeds the capacity of the orbit and spectrum to support this market. Accordingly, in addition to spatial reuse of spectrum, as pointed out above, to solve this spectrum and orbit dilema, interconnectivity in space as pointed out by the present author and by W. Morgan and Dr. B. Edelson (15) is another viable solution to this dilema. Figure 11 shows a type of transponder which can be used for this interconnectivity in which each beam provides a sequence of incoming bursts, each with a destination code in its preamble. A demodulator and address decoder then supplies the bursts to a memory buffer, from which it is passed through a matrix and reassembled with other bursts of similar destination for remodulation and transmission to earth. This immediately suggests an all LSI system, using FET's which recently was discussed by the author and Dr. P. T. Ho (16) at the 1978 AIAA Satellite Communications Conference in San Diego.

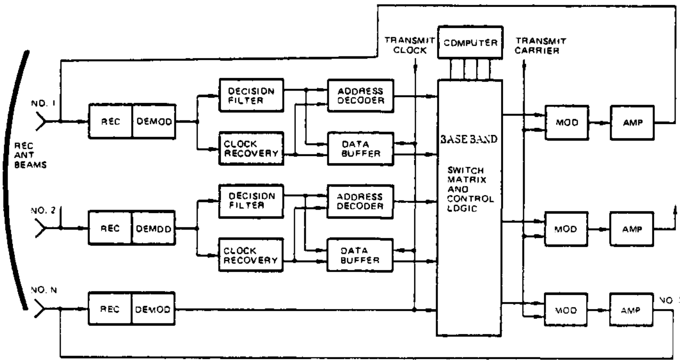

Fig. 11. Multibeam Satellite Using Baseband Matrix Switching

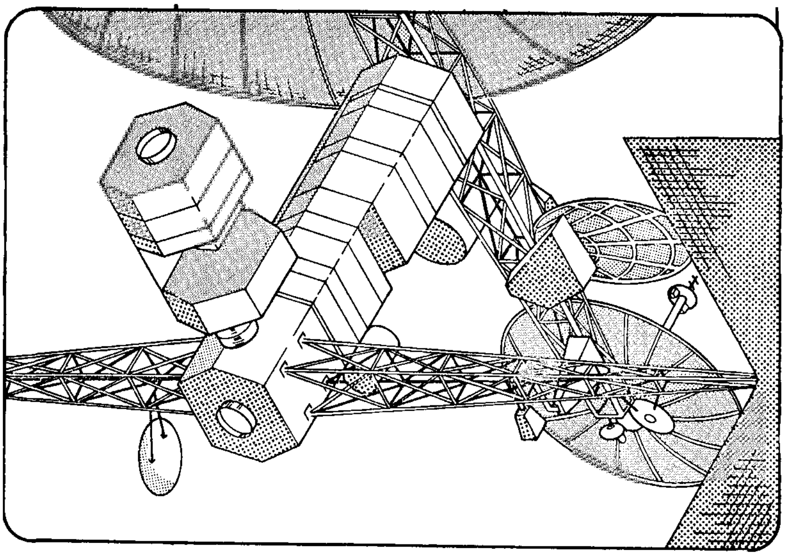

Fig. 12. The Edelson-Morgan Orbiting Antenna Farm (OAF)

LARGE MULTIFUNCTION COMMUNICATION SATELLITES IN THE 1990'S

During the period from September 1977 to April 1978, several major concepts for large multifunction communication satellites were published which disclosed a commomality of perception of satellite configurations which closely followed the Edelson-Morgan concept of OAF. System studies of the role of several large orbiting multifunction antenna systems during this period have also shown advantages over and above the use of many separate satellites serving regional, domestic and international interests in an orbit saturating fashion. These include the virtual elimination of multiple-hop satellite communications and the potential establishment of a "condominium" approach to large multiple antenna systems, where a country or an industrial company, or a regional group can own or lease a portion of large multifunction telecommunications space platform. This will bring up the problem discussed by W. Pritchard at the conclusion of the Edelson-Morgan paper (AIAA 78-546) to the effect that "who is going to control the housekeeping functions in this spacecraft and ... the greater problems are institutional rather than technical". Fig. 12 shows the basic Edelson-Morgan OAF concept introduced a year ago, showing a satcom system having the functional equivalence of eight satellites which uses modularity, antennas connected by large light-weight structures, and a capability for repair and maintenance. This OAF concept is based on using separate electronic modules for each mission - with these modules not significantly different from those serving single mission satellites.

Fig. 13 shows one of the multi-mission communication satellite concepts given by the author at IAF-28 in Prague in 1977, illustrating the type of large satellite also with eight functions whose pieces and modules could fit into a single Shuttle bay and be assembled in space. Two features of this satellite are the use of a common central structure containing all horns which are offset to - and illuminate a variety of reflectors. Also, this satellite uses two large 28-ft. reflectors, each of which can be made as two 14-ft. wide sections which can fit into the Shuttle bay and be easily assembled in space. This type of satellite is a logical development of Intelsat V which has pioneered using a large multi-beam antenna farm, and can be considered to be an interim step to - say - the giant Jaffe-Fordyce geostationary platform shown in Fig. 14 which is about as large as an American football field; i.e., 30 yards wide and 100 yards long.

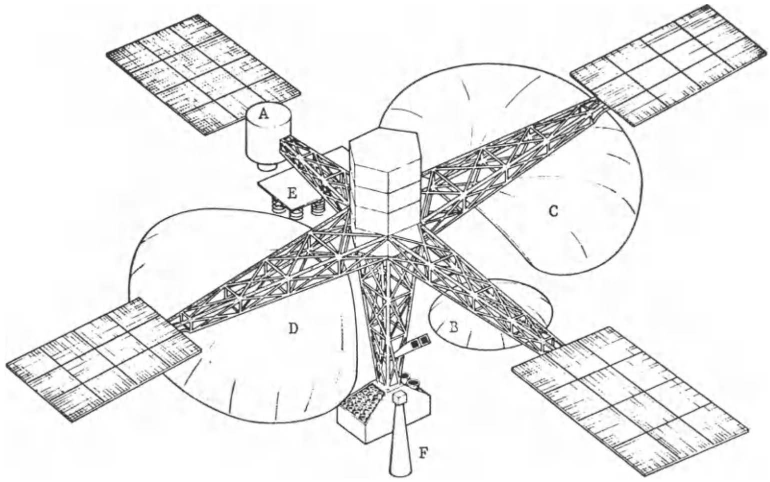

Fig. 13. The Multimission Communication Satellite Described By C. L. Cuccia at IAF-28 at Prague 1977

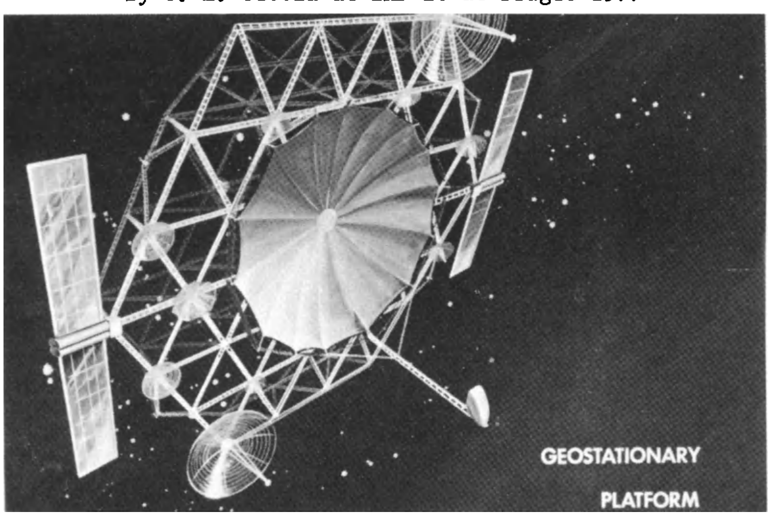

Fig. 14. The Jaffe-Fordyce Geostationary Platform Communications Satellite System

The Jaffe-Fordyce geostationary platform requires the development of new light-weight mechanical structures which can be assembled in space and which can be designed for structural stability and minimizing of vibration which could produce significant pointing errors in the larger antennas assembled on this satellite. The geostationary platform is presently under intensive study at NASA's Marshall Space Flight Center under the direction of Mr. T. E. Carey and can well provide the technology base to the OAF. At MBB in Germany, Dr. D. E. Koelle has also contributed the design of space-type assembleable lattice-like structures and platform which could also provide a significant technological base.

Fig. 15 shows a concept of another approach to large antenna telecommunications structures by I. Bekey, illustrating a large 200-ft. diameter lens antenna operating in the one to two GHz range which can switch 1600 beams.

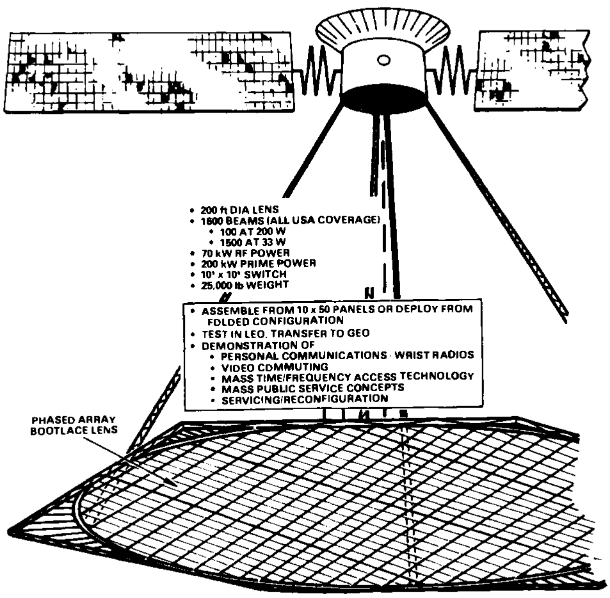

Fig. 15. The Bekey Personal Communications Satellite System for the 1990's

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SUPERVISION OF YOUTH ROCKET EXPERIMENTS (SYRE); A SUMMARY OF THE TENTH ANNUAL IAF SESSION FOR EDUCATORS

George S. James

Chairman of the SYRE Study Group of the IAF,
National Science Foundation, Washington, D.C.

This year's SYRE session, at the 29th IAF Congress in Dubrovnik, had as its theme, Supervision of Experimental and Model Rocketry. The majority of papers were devoted to programs being conducted in Yugoslavia under the supervision of the Yugoslav Astronautical and Rocket Society. The session, on Monday afternoon, October 2nd, was co-chaired by Vladimir Gencic, the SYRE representative for Yugoslavia, and George S. James. It provided an enthusiastic forum for teachers and rocket club supervisors to discuss their rocket and science motivation programs for young people.

SYRE endeavors to facilitate information exchange between educators who are involved in using knowledge obtained from the space sciences for motivation of students in many areas of classroom and extra-curricular study and for supervision of student rocket and payload experiments. Space limitations of this volume necessitate that the six papers presented at this session be in summary form rather than full text. Educators wishing to obtain copies of the full papers should contact the SYRE Chairman in care of the IAF, 250 Rue Saint-Jacques, 75004 Paris, France.

(78-73) UNDERGRADUATE SPACE RESEARCH IN THE SHUTTLE ERA
By R. Gilbert Moore, Thiokol Corporation, Ogden, Utah, U.S.A.

At the XXVII Congress of the International Astronautical Federation, held in Anaheim, California, in October 1976, Mr. John Yardley, NASA's Associate Administrator for Space Flight, announced an exciting new opportunity for universities, small companies and individual citizens of all nations to participate in space research and engineering. He explained that, in order to introduce the Space Transportation System to a new generation of potential investigators, NASA had established a "Getaway Special" tariff for small, self-contained, scientific payloads to be carried in the cargo bays of Space Shuttle orbiters on a space-available basis during Shuttle fleet operations from 1980 to 1992. He stated that payloads ranging in weight from 25 kilograms to 90 kilograms would be carried aloft in the orbiter bay, exposed to the vacuum and weightlessness of earth orbit for periods ranging from one to thirty days and returned to earth, for a fee ranging from $3,000 to $10,000, reckoned in 1975 U.S. dollars and escalated for inflation to the year of launch.

The author of the present paper, inspired by the educational implications of Mr. Yardley's concept, became, on 14 October 1976, the first person to reserve experiment space aboard the Shuttle for one of these payloads. The reservation was messaged from the IAF Congress in Anaheim to NASA via the Marisat communications satellite in geosynchronous earth orbit. (Also during that week, Mr. Moore alerted educators and students to the possibilities of payloads aboard the Shuttle in his paper, 76-246, *Piggy-Back Student Payloads on Large Sounding Rockets*, delivered at the 8th IAF SYRE session - ed.)

In the intervening two years, the Getaway Special offer has been refined and somewhat expanded, as a result of interaction between NASA and the investigators thus far committed to the program. The offer now stands briefly as follows: For a fee of $10,000 U.S. (FY 1975), NASA will transport to earth orbit, on a space-available basis, an investigator-supplied experiment weighing not more than 90 kg. housed in a NASA-supplied, cylindrical canister of net volume 0.14 m^3; will provide one "on" and one "off" signal on each of three NASA-supplied switches mounted inside the flight canister; and will return the experiment to earth and make it available to the investigator shortly thereafter. For a fee of $5,000 U.S. (FY 1975), NASA will perform the same services for an investigator-supplied experiment weighing not more than 45 kg, housed in a NASA-supplied, cylindrical canister of net volume 0.07 m^3. For a fee of $3,000 U.S. (FY 1975), NASA will perform the same services for an investigator-supplied experiment weighing not more than 30 kg, housed in a NASA-supplied, cylindrical canister of net volume 0.07 m^3. An earnest money payment of $500 U.S. will establish the investigator's position in the flight queue for any of these three sizes of payload. Fees for custom services, such as Shuttle manuevers, additional commands and the like, are to be negotiated at a later date.

As of the preparation of this paper (July 1978), earnest money payments have been received by NASA for 245 Getaway Special payload spaces. Although the exact use to which each payload will be put is not clear at this early time, the reservation list has been subdivided preliminarily into three categories - individual investigators, for which there are 45-1/2 reservations, educational institutions, for which there are 57-1/2, and 142 industrial reservations. The "1/2" reservations result from the author's having donated half his first payload space to an educational institution, while retaining half for his own family's use. Some 194 Getaway Special reservations have thus far been made by individuals and institutions within the United States, with the remaining 51 coming from the Federal Republic of Germany, Denmark, Great Britain, Canada, Japan and Egypt.

Now as the the educational implications of the Getaway Special program. The downturn in public interest and the lack of opportunity to participate in the space program in recent years has created a real "generation gap" among space investigators. In the author's opinion, a most excellent way to reinject excitement, enthusiasm and creativity into our somewhat "middle-aged" space program is to provide talented young men and women with opportunities to send their own experiments into orbit before they have completed their educational careers. In addition to contributing fresh concepts and boundless energy to the field of space research and development, these young people will receive a stimulus, unparalleled in recent times, to achieve educational excellence.

Individuals, corporations, and professional societies, the American Institute of Aeronautics and Astronautics notable among them, have moved to capitalize upon Mr. Yardley's offer by purchasing payload spaces on the Shuttle orbiter, donating these spaces to educational institutions, and offering knowledgeable assistance to the fledgling investigators in the recipient institutions, if desired. Although most of the resulting research programs have been undertaken so recently that no specific investigations have been selected as yet, a few institutions did get underway in 1976 and 1977 and have progressed to the point of initiating individual experiments. The examples which follow are those with which the author is most familiar.

In late 1976, Utah State University, located in Logan, Utah, became the first educational institution to participate in the Getaway Special program. A scholarship fund was established, and a faculty Space Science Experiment Committee was convened to solicit and evaluate experimental proposals from high school seniors and to act as advisors for scholarship recipients chosen from the body of proposers. Three students, James Elwell, David Edwards and Daniel Adkins, were selected in the spring of 1977 to receive four-year tuition scholarships to Utah State University and part-time employment, commencing in the fall of the year. Each of these three students has now completed his first year of academic studies, during which he has performed a literature survey in his chosen field of research and has conducted a preliminary design of an experiment to be flown in the Shuttle cargo bay. Elwell's experiment consists of melting and forming an optical-quality surface in microgravity, then solidifying the material and returning it to earth for subsequent metallizing. The material chosen is too fragile to withstand grinding and polishing, but has otherwise optically desirable physical properties. Edwards' experiment consists of determining the energy distribution of the solar spectrum from 1 to 50 Å by means of a multiple pinhole camera, film transport and selected absorbers. Adkin's experiment consists of measuring the effects of microgravity on the growth of various bacteria.

During the 1978-79 academic year, these students will fabricate their instruments. During the 1979-80 academic year, they will integrate their individual instruments into a single experiment package and subject it to extensive laboratory and environmental testing. Balloon or sounding rocket flights will be employed, as available, to provide the investigators with preliminary experience in the techniques of space experimentation. During the 1980-81 academic year, their combined experiment package will be installed in a Getaway Special canister, mounted in the Shuttle cargo bay, flown into orbit for several days, returned to earth, removed from the canister and turned over to the students for post-flight examination.

After completion of the evaluation and analysis phase, each student will prepare an undergraduate thesis on the results of his scientific investigation. Since each of these students intends to pursue graduate studies at Utah State University, he will complete his thesis in graduate school in the event of a slip in the Shuttle launch schedule, or if the combined experiment is not ready on schedule.

A second group of three students is entering Utah State University in the fall of 1978 to embark on a scholarship program identical to the one just described. In this case, the Getaway Special fee has been contributed by Dr. Rex Megill, Director of the USU Center for Atmospheric and Space Sciences and Chairman of the aforementioned Space Science Experiment Committee. One of the new students, Cris Alford, plans to examine separately the effects of the various components of the space environment, namely, weightlessness, vacuum and radiation, on the growth of selected biological specimens. Steven Walker will perform an on-orbit microscopic examination of the response of Chorella algae to weightlessness, in an extension of an experiment he flew in an Astrobee F sounding rocket at the White Sands Missile Range in May of this year, while he was still a senior at Austin High School in El Paso, Texas.

Another experiment in the planning stage at Utah State University is being managed in a manner quite different from that described above. Here, the university's senior electrical and mechanical engineering classes are utilizing the aerospace industry team approach to design and build a free-flying, solar-powered, Air Traffic Control Radar Beacon calibration satellite. Faculty support is being provided by a committee headed by Dr. Clair Wyatt of the Electrical Engineering Department. The satellite is being designed to transmit, in response to a coded R.F.

command from the ground, a stable stream of 1.2 kW pulses, at 600 microsecond intervals, on a carrier frequency of 1090 MHz. As the satellite passes over an Air Traffic Control Radar Beacon on the ground or a ship below, it will be commanded on, to act as a signal source for a new beam tilt adjustment procedure devised by Mr. Charles Bonsall of the U.S. Federal Aviation Administration. Discussions are being held with NASA and FAA because this experiment represents a departure from the standard Getaway Special concept, by virtue of its requirement for ejection into independent orbit and the fact that it contains both an R.F. receiver and transmitter. Senior mechanical and electrical engineering students at the University of Utah in Salt Lake City are planning to demonstrate the basic principles of solar sailing in a Getaway Special flight opportunity provided to them by the Utah Section of the AIAA. With assistance from a faculty committee headed by Dr. Gary Flandro of the Mechanical Engineering Department, the students are performing a feasibility study during the summer quarter of 1978. Some of the students plan to continue with the experiment into graduate school, since the flight to which this package will be assigned is not likely to occur until 1981. At Weber State College in Ogden, Utah, a group of sophomore science majors is planning a group of astronomical and biological experiments, with the assistance of a faculty team headed by Dr. David Tripp of the Physics Department. At the Weber County School District, near Ogden, Utah, students from three high schools are planning experiments which involve the detection of high Z cosmic rays by means of a stack of Lexan sheets, a micrometeorite detection experiment utilizing polished metal plates, and a microgravity materials processing experiment in which an attempt will be made to cast an extremely uniform sheet of polymeric material under weightless conditions in a study of artificial heart component fabrication techniques.

Dr. Leland Burningham, Weber County School District Superintendent and Dr. James West, District Science and Math Coordinator, are assembling a team of high school science teachers and university faculty members to advise the student researchers. They are also organizing Space Shuttle seminars and appropriate field trips to provide motivation for the students and their teachers.

The foregoing examples, although limited in geographic scope, are illustrative of the range of experiments being planned by student investigators in the Getaway Special program. Page limitations and the author's lack of knowledge do not permit a complete discussion of every Getaway Special program under way in other states within the U.S. and around the world. However, the overall message is quite clear. The young people of this earth find the concept of direct participation in space research and development an exciting prospect, and they are entering the field in ever increasing numbers. The forces unleashed by John Yardley at the XXVII IAF Congress in 1976 will continue to grow throughout the Space Shuttle Era and beyond. The Getaway Special concept is destined to have a profound effect on the space program into the indefinite future.

(78-76) POSSIBILITY OF APPLYING THE ADSORPTION METHOD IN STUDYING ROCKET EXHAUST GASES DIFFUSION OVER THE GROUND WITH PROTECTIVE ZONES

By S. Koncar-Djurdjevic and O.M Stojanovic, Faculty of Technology and Metallurgy, Belgrade, Yugoslavia

The objective of this paper is to indicate the possibility of applying the absorption methods developed by the author and his associates in the study of the diffusion of rocket exhaust gases, with homogeneously or unhomogeneously distributed pollutants, over the surface of the ground and around shelters through the use of scale models in hydraulic channels. "Stream chromatograms," obtained by dynamic dye adsorption from a solution on objects coated with silica gel, supply information on concentration, and by analogy, on stream and temperature fields around the

objects. The model of air pollution, i.e. distance from the source was simulated by dye intensity and solution homogeneity. Depending on hydrodynamic conditions or dye concentrations in solution, colored areas of different shapes and intensities are formed around and on the objects under test. These colored areas are called "absorption chromatograms." Qualitative conclusions can be drawn from visual observation of adsorption chromatograms; quantitative by colorimetric analysis thereof. This enables direct determination of the amount of mass transported on the surface of the object. It may be used for the calculation of mass transport coefficients, as well as mass fluxes or equilibrium solution concentration above the observed element. Due to the analogy between transfer of mass, momentum and heat, such observations may be applied to thermal fields as well.

The open hydraulic channel used to demonstrate these techniques was 310 cm long, 12 cm wide and 24 cm high. It contained 0.8 m^3 of solution. The value of reynold's number, based on channel cross-section ranged up to 60,000. The concentration of the basic methylene blue solution in water was 25.10^{-4} g/l; adsorption time for qualitative tests was 10 minutes and for quantitative tests from 2.5 to 5 minutes. Maximum height of the objects was 8 cm; they were fixed on the floor of the channel at 1.5 m from the inlet; fluid height above the floor was 14 cm. The objects were coated by spraying with prepared silica gel suspension. Upon adsorption, the chromatograms were dried in the air in the absence of strong light. The regular shaped objects were made of aluminum; the tree and hedge models were cut from spongy plastic; and the tree trunks were cylindrical screws which also served to fix the models to the bottom of the ground model channel.

(Dr. S. Koncar-Djurdjevic showed during his presentation a number of chromatograms of exhaust gas flow around rocket test shelters demonstrating the effect of distance from the point of rocket firing and the effect of protective zones of trees, hedges, and other living plants. Educators interested in the adsorption method should also obtain IAF 78-177, *Experimental Study of Mass and Momentum Transport on Flying Object Models by the Adsorption Method,* by S. Koncar-Djurdjvic and Manojlo Glisic, presented at the Fluid Dynamics in Planetary Atmosphere session - ed.)

(78-78) THE AID TO ROCKET CLUBS THROUGH THE PROFESSIONAL LITERATURE

By Dusan Radojkovic, Yugoslav Astronautical and Rocket Society

This paper describes a four volume professional-level, educationally oriented, rocket manual being prepared for use by the supervised rocket clubs in Yugoslavia. These clubs are organized under the guidance of the Union of Astronautical and Rocket Organizations. Over the past several decades, the projects developed by the clubs have increased in complexity as members progressed from paper-cased rockets to larger flight vehicles potentially capable of meteorological research.

In order to assist these members with the professional level of educational material required, the Union of Astronautical and Rocket Clubs has undertaken the preparation and distribution to the individual clubs of this manual on the design and construction of meteorological rockets written by properly qualified specialists.

The manual is being written in such a style that advanced members of all the clubs, with the assistance of their supervisors, will be able to use it. In this regard, only the most important formulas are presented along with sufficient theory to make clear their derivation. All other data are presented through tables and, at the end of each chapter, extensive references to the unclassified U.S., English, French, and Russian literature.

The design and construction of a single type of meteorological rocket is the unifying theme of the manual. The subjects covered are divided among the volumes as follows:

Volume I - Aerodynamics and Flight Dynamics
Volume II - Rocket Propulsion
Volume III - Rocket Design and Construction
Volume IV - Rocket Launch Equipment and Facilities

Displayed at the SYRE session was Volume I, of 260 pages, authored by Djordje Blagojevic, Branislav Jojic, Zoran Stepanovic, and Miroslav Dervisecvic, with a preface by Professor Dr. Tatomir Andjelic, one of the SYRE founding members. Volume II, published during the week of the IAF Congress, contains 593 pages and is authored by Branislav Jojic, Djordje Blagojevic, Aleksander Pantovic, and Vladimir Milosavljevic. Volume III is expected to contain 300 pages and Volume IV, 450 pages. The entire project is under the over-all management of the author of this paper, Dipl. Ing. Dusan Radojkovic, and Dr. Ing. Dusan Draskovic.

As the volumes are published, they are made available to the instructors of all the supervised clubs. As the first volume has demonstrated, these books are proving of great educational assistance to members interested in advancing the level of their research projects.

(78-79) NEW GENERATION OF MICRO-ROCKET ENGINES - DEVELOPMENT, EXAMINATION AND PRODUCTION
By M. Dervisevic, ARAK Jet Propulsion Laboratory, Belgrade, Yugoslavia

This paper describes the development program resulting in a new generation of Yugoslav model rocket engines, called micro-rocket engines, now in pilot-plant production by the ARAK Jet Propulsion Laboratory.

The characteristics and faults of past model rocket engines were closely studied. These studies formed the basis of the development program for three new types of micro-engines, one using double-base propellant and two using composite solid propellant. A particularly unique piece of test equipment created during this program allows the electronic measurement and recording of both thrust and chamber pressure simultaneously during a test firing of a micro-rocket engine. Space limitations prevent the reproduction of the equipment photographs and thrust, chamber pressure, and combustion stability curves presented in the full paper.

The initial type of micro-engine developed uses double-base propellant, has a total impulse of 5.5 Ns, a diameter of 14 mm and a length of 65 mm. Maximum thrust is 17.5 N and average chamber pressure is 28.0 bars. The engine chamber is made of phenolic material with an ablative nozzle. It is believed that this is the first micro-rocket with the electric igniter built into the combustion chamber.

Next, following an extensive development program, two types of micro-rocket engines, with total impulses of 5 Ns and 80 Ns, were placed into pilot-plant production. As an indication of the efforts to produce the highest reliability in micro-rocket production, a run of 2500 5 Ns engines was completed and evaluated before production began of the 80 Ns engines. These engines use ARAK-Plastisol 75 composite propellant. The engine chambers are made of polyamide plastic and Duretan BKV 30 fiberglass with KER 520 ceramic nozzles.Engine characteristics are:

	Type 5-B10-6	Type 80-F60-10
Total impulse	10.0 Ns	80.0 Ns
Initial mass	12.5 gr	150.0 gr
Maximum thrust	10.0 N	60.0 N
Thrust duration - total	0.9 s	2.0 s
Outer diameter	14.0 mm	32.0 mm
Total length	65.0 mm	155.0 mm

Among the equipment which had to be designed and constructed for this development program and pilot plant production line were a vacuum dryer, a high speed oxidizer micro-pulverizer, a propellant mixer of from 20 to 100 liter capability, an extruder for making inhibited propellant grains; a moulding machine for plastic parts; and a press for pressing tracer compounds and nozzles into the chambers.

ARAK eagerly looks forward to the use of these new micro-rocket engines in Yugoslav model rocket competitions and in rocket sporting events in other countries around the world.

(78-80) SURVEY OF THE RESULTS OF THE WORK OF THE ASTRONAUTICAL AND ROCKET SOCIETY IN CELJE

By P. Omersel, ARS Celje, Celje, Yugoslavia

The founding of the Astronautical and Rocket Society in Celje dates back to 1962 when a rocket section was formed within the Aero Club Celje. Over the past 16 years members of this supervised organization have conducted a very comprehensive series of flight vehicle development programs; made a number of significant rocketpost demonstrations; designed, constructed, and demonstrated a practical anti-hail rocket; developed a number of computer simulation models; and carried out extensive public education programs through lectures and exhibitions. The members also supervise model rocket competitions among young students.

The full paper contains descriptions and detailed tables of the characteristics of over 14 different types of solid and liquid propellant ARS Celje flight vehicles. Space limits this summary to only two examples. At the XVIII IAF Congress, held in Belgrade in 1967, a rocketpost demonstration was conducted by ARS Celje. The three-stage, micrograin solid propellant, VEGA-3-C rocketpost vehicle was launched in the Fruska Gora national park near Belgrade on August 30, 1967 with over 500 participants of the Congress watching. The final, mail-carrying, stage reached an altitude of 32.5 kilometers. (An excellent photo of this impressive experimental rocket appears on page 1082 of T.P. Andjelic's "Youth Rocket Activities in Yugoslavia," in *Astronautical Research 1970; Proceedings of the XXIst Congress of the International Astronautical Federation,* eds. L.G. Napolitano, P. Contensou, and W.F. Hilton, (Amsterdam and London; North-Holland Publishing Company, 1971)-ed)

Characteristics of the vehicle were:

1st stage diameter (four motors)	280 mm
2nd stage diameter (one motor)	167 mm
3rd stage diameter (one motor)	104 mm
Vehicle total length	7460 mm
Vehicle total weight	568 kg
1st stage thrust	9800 kp
2nd stage thrust	4500 kp
3rd stage thrust	2000 kp
1st stage burning time	1.3 sec
2nd stage burning time	0.9 sec
3rd stage burning time	1.0 sec

Protection against hail is a widespread problem in Slovenian agriculture. The hail containing clouds from the Alps are at altitudes of approximately 8,000 m thus making rockets one of the few effective methods of anti-hail protection. During 1970, a modern radar system for anti-hail protection was introduced in the northern parts of Slovenija. The existing KAMNIK and SAKO rockets often do not ascend high enough to be effective. Consequently in the period from 1972 to 1975, ARS Celje designed, constructed, and demonstrated a two-stage, plastic cased, rocket capable of reaching 10,000 m altitudes. The unit is easy to handle and can be launched from single or multiple launchers. Internal and external ballistic and design parameters were optimized by computer programs developed by ARS Celje.

The characteristics of the RPT-C4 anti-hail rocket are:

Diameter of both stages	80 mm
Total rocket length	1061 mm
Rocket weight	8.4 kg
1st stage thrust	500 kp
2nd stage thrust	38 kp
Altitude	10,299 m

In addition to the flight tests, over 100 static tests were performed to develop this rocket for use in helping to solve a serious agricultural problem.

The skill that members of ARS Celje have attained in the use of modern computer methods, such as simulations, optimizations, adaptive methods, and programmed numerical methods, since 1970 has been clearly reflected in the success of the solid and liquid propellant rocket programs undertaken. ARS Celje looks forward to again at a future IAF Congress presenting to SYRE the results of its scientific research, development, training, and educations programs.

78-75 BOOST/GLIDER DESIGN - A CHALLENGE FOR AEROSPACE ENGINEERING STUDENTS
By G.M. Gregorek, Ohio State University, Columbus, Ohio

This paper discusses the many technical challenges encountered by aerospace engineering students when designing a Boost/Glider propelled by a model rocket engine. It is based on the author's experience in teaching applied aerodynamic and experimental courses in the Department of Aeronautical and Astronautical Engineering of Ohio State University and from his experience at national and international aerospace model competitions.

The learning potential for students who design a Boost/Glider on paper, predict its performance, then test it in a wind tunnel to document its characteristics, is great. This same process could, of course, be followed using a full scale airplane design that is modelled and tested in a wind tunnel. What makes the Boost/Glider a unique design experience is that it can be built and *flown*---and at low cost, with little expenditure of time. Thus, the students become involved in a complete aerospace project, one that encompasses challenging elements of design, fabrication, experimental methods, and flight testing. Although in development for less than two decades, Boost/Gliders have been built in a variety of shapes and sizes---flying wings, canards, and "conventional" configurations. Sizes range from tiny sheet balsa birds with 15 cm wing spans to large built up models with spans in excess of 1 meter. The littlest birds, powered by the smallest rockets, barely reach 10 meters in altitude, while the larger B/G's can achieve heights above 200 meters. Likewise, time aloft can range from a few seconds to many minutes. When a B/G, free of its rocket, sniffs out a thermal, and circling slowly, slips silently up and away into the wild blue yonder---that's an experience of the beauty of flight not soon to be forgotten.

(Because of the enthusiasm in Yugoslavia for model rocketry and Boost/Gliders, Dr. Gregorek, a SYRE member, was invited to make this presentation originally published in the Fall, 1977, issue of the *AIAA Student Journal*, a publication of the American Institute of Aeronautics and Astronautics, pages 10-17. The paper was read by Jeffrey Irons, Editor of the *AIAA Student Journal*, because Dr. Gregorek could not attend. Neither could R. Gilbert Moore or Dusan Radojkovic. Their papers were read by Robert Freitag of NASA Headquarters, Washington, D.C., and Djordje Blagojevic of the Union of Astronautical and Rocket Clubs, Yugoslavia, respectively. -ed.)

EXPERIMENT MORAVA ON BOARD OF SALYUT 6 I. CRYSTALLIZATION OF LEAD CHLORIDE FROM EUTECTIC SOLUTIONS IN $PbCl_2$-CuCl AND $PbCl_2$-AgCl SYSTEMS

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ABSTRACT

Out of the experimental complex known under joint title MORAVA were carried out the experiments devoted to the study of crystallization of lead chloride from eutectic solutions with cuprous chloride and silver chloride under terrestrial conditions and under microgravity conditions. The methods of optical and scanning electron microscopy were used to study the external shape of the samples, the dimensions and orientation of the lead chloride crystals and the texture of the solidified eutectic. On the basis of the information obtained, samples containing a uniform volume pattern of linear $PbCl_2$ crystals were prepared under terrestrial conditions.

INTRODUCTION

In studying the processes of the crystal growth and solidification of melts, some problems can be solved only by making use of the experiments performed under conditions of zero gravity. Gravity is the cause of a number of phenomena that limit our possibilities of a deeper understanding of the true nature of the mentioned processes as well as the possibilities of deliberate control of the properties of the obtained materials. The conditions of zero gravity, on the other hand, enhance the role of other phenomena, such as surface tension, diffusion processes etc., whose manifestation under terrestrial conditions is either suppressed or distorted.

The experimental complex MORAVA, which represents the first stage of our planned research under conditions of changed gravity, aim at an explanation of some fundamental principles and at a completion of existing knowledge of the relations among the crystallization conditions, structure, texture and the properties of the condensed systems obtained. The model materials selected for the experiments were the materials either newly developed in the Institute of Solid State Physics, ČSAV, or those already well known.

In the first case we investigated the solidification of the melt of two ionic substances exhibiting eutectic behaviour, with one of the components inabundance, so that the solidification proceeds in two stages: crystallization of the excess component from the molten solution, and solidification of the remaining eutectic. The role of the main component of the system is played by a substance exhibiting anisotropic crystal field, in order to enhance the significance of vector differences between the temperature and gravitation fields. As the main component for the first experiment we chose lead chloride; for the second experiment we chose mercury bromide, a substance belonging to the calomel family which shows the largest known anisotropy of bonds in the crystal lattice. In the second case we were concerned with the study of crystal growth from the vapour phase under conditions of zero gravity. As a model material we chose bismuth oxichloride, which is interesting for its strong vector dependence of the optical properties.

The third topic of the experiments is a study of solidification of glassy systems, represented by semiconducting glasses in the germanium-antimony-sulphur system. Beside the questions connected with the existence region of the glassy phase we were also interested in the influence of zero gravity on the structure and on fundamental physical properties.

On board of the orbital complex Soyuz 27 - Salyut 6 - Soyuz 28, the first experiment from the described set has been performed till now: the crystallization from the melt containing lead chloride as the main component. The objective of the present paper consists in summarizing the preliminary results of this first experiment.

SAMPLES AND THEIR CONTAINERS

As the main component of the system, lead chloride was chosen for the anisotropic nature of the bonds in its crystal lattice and for its interesting crystal structure, where each Pb ion is surrounded with nine Cl ions. The choice of the second components of the system was limited by requiring that they should form no compounds with $PbCl_2$, but only eutectics, that they have sufficiently different crystal lattice, identical anions, and that the cations should show sufficiently large difference in their ionic radii. These requirements were well met by cuprous chloride (sphalerite structure) and by silver chloride (NaCl structure).

As shown in the equilibrium phase diagram of the $PbCl_2$-CuCl in Fig. 1, the eutectic contains 50 mole % of $PbCl_2$ and the working mixture corresponds to 63.3 mole % of $PbCl_2$. The phase diagram of the second mixture is analogous, the only difference being the contend of $PbCl_2$ in the eutectic, approximately by 20% lower than in the former melt. In our case the eutectic contains 61.7 mole % of dissolved $PbCl_2$; the solution is thus about two times more concentrated than in the case of the eutectic with CuCl.

The working mixtures were placed in evacuated quartz ampoules of 8 mm in Dia. and 50 mm long. The ampoules with the samples were inserted into a standard stainless steel container of the apparatus "Splav 01". The container, 172 mm long, was charged with two ampoules, evacuated and welded with electron beam. The apparatus Splav is situated at the wall of the Salyut cosmic ship, not far from its centre of gravity, as shown in Fig. 2 together with location of the container.

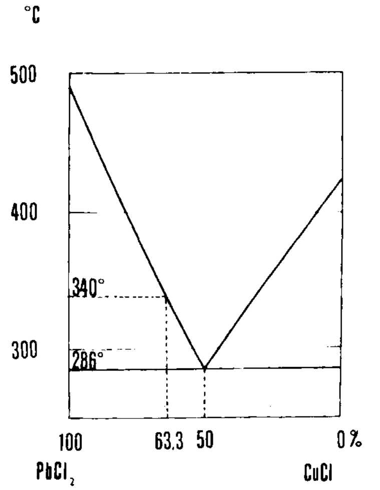


Fig. 1. Phase diagram of the $PbCl_2$ - CuCl system.

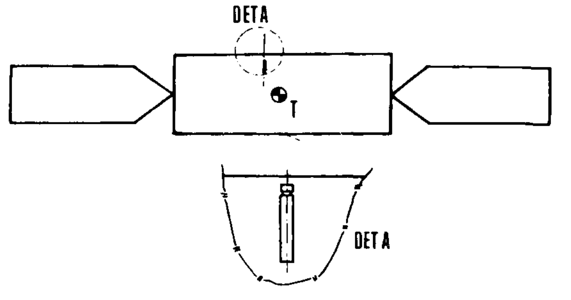


Fig. 2. Location of the container on board of Salyut 6.

PROGRESS OF EXPERIMENT AND SAMPLE TREATMENT

The crystallization in the Splav apparatus proceeds by placing the container with samples into an evacuated cylindrical cavity which is heated from one side only. The container is therefore situated in a longitudinal temperature gradient due to thermal conductivity of the whole system. After the temperature is stabilized, controlled decrease of the temperature follows. The original position of the container remains unchanged, so that one deals with crystallization using the technique of static crucible.

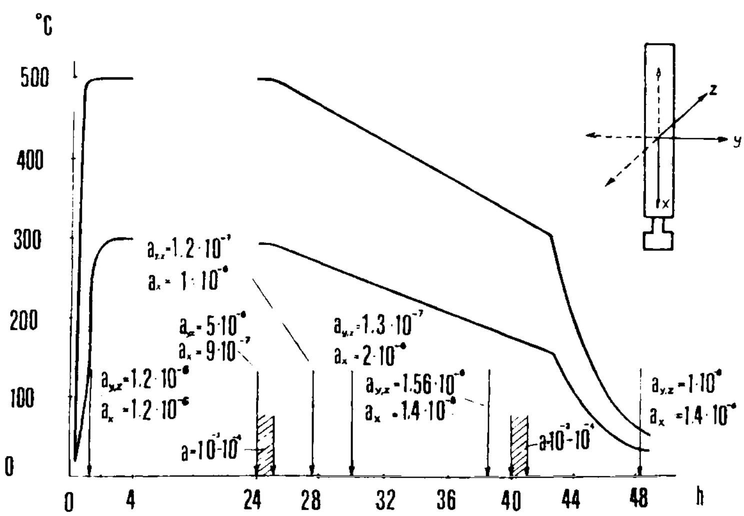


Fig. 3. Temperature program of the experiment with microgravity values.

The time dependence of the temperature during the experiment is shown in Fig. 3. The graph was based on the values measured in the course of the experiment outside the container in the hot (upper curve) and cold (lower curve) zone of the crystallizer. The temperature of the hot zone was set at 500° C. Controlled cooling took place at a rate of 11.3° C/hour. The microgravity values measured in the directions shown in the drawing of the container are also given in the figures. During the experiment, the orbital complex was situated in autostabile position with the longitudinal axis to the Earth centre.

In the first stage of the complex study of the influence of changed gravity on the physical properties of the samples of selected systems, the ends of the ingots were studied using methods of optical and scanning electron microscopy. Both the original and fracture surfaces were investigated, as well as etched or unetched surfaces of various orientations. The etchants were chosen in such a way as to be active only for one component of the system, enabling thus to examine individual phases as well.

RESULTS AND DISCUSSION

In preliminary quantitative evaluation of the samples, attention has been paid to the external shape, to the dimension of the lead chloride crystals in the solidified solution, and to the texture of solidified eutectic.

The samples prepared under ideal conditions of zero gravity should acquire the shape of an elongated drop filling the ampoule diameter provided the melt does not wet the ampoule walls. In the case of wetting, the ingot should adhere to the ampoule walls and show a cylindrical cavity in its central part.

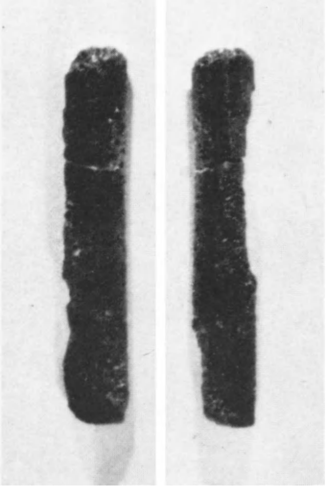
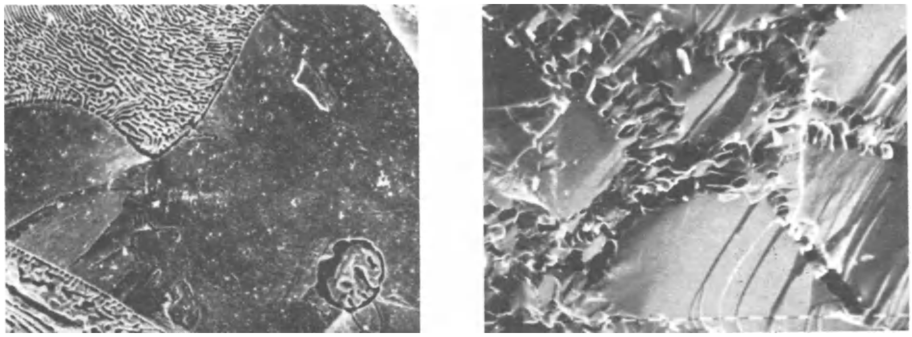


Fig. 4. Shape of the $PbCl_2$-AgCl ingot from two sides.

The shape of the samples prepared in the orbital complex was somewhat different (Fig. 4.). The ingot of the $PbCl_2$-AgCl system (P-A) was deformed in such a manner that a slight flattening appeared on one side of a part of the sample and on the nearly opposite side of the other part. It is evident from the overall sample shape that during gradual solidification the melt was acted on by a force of varying direction perpendicular to the ampoule axis. The resulting ingot thus acquired slightly screw-like appearence. Also the shape of the ingot of the $PbCl_2$-CuCl system (P-C) does not correspond to any of the ideal cases mentioned above. The ingot fills the ampoule diameter and has a regular cylindrical shape but its ends are deformed, being convex in one plane and concave in the other, perpendicular to it. These effects could be due for example



a) b)

Fig. 5. Section through the $PbCl_2$- CuCl ingot solidified a) on Earth, b) on board.

to microgravitation or to anomalies of the surface tension. As concerns microgravitation, an estimate of the magnitudes of individual components of the resultant microgravitation field has shown that they do not exceed the value of 10^{-6}g, which is in agreement with the measured values. The ingot shape thus indicates that the investigated materials are sensitive to changes in the forces of gravity even at such low gravitation levels. The analysis of the cause of these phenomena will be the subject of our further studies.

Fig. 6. Section through the $PbCl_2$- AgCl ingot solidified under modified conditions.

As concerns the difference between the samples prepared on the Earth and in the orbital complex, it has been found that the dimensions of the 1st generation of the $PbCl_2$ crystals grown under microgravity conditions are smaller that those of the crystals grown under otherwise identical terrestrial conditions. It is worth noting that the second generation of crystals, i.e. those contained in the eutectic, behave in opposite manner: the crystals are larger in the samples prepared under conditions of microgravity and smaller in the samples prepared on the Earth. As an example we can compare Fig. 5a and 5b obtained at identical magnification. They show an etched transverse section through the P-C sample, prepared on the Earth and in the orbital complex, respectively. The second generation lead chloride crystals grown under conditions of microgravity are noticeably better developed and form a more uniform system with the first generation crystals.

On the basis of the findings collected in the MORAVA experiment so far, we decided to verify the possibility of forming in the P-A eutectic a uniform volume pattern of linear lead chloride crystals. We increased the temperature gradient by about one order of magnitude, up to 50 - 70 $^{\circ}$C/cm and narrowed the migration zone of individual components to about 5 mm. The verifying experiment was realized for parallel direction of the temperature and gravitation fields. The result is shown in Fig. 6 showing the texture of one of regular cleavage planes of the obtained ingot.

All collected factographic material is subject to crystallographic studies. At the same time, the samples are analysed with respect to their microstructure, topography of the distribution of impurities, and to their physical properties.

DYNAMICS, CONTROL AND STRUCTURAL FLEXIBILITY RESULTS FROM THE HERMES MISSION

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ABSTRACT

HERMES (also known as the Communications Technology Satellite) is a 3-axis stabilized experimental high power communications satellite operating in the 12/14 GHz band. The satellite is structurally non-rigid as a result of its large lightweight deployable solar array, and is instrumented with accelerometers and other special purpose sensors which enable observation of its structural dynamics properties. A formal program of prelaunch analysis, ground test, and in-orbit observations and tests has been conducted with a view to establishing the solar array and attitude control technology required for future high-power satellites of this type. The current paper reviews and summarizes results from this activity.

INTRODUCTION

The HERMES satellite (also known as the Communication Technology Satellite) was launched into a geosynchronous orbit in January 1976. The satellite has been in use to date, and has been shared by Canadian and U.S. experimenters investigating communications services that could be provided by the 14/12 GHz frequency band and technological aspects of the satellite (Davies 1977).

Two of the technological objectives are "to develop and flight test a 3-axis stabilization system to maintain accurate antenna boresight pointing on a spacecraft with flexible appendages" and "to develop and flight test a lightweight extendible solar array with initial power output greater than one kw". A formal program has been conducted to achieve these objectives following a strategy and plan described in an earlier publication (Vigneron 1976). Investigators from the University of Toronto (P.C. Hughes and S.C. Garg), SPAR Aerospace Products Ltd (D. Tong, G. Lang), NASA-LERC (F. Shaker), ESA (K. Bogus), Telesat Canada (B. Burleton) and the Communications Research Centre (R.A. Millar, J.V. Gore, and author) have contributed to the program jointly and as individuals.

This paper reviews results from this activity and summarizes general conclusions.

SPACECRAFT DESCRIPTION

Earlier publications have provided a comprehensive description of HERMES (Franklin 1973, Vigneron 1978, Sansevero 1976, Harrison 1976, Bassett 1976). A brief outline of relevant areas is included here.

The launch of HERMES followed a standard Delta synchronous orbit profile. The spacecraft with its solar array stowed was spin-stabilized in transfer orbit, during apogee motor burn and until it was located on station at 116° W longitude. In the attitude acquisition sequence the satellite was despun, the solar array was deployed, and the 3-axis stabilized system was initiated. The configuration in its normal operating state is shown in Fig. 1.

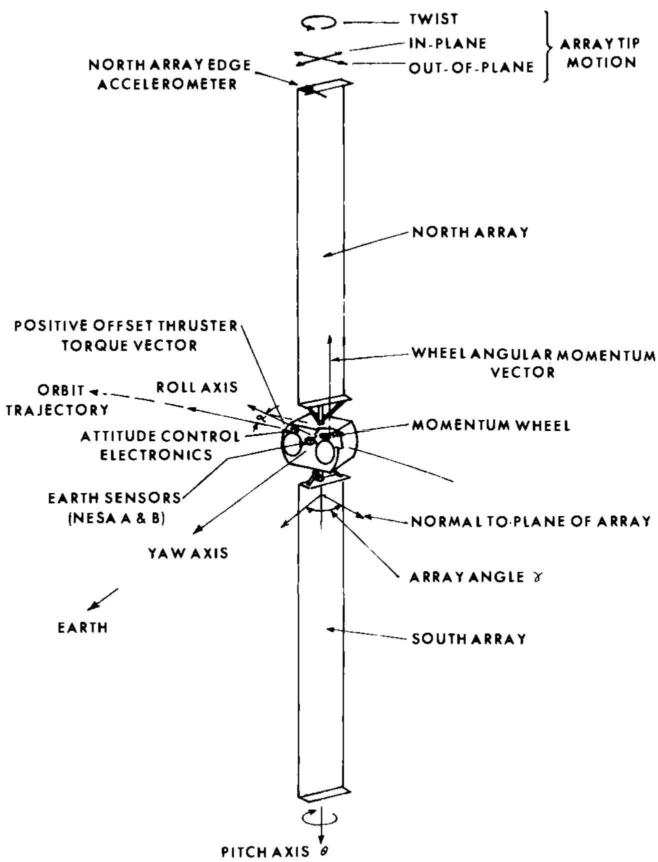


Fig 1 Hermes on-orbit state

The solar array consists of two fold-up deployable solar array units (DSA's), each of which when deployed is 7.2 m long and 1.3 m wide. Each DSA has a flexible blanket upon which are mounted the solar cells and wiring, a steel boom (BISTEM), a deployment actuator, an inboard pallet, and outboard pressure plate, a slip ring assembly, and related structure (Fig. 2). A drive and track mechanism rotates the array relative to the spacecraft about the pitch axis, enabling the array to face the sun. The DSA may be rotated in 'clock mode' at the rate of one revolution per day. Autotrack mode utilizing feedback from an analog sun sensor mounted on the array is also available. During the launch and spinning phases, the blanket is stowed folded in accordion fashion under pressure between the pallet and the pressure plate. After the DSAs have been deployed, the blanket is structurally supported by the deployable BISTEM (3.40 cm diameter) which is offset from the blanket by approximately 6.3 cm. The deployed blanket is maintained at a nominal tension of 35.6 N via a constant-force spring mechanism located at the outboard end of the boom. To provide twist stiffness, at the edges of the blanket there are thin stainless steel lines under constant tension (1.3 N).

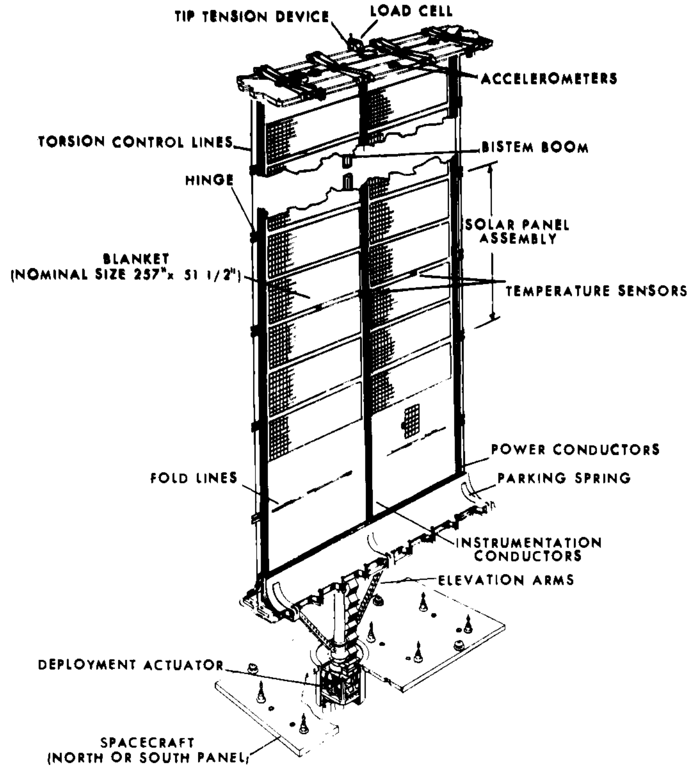


Fig. 2 Deployable Solar Array Unit

The satellite utilizes a 'momentum wheel with offset thrusters' system for 3-axis on-orbit stabilization. The spacecraft is a 'tri-spin' satellite in this mode, in that the momentum wheel, the spacecraft body, and the solar array each rotate at different rates about a common minimum of inertia axis (the pitch axis).

A non-spinning earth sensor assembly (NESA) provides pitch and roll error signals to separate channels of the controller electronics. The pitch controller is of the linear proportional-integral-derivative (PID) type and utilizes the pulse width modulator driven momentum wheel as its torque actuator. Tachometer feedback around the pulse width modulator and wheel (with the PID controller disconnected) provides a 'constant wheel speed hold mode'. The pitch thrusters can be activated for momentum dumping via ground command (Fig. 3).

Roll/Yaw stabilization is based on gyroscopic stiffness contributed by the momentum wheel. The roll/yaw controller (or offset controller) is basically an augmented dual time constant pseudorate controller which activates, via response to earth sensor derived roll error signals, a set of thrusters whose torque vector is offset from the roll axis in the roll/yaw plane. The thrusters produce a torque that nulls both roll and yaw errors.

In addition to offset and pitch axis thrusters, there are roll and yaw thrusters (i.e. thrusters which produce torques about roll and yaw axes respectively) and East and West thrusters for E-W station keeping. All thrusters can be operated by ground command. The yaw thrusters may be fired in pairs to achieve N-S station keeping.

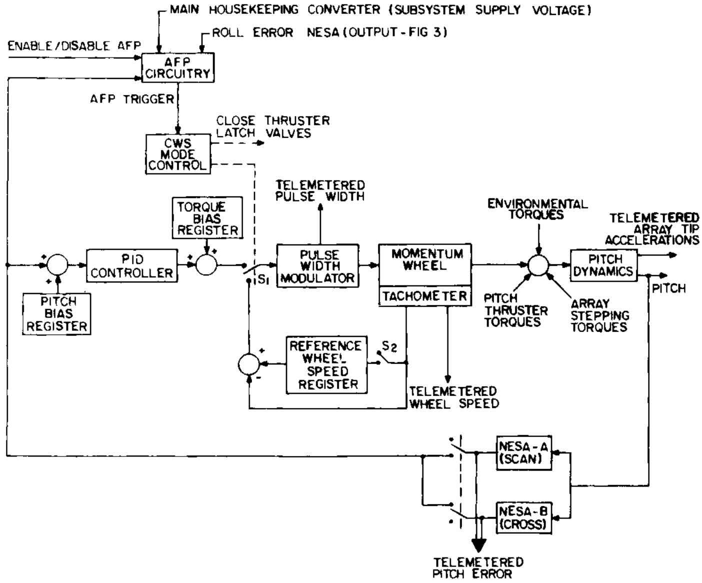


Fig. 3 Pitch Control Loop

The following instrumentation is available for structural dynamics and solar cell performance measurements (Fig. 2).

a) Array Accelerometers. Six accelerometers, three on the outboard pallet of each DSA, enable measurement of pallet accelerations normal to and in the plane of the blankets;
b) Array Deflection Sensing System. The spacecraft carries four deflection sensors which enable measurment of static and quasi-static deflection of the array tip relative to the main body. The sensors operate in sunlight or eclipse and during deployment.
c) Array Temperature Sensors. Five platinum resistance thermometer temperature sensors are mounted on the blankets.
d) Array Tension Load Cell. A specially-designed strain-gauged beam is incorporated into each DSA at the outboard pallet, and enables measurement of DSA tension.
e) Solar Cell Test Group. A solar cell test group enables measurement of eleven reference points of power-related data (I-V curve, etc.) on the DSA.

In addition, a number of sensors which support spacecraft operations are used as instruments for flight evaluation. These are boom length potentiometers, potentiometers in the tip tension mechanism, digital angular position encoders, DSA mounted sun sensors, extension arm microswitches, earth sensor, sun sensor, and rate gyros.

RESULTS AND FLIGHT EXPERIENCE

An overview and perspective of results and flight derived experience are given in the following subsections. More detailed supporting information is available in the referenced papers.

Solar Array Deployment

Because the solar array blanket is a membrane and is stored in folded state, design and qualification for deployment merited special consideration. It was recognized early that in-orbit deployment dynamics could not be simulated in ground tests because the array needs substantial support due to the one-g environment. Also it was felt that the confidence in a computer simulation based on mathematical modelling would be low due to the difficulty in modelling the way in which flexible blanket releases from its folded-up state and the lack of confirmatory data. As part of the flight qualification strategy, the following tasks were performed before launch:

a) the array mechanism was designed so that there was no possibility of unrestrained motion (i.e. unrestrained degrees of freedom) during the deployment. This was achieved by the design of special deployment fingers and torsion control lines;
b) the deployment mechanisms were established to function as components and part of the system on a specially-designed horizontal deployment rig in the one-g environment in vacuum with solar simulation. The tests confirmed that deployment did not induce large internal forces or accelerations.
c) a dynamic model was formulated which indicated that large or unrestrained motions were unlikely. Also it was rationalized that since deployment would be complete in less than 10 minutes, spacecraft attitude control instabilities would also be unlikely.
d) constraints were imposed in mission operation whereby the array would be deployed only when attitude rates were near zero and without thruster firings.

Thus before launch the details of how the array would behave dynamically were not known, but it was judged that the dynamics would be benign.

Deployment was achieved successfully and a full complement of data was recorded. Flight data from the south array load cell and one accelerometer are shown in Fig. 4. The array experienced oscillatory tip deflections of up to 18 cm out-of-plane, 5 cm in-plane, and a small amount of twist, which were caused by internal forces associated with release of the folds of the blanket(stowed accordion style). In Fig. 4, the first "spike" in the array load cell history is caused by the locking of the elevation arm assembly, and the next 28 peaks are caused by the releasing of the 30 folds of the blanket as the array deployed. A final increase in tension to 36 N indicates the termination of deployment. No control system interaction or attitude control thruster firing were evidenced. Deployment dynamics and data are being analysed with a view to improving the status of mathematical modelling for future design purposes. (Vigneron 1974, Bassett 1976, Harrison 1976, Hughes 1976).

Solar Array Performance

The drive and track units have functioned without anomaly since launch, and do not show signs of wear or degradation. The power output from the solar cells is degrading as per prelaunch expectations, with the exception of one event where a sudden drop of about 13% was experienced which was possibly associated with spacecraft charging.

Data from the array accelerations, load cells, temperature sensors, and the deflection sensors has been unavailable since June 1977. The cause is due to an electrical malfunction. There is a chance that they may be reviewed later in the mission.

The static deflection of the array and external torques have been deduced on the basis of deflection sensor measurements, control system thruster firings, and attitude drift special tests. As expected prior to launch, magnetic torques are essentially zero and solar torques are due to the dihedral shape effect and a propellor effect associated with the solar array. The static deformation of the solar array is about 17 cm out-of-plane and the largest solar torque is 8x10-6 nt-m and occurs during summer or winter solstice.

Temperature and array tension have remained within design limits to date, and are in accord with theory. The array blanket was noted to gradually lengthen in the first three days by 0.4 cm as the blanket folds flattened out, and henceforth blanket length has changed due to creep by less than 0.2 cm/year. In Fig. 5, temperature and load cell readings emphasize that eclipse is a harsh environment from the standpoint of thermally-induced stress. Temperatures are noted to change by 230° C and array tensions and deflections increase by 30% over a 10 minute period (Harrison 1976, Gore 1976, Wehrle 1976).

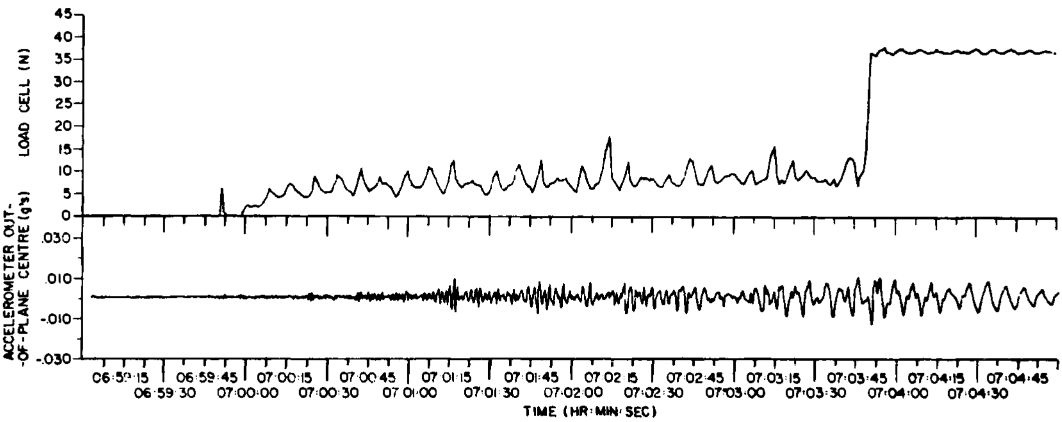


Fig. 4 Load Cell and Accelerometer Output During Deployment

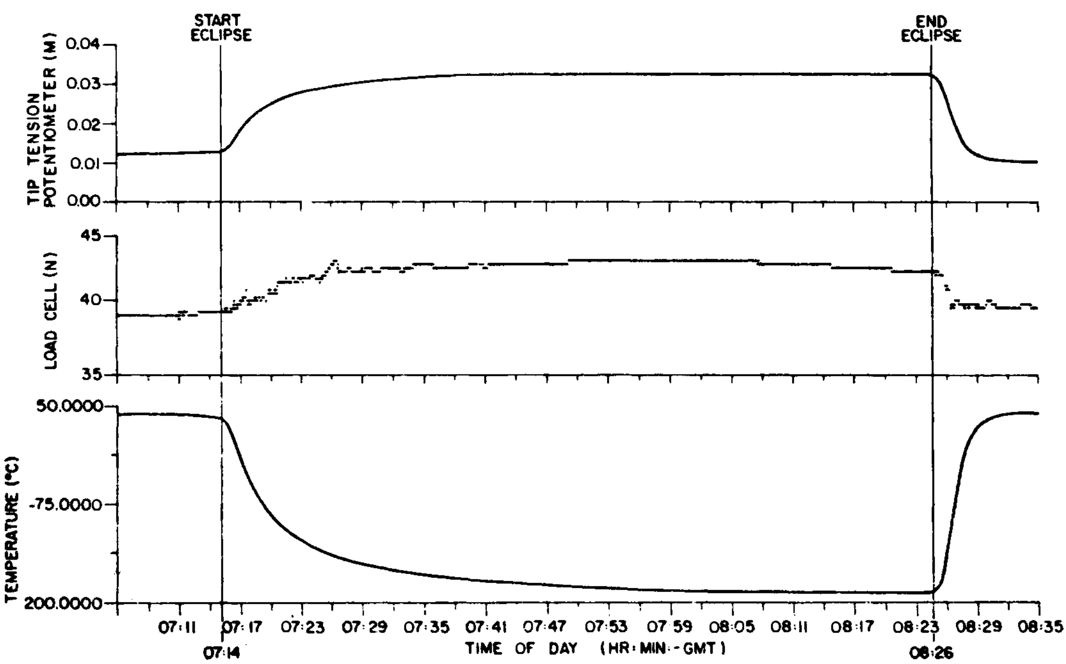


Fig. 5 The Effect of Temperature Change of the March 21 Eclipse on the South DSA Unit

Structural Dynamics Modelling and Measurement

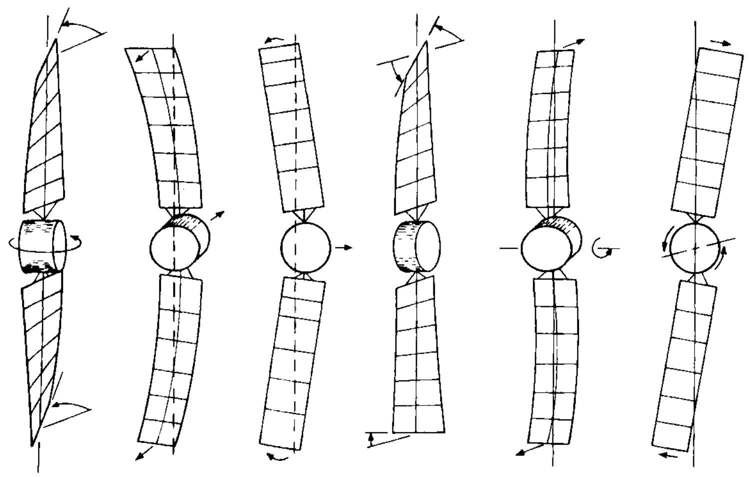
Structural dynamics modelling for the fully deployed configuration was done to varying levels of detail by the classical continuum mechanics method with natural (unconstrained) modes and fixed base modes, and by the finite element method using NASTRAN and STARDYNE and also from first principles. In general terms it was found that the finite element methods were well suited for static stress analysis, particularily as it applied to the solar array blanket. The preferred approach for dynamics and control system application proved to be the classical continuum mechanics method with discretization in terms of unconstrained modes. By comparison to finite element methods the analysis was computationally more efficient and interpretation of results was more straightforward. Unconstrained modes are found to be preferable to constrained or other hybrid modes because they relate most closely to physical observation; consequently they enable control system design and interaction to be interpreted physically in a direct manner, and flight accelerometer data can be compared with dynamics modal frequencies directly.

The spacecraft unconstrained modes are visualized in terms of sets depicted in Fig. 6. Three sets involve attitude motion, namely (pitch and symmetric twist), (roll/yaw and antisymmetric out-of-plane bending), and (yaw/roll and antisymmetric in-plane). The motion equations are written in terms of coordinates corresponding to the modes. The mathematics and computer software were originally developed by analysis only, and the values of the corresponding key elements (gains, frequencies and damping factors) are given under "1971 Estimate" in Table 1.

Later, ground-based vibrational testing was conducted on solar array units in vacuum and under simulated thermal conditions. Comparison of test results with modelling results (for the one-g test situation) brought to light several factors that resulted in changes to the in-orbit modelling and as appreciation of where the modelling would have shortcomings. In-plane modes, which were originally ignored, were found to be significant and included. Spanwise blanket tension variations were found to be important to twist frequencies and were accounted for. Non-linear effects and blanket vibrational modes, which were originally unforeseen, were also noted. Also certain key stiffnesses and masses determined earlier by calculation or component test were found to be in error and full array testing served to calibrate the model with respect to these parameters. The values of the modal frequencies as revised on basis of ground tests are given in Table 1 under '1975 Estimate'.

Ground testing also served to provide the only credible source for preflight damping information. However, the damping data from tests had to be extrapolated to the in-orbit situation, and this proved to be a task which was well beyond standard engineering practice. Methods were devised, and in-orbit projections were as given in Table 1.

During the course of the first year in orbit, modal data became available from incidental structural excitation that accompanied deployment, momentum dumping, E-W station keeping, and array slewing. To fill in certain missing data and to make the modal parameters already available more precise, a special excitation (SPEX) experiment was designed and carried out in January of 1977. Basically SPEX involved exciting a given spacecraft mode at a resonant frequency by firing hydrazine thrusters, and then deriving modal frequencies, damping factors and gains from the measured response. A sample of data from the January 1977 tests is shown in Figs. 7 and 8. The modal parameters obtained from flight data are summarized in Table 1 under "Hermes Flight Data".



SYMMETRIC (EVEN) (Hz)			ANTISYMMETRIC (ODD) (Hz)		
PREDOMINANT TWIST	PREDOMINANT OUT-OF-PLANE	PREDOMINANT IN-PLANE	PREDOMINANT TWIST	PREDOMINANT OUT-OF-PLANE	PREDOMINANT IN-PLANE

Fig. 6 Major Natural (unconstrained) Structural Modes of Vibration

TABLE I - STRUCTURAL DYNAMICS PARAMETERS DURING HERMES PROGRAM

DESCRIPTION		1971 ESTIMATE (before manufacture/ground test)			1975 ESTIMATE (after manufacture/ground test)			HERMES FLIGHT DATA		
		ω_n (Hz)	k_n	ζ_n	ω_n (Hz)	k_n	ζ_n	ω_n (Hz)	k_n	ζ_n
Sym.	Out-of-Plane First	0.15	N/A	_0.001	0.16	N/A	0.003-0.006	0.15	N/A	0.020-0.030
Sym.	In-Plane First	∞	-	-	0.34	N/A	0.014-0.02	0.31	N/A	0.02-0.03
Sym.	Twist First	0.13	0.025	0.001	0.17	0.031	0.09-0.16	0.20		0.06-0.08
	Second	0.41	0.003	0.001	0.50	0.003	0.01-0.02	0.49		
Anti-Sym.	Out-of-Plane First	0.40	0.63	0.001	0.38	7.69	0.005-0.009	0.44	7.3	0.02
	Second	0.46	6.04	0.001	0.50	0.40	No estimate	0.50		0.007(?)
Anti-Sym.	In-Plane First	∞	-	-	.75	7.45	No estimate	0.88	7.0	0.016

NOTES: (1) Flight Values of damping are amplitude dependent

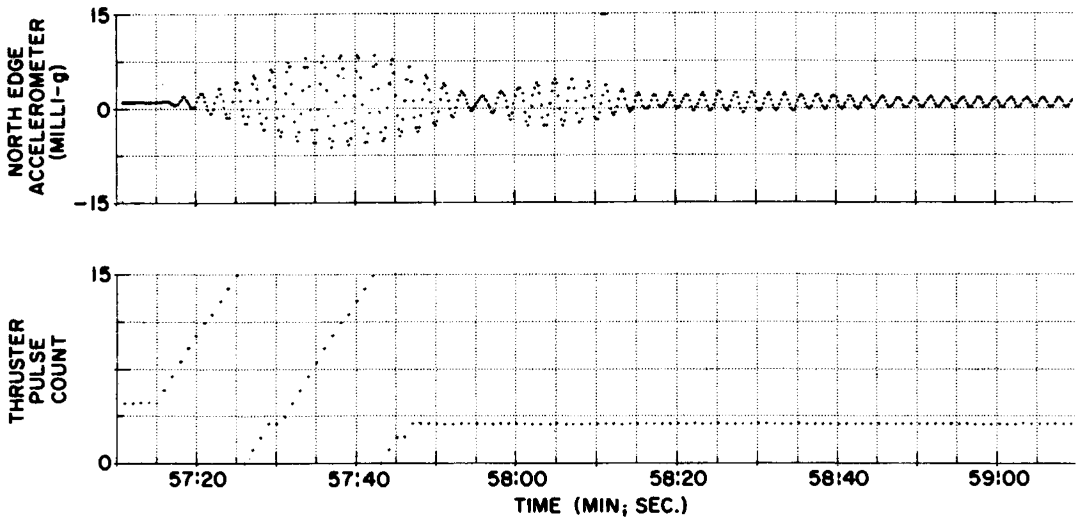


Fig. 7 Accelerometer Response to Thruster Firings, SPEX Event, Day 28 1977

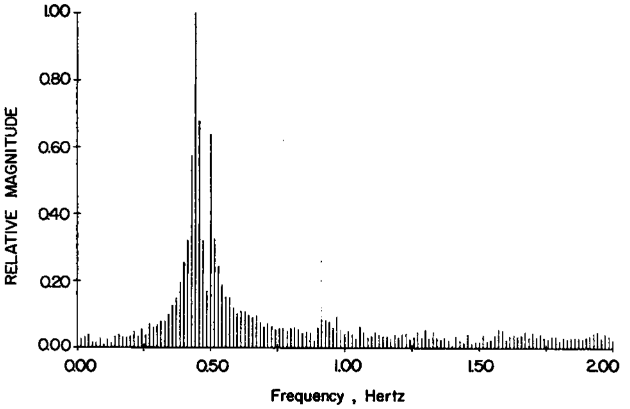


Fig. 8 Fourier Transform of Accelerometer Response, SPEX Event, Day 28 1977

Thus Table 1 shows the progression of modal estimates made during the program and illustrates the degree of accuracy at various stages. The differences in modal frequencies between prelaunch and post-launch are due mainly to prelaunch uncertainties in mass and stiffness parameters, and changes in mass of the spacecraft made very late in the program. One can virtually match flight-derived frequencies and modes with software-generated results (with no changes to the model and computer code) by adjusting stiffness and mass values (results not shown).

Damping factors estimated on the basis of ground tests are somewhat lower than flight results. Although the numerical agreement is in accord with the current state-of-the-art, clearly there is a need for further improvement in this area.

In general terms it can be said that the knowledge of frequencies, gains, and damping was well in hand prior to launch. Ground testing played a key role. For this type of spacecraft it appears that if accuracy of better than 15% for fundamental modes and 25% for higher order modes is critical to controller performance, then a ground testing program is warranted. (Vigneron 1977, Garg 1978)

Attitude Stabilization in Autonomous Mode

The 3-axis stabilization system has operated successfully to date. The normal operation and specially designed test events have served to provide data to verify the characteristics of the system. The environmental parameters upon which the design and sizing of the control system was based are found to be within the bounds established by calculation and analysis. As noted earlier the measured environmental torques are primarily due to solar pressure and are in accord with pre-launch formulas and calculations. The RCS thrusters were found to be aligned to within almost an order of magnitude better than design tolerances. Traverse through eclipse is found to not affect the angular momentum, but nutation angle changes (0.04^{o} or less) believed due to solar induced thermal shock are observed. The alignment of the momentum wheel relative to the earth sensor boresight is found to be within 0.05^{o} of nominal, which is within tolerance. Array slews, E-W Stationkeep, and momentum dump induce torque environments which are within the autonomous stabilization system's capability.

The pitch axis control loop performs as per design with one minor deviation due to momentum wheel drag torque variations. Typical data taken during steady state operation of the wheel is shown in Fig. 9. The controller holds the sensed error to within $\pm 0.03^{o}$. The sun sensor and accelerometer traces illustrate the array sun-tracking operation. Each time the array drive and track steps a nominal 0.5^{o}, the array twists and then damps out between steps. Occasionally an abrupt increase in wheel bearing drag torque of about 5% causes the pitch attitude to deviate by about 0.1^{o} for about 2-3 minutes. This minor anomaly which occurred frequently during the first month of the mission now seldom occurs, and is felt to be associated with wear-in and adjustment to zero-g of the momentum wheel. There is no evidence that this behaviour will affect the life of the wheel.

Flight data and operational experience fully validate the "momentum wheel plus offset thrusters" stabilization principle for roll/yaw control. Earth capture and response of the system to disturbances match well with simulation results. Typical capture data is shown in Fig. 10. All perturbations in roll/yaw (due to array slew, momentum dump, E-W stationkeep, eclipse traversal, earth sensor switching, etc.) are handled by the system without significant deviation in attitude.

There have been occasional anomalies with the momentum wheel (noted above), the earth sensor, and the hydrazine reaction control system. One of two scanning-type IR earth sensors has failed to turn on properly five times, and has stopped once during normal operation. The fault is associated with a mechanical restriction of the scan mirror motion. In the event of failure, the procedure has been to turn off immediately and try again. The sensor has always successfully started on the second or third attempt with no degradation of performance. On numerous occasions with about four of the 14 thrusters of the RCS, the delivered impulse is 70-10-% lower than the expected impulse for individual pulses. The low thrusts are believed to be a result of nitrogen bubbles being expelled with the hydrazine, the nitrogen being a pressurant which has leaked through a bladder to contaminate the hydrazine.

A pointing error summary is given in Table 2.

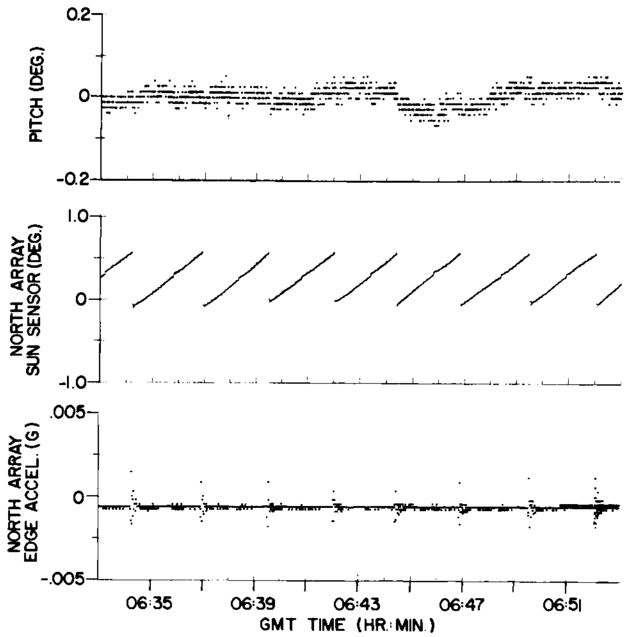


Fig. 9 Steady State Pitch Operation - Day 281, 1976

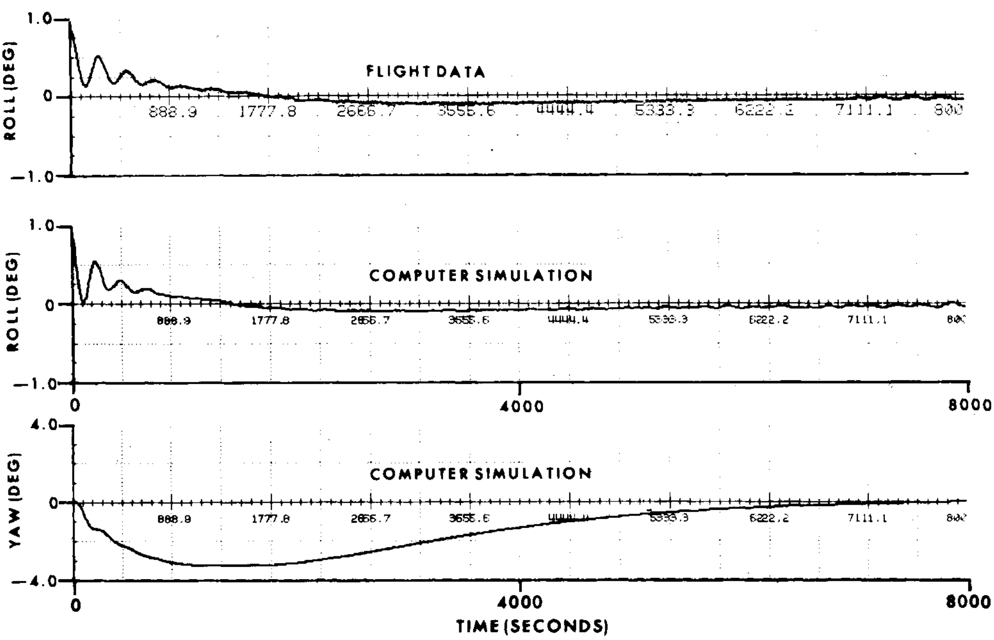


Fig. 10 Comparison of Data and Simulation Results for Capture from 0.83° Roll Angle - Day 93, 1976

TABLE 2 POINTING ERRORS ASSOCIATED WITH CONTROL SYSTEM

	Normal Mode*			Momentum Dump			E-W Stationkeep.		
	Pitch	Roll	Yaw	Pitch	Roll	Yaw	Pitch	Roll	Yaw
Alignment/stability of NESA (deg)	±0.08	±0.08		±0.08	±0.08		±0.08	±0.08	
Alignment of momentum wheel (deg)			0.05			0.05			0.05
Stabilization system null error (deg)	±0.04	±0.06	±0.5	±0.6	∓0.07	±0.5	±0.1	∓0.09	±0.5
Pointing error, at antenna base (deg) (RSS of above)	±0.09	±0.1	±0.5	-0.08, +0.6	±0.11	±0.5	±0.13	±0.12	±0.5

*includes sunlight, eclipse, sun and moon interference

During the design phase it was apparent that the structural frequencies would be outside the desired control system bandwidth by a factor of about five. Consequently the control system design strategy adopted was to assume that the spacecraft was rigid for purposes of synthesis and initial design, and then to verify and finalize the controller parameters via detailed computer simulation and flexibility included. This approach, which provided an engineering solution to an otherwise very complex problem, was essentially successful. However instabilities were found by simulation to be possible in both pitch and roll/yaw for the HERMES design for certain assumed parameter combinations, particularily for low modal damping and large amplitude flexible oscillations. Prior to launch it was concluded that the probability of instability was about 5% and that workable non-standard procedures were available for such an event. HERMES has performed with no detectable structural dynamics/control system interaction. This is as planned during the design; as well the damping factors experienced in flight are somewhat higher than ground-based forecasts (as noted earlier, Table 1) and this has also contributed significantly to the lessening of potential interactions. (Vigneron 1977, Vigneron 1978)

Ground-based Attitude Control

During the conceptual design an area of some uncertainty was the extent to which ground-based control modes of operation would be feasible and desirable in attitude acquisition and on-orbit phases of the mission. Some of the HERMES experience in this regard is summarized in this section. It is felt that the experience will be applicable to most 3-axis stabilized communications satellites.

Attitude acquisition was done over a two day period entirely via ground-based 'man-in-the-loop' and 'mini-computer-in-the-loop' controllers. Specifically, attitude information is sensed on the spacecraft and telemetered to the earth in raw form; the signals are processed by software and then used to derive and initiate thruster commands either by a human operator (and perhaps interactive software aids) on a minicomputer-based algorithm (minicomputer-in-the-loop); the commands are then telemetered back to the spacecraft and executed. The sequence of simple dynamic maneuvers is listed below.

a) Passive spin stabilization (of up to two days);
b) Despin from 60 rpm to about 2 rpm via yaw thrusters and a yaw rate gyro (spin about maximum moment of inertia axis);
c) Nutation monitoring (rate gyros and non-spinning sun sensor) and active nutation damping via roll and pitch thrusters;
d) Further reduction of spin rate using yaw thrusters;
e) Acquire and maintain sun line of sight lock along the negative roll axis using pitch and yaw angle information from a non-spinning sun sensor;
f) 90° rotation about pitch to transfer sun-line lock from the negative roll axis to the positive yaw axis;
g) Solar array deployment;
h) Momentum wheel spin up, enable on-board constant wheel speed hold mode;
i) Precess about sun line to place the positive pitch axis southerly and positive roll axis approximately tangential to the orbit trajectory;
j) Rotate about pitch to acquire earth in the non-spinning earth sensor field of view;
k) Activate the on-board attitude control system to enable capture of the final on-orbit pointing mode.

It was found that all maneuvers could be done by man-in-the-loop with sufficient training using real-time simulation. Time constants in pitch control and roll/yaw control turn out to require a manually-initiated command every 30-300 seconds and 2-10 minutes, respectively. However it was found desirable to do (e-f) and (h) and (j) with minicomputer-in-the-loop, and they were so done in flight. For nutation damp and (precession) maneuvers, (c) and (i), the spacecraft is passively stabilized by stored momentum and required attitude trims by thruster firings were done manually aided by on-line interactive software. This particular strategy for achieving attitude acquisition is a viable practicable option available for future missions. It has the following advantages: it reduces the amount of hardware required on the spacecraft to a minimum, it permits the modification until very late in the program, and it allows the greatest degree of freedom or adaptation in the event of non-standard or failure events during the mission; it can be implemented for either stored-momentum or zero-momentum systems, and it leaves the program with a team which can handle any later-occurring malfunction. The disadvantages are that it requires a fair degree of operator training via real-time simulation and development of written procedures, and perhaps more-than-usual minicomputer redundancy and capacity (Bassett 1976).

The spacecraft has, as an automatic failure protect (AFP) feature, a mode whereby the wheel is automatically switched into a constant speed state in the event of a failed pitch controller, a stuck-on thruster, a failed earth sensor, or certain types of power failure. The constant wheel speed state is stable and requires no sensor or controller operation. The mode has been automatically entered about five times to date due to earth sensor malfunctions and in each case the mode successfully maintained the spacecraft in a benign stable state (with a nutation cone, a slow rotation of the central body about pitch, and the arrays continuing with sun track) until flight operations people arrived. In all cases operators have been able to safely and efficiently damp nutation, capture pitch via sun sensor and thrusters and restart the earth sensor and automatic earth lock within hours, via the 'man-in-the-loop' mode. It is concluded that the AFP and recovery is feasible, simple, and a highly desirable feature for spacecraft of this type (Vigneron 1978).

Three-Axis Stabilization With Minimal Earth Received Telemetry

Since August 1977 the telemetry subsystem of HERMES has been degrading, and often there is no telemetered housekeeping data for several hours per day. By 1979, only very intermittent telemetry will be available. The key ACS data lost will be wheel speed, sun, and earth sensor data.

This failure does not affect the ACS normal mode stabilization directly, as the system operates autonomously with on-board hardware. It does influence wheel speed management and momentum dumping (which must be done every month or so) and recovery from AFP if necessary. Procedures are being developed which will enable operation using only ground-received signal strength from the SHF system.

The spacecraft nutation can be detected in SHF signal strength variations. It has been demonstrated that wheel speed can be calculated accurately from the SHF-derived nutation period, and this data is sufficient for wheel speed monitoring and momentum dump operations.

The risk of loss of attitude pointing or AFP trip is greatly reduced if the hydrazine thrusters are inhibited. Special drift tests conducted in 1976-77 with the offset thrusters inhibited have demonstrated that roll/yaw attitude remains within reasonable tolerance for several days when solar torques are low (near equinoxes) and that the degree of drift is predictable at other times. Consequently it is planned to inhibit the offset thrusters during long periods of no telemetry and either accept the small roll and yaw errors, or correct them infrequently by temporary activation of the on-board system or by ground-commanded RCS firings.

The strength of various identifying side lobes and spikes of the SHF signal have been calibrated to pitch angle. It is felt that in the event of an AFP trip, pitch attitude and restoration of earth lock can be achieved provided that nutation cones is sufficiently small.

CONCLUDING REMARKS

The proven theory, techniques, design guidelines, and software, is thus in place to permit the reliable synthesis and design of solar array structure and attitude control systems for spacecraft similar to Hermes. Further it is believed that the experience described herein and in the references will enable solar arrays and attitude control systems to be designed with confidence for spacecraft whose pointing requirements and structural flexibility are significantly more demanding than Hermes.

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DEVELOPMENT OF JAPANESE H-I LAUNCH VEHICLE

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ABSTRACT

The most advanced attempt towords the development of an expendable launch vehicle now in Japan is the H-I launch vehicle. The H-I launch vehicle is planned to be completed by the winter of 1985. After two tests flights it will be available for the payload users. The capability of H-I launch vehicle is to send 500 kg or more useful payload into a geostationary orbit from Tanegashima Space Center (TSC). The highlight of the H-I launch vehicle is a cryogenic LOX (Liquid oxygen)/LH2 (Liquid hydrogen) second stage with an inertial guidance system. The second stage propulsion system is equipped with 10 ton-f thrust (at altitude) regeneratively fuelcooled tubular thrust chamber. A gas generator cycle is adopted and LOX and LH2 pumps are driven on separate shafts-2 turbines in series. This engine has a restart capability and thrust and mixture ratio are controlled to ensure the high performance. While, the guidance system is a four gimballed stable platform type inertial guidance with self inertial alignment capability. This report covers the historical background, the result of feasibility studies, a total vehicle configuration, preliminary designs and development plans. Details and development status of major subsystem such as a second stage propulsion system, a guidance and control subsystems are included.

INTRODUCTION

Japanese space programs are executed by either NASDA (National Space Development Agency of Japan) or ISAS (Institute of Space and Aeronautical Science, University of Tokyo). Application and practical projects are covered by NASDA, while sounding and scientific research projects are covered by ISAS. NASDA has launched ETS-I (Engineering Test Satellite type I), ISS (Ionosphere Sounding Satellite), ETS-II, and ISS-b by NLV (N Launch Vehicle) from Tanegashima. Also NASDA has sent GMS(Geostationary Meteorological Satellite), CS (Medium capacity Communications Satellite for experimental purpose) and BSE (medium scale Broadcasting Satellite for Experimental purpose) into geostationary orbits by U.S. Delta launch vehicle. By the winter of 1981 NASDA will be equipped with up-rated N launch vehicle , NLV-II, which will be able to place 350 kg payload into geostationary orbit.

according to the Japanese space development plan established by the Space Activities Commission, National Space Development Agency of Japan should develop a space launch vehicle with the capablity of placing more than a 500 kg payload into geostationary orbit by the end of FY 1984 (Japanese Fiscal Year starts in April). The vehicle is also required to adopt a LOX/LH2 second stage with an inertial guidance system. With these requirements in mind a feasibility study has started in FY 1976. The final configuration will be fixed by the end of FY 1978. After the completion of decision phase, the development of H-I vehicle will start in FY 1980.

Two options are open to us as regards the first stage i.e. liquid propellant booster stage or solid booster stage. The result of feasibility study shows the preference for using a similar liquid engine as those of N and N-II Launch Vehicles, because of the fewer risk factors involved and no new development necessitated. By the proper selection of strap on boosters, payloads of 500 kg, 600 kg and 750 kg will be possible. The final configuration has not yet be decided, however, it is very likely that the 2nd stage will remain the same regardless of how the first and the third stages develop, and it will be the highlight of H-I Launch Vehicle Project. Therefore in this paper our primary concern is with the development of second stage.

HISTORICAL BACK GROUND

In 1975, N Launch Vehicle (NLV) project had achieved the first goal of sending ETS-II satellite into a geostationary orbit. From next year, 1976, NLV-II has officially started. On the other hand a feasibility study of post NLV program had started in 1972. It came to the conclusion that NLV should be improved to the vehicle with the capacity of sending 350 kg payload into a geostationary orbit by 1980, i.e. NLV-II, and to the vehicle with the capability of sending more than 500 kg payload into a geostationary orbit by 1985 using a LOX/LH2 second stage engine, i.e. H-I launch vehicle. It was the starting point of H-I project, but configuration and details were quite open yet. The feasibility study of H-I vehicle has intensified from 1976.Basic requirements and conditions imposed on H-I vehicle are as follows;

(1) H-I vehicle should be the main launch vehicle of Japan for late 1980's.
(2) H-I vehicle should have the capability of sending a minimum of 500 kg payload into a geostationary orbit, and should achieve the goal by the end of FY 1985.
(3) Devlopment of H-I vehicle should help the level up of Japanese space technology reading to the advanced H-II (Post H-I) project or space trasportation vehicle technology of 1990's.
(4) H-I vehicle should use a LOX/LH2 cryogenic engine and an inertial guidance system.

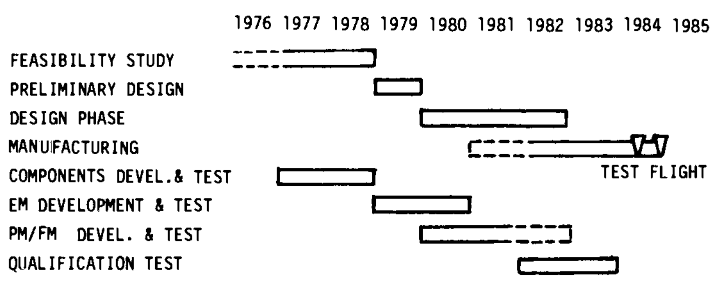


Fig. 1 H-I Development schedule

Considering these requirements and conditions, we made a major development plan upto the two test flights. Several subsystems with critical components have started the BBM (Bread Board Model) level tests. A general concept of test facilities, which needs advanced development to be in time for vehicle testing, had studied, and the design of some facilities, which are required for an early stage of development tests, had completed and they are now under construction. At the same time the configuration and an overall design study of H-I vehicle is in preparation stage now. At present, only basic tests of critical elements and preliminary studies are officially funded, and no flight hardwares developments were authorized yet.

Due to the delay of the decision of H-I configuration and hardware start, development plan should have to be revised each year. The key milestones and a master schedule are shown in Fig.1, wich was up dated in this year. The configuration of H-I vehicle will be decided at the end of FY 1978 depending on the result of the feasibility study and reflecting upon the result of basic component (BBM) tests. FY 1979 will be a definition phase of H-I vehicle project and, as a hardware development, an Engineering Model (EM) development will be started and tested to ennable the Proto and Flight Models (PM & FM) start in FY 1980. A Flight Model design will be started in the FY 1980 and will be proceeded to a manifacturing phase, which is preceeded by the qualification tests. Two test flights are planned in FY 1984 to ensure the flight readiness for succeeding missions.

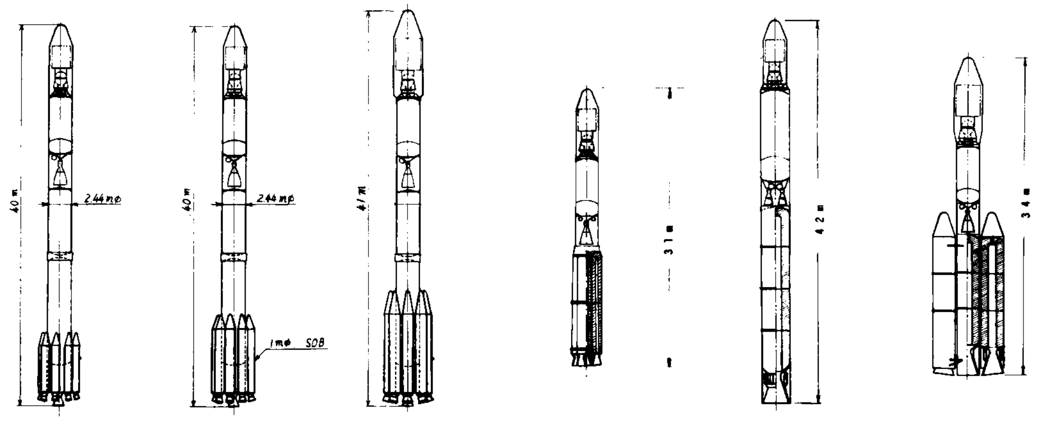
CONFIGURATION

As result of feasibility studies, several configurations are proposed as a H-I launching vehicle. Each configuration has its merits and demerits. Configurations are mainly differed by their payloads and first stages. By payloads they are put into three categories i.e.;

(1) 500 kg class (up to about 550 kg)
(2) 600 kg class (up to about 650 kg)
(3) 750 kg class (up to about 800 kg)

Two options are open to us as regards the first stage,i.e. a solid booster and a liquid booster. There are a few configurations as for the solid first stage. Only one most typical configurations from each payload category are considered and evaluated in this paper (see Fig.2).

Liquid first stage cases Solid first stage cases



500kg class 600kg class 750kg class 500kg class 600kg class 750kg class

Fig. 2 H-I vehicle configurations

Two of them with large payloads have difficulty with launch site safety at the Tanegashima Space Center (TSC). It is difficult to find the place to meet the safety distance requirement at any where in TSC. Besides they are needed to develop a large solid booster with a thrust vector control (TVC), and some kind of roll control devices. A 500 kg class solid first stage case is also required to develop TVC, and cluster and separation mechanisms. Development elements for those solid booster cases will need extra time and cost than the case where the liquid first booster are employed.

As a liquid first stage, the first stage of NLV or equivalent are only feasible cases within the limited time and cost. By the proper selection of SOBs there will be three configurations as shown in Fig.2. For all these cases the safety distance requirements at TSC are cleared. As case of payload of 750 kg class, the result of feasibility study showed the insufficiency of first stage main engine control moment, because of strong easterly jet stream prevailing at the middle latitude in winter (see Fig.3).
Therefore it is required to equip fins or TVC to SOBs. This fact will make a development schedule tight and add extra development cost. Meanwhile the feasibility study results in the fact that the first stage main engine control moment is sufficient to ensure the stability margine for the 500 kg class, and the same strap on boosters as NLV are sufficient as SOBs. Therefore there are no new development factors for the first stage of this case, and it reads to the minimum development cost,risk and time schedule. On the other hand, it is obvious that the shortcomings of 500 kg class lie in the payload capability. However, another investigation over the future needs and trends of Japanese potential satellite users indicates that many of communication satellites to fixed or moving stations, broadcasting satellites, meteorological satellites, and ground observation and marine observation satellites of late 1980's will be within the 550 kg and very few will be over the 550 kg. Also it is important to know that for the liquid first stage booster cases the grade up from 550 kg class to the 600 kg class or the 750 kg class will be achieved without changing the second stage. At the beginning, the 600 kg class case is considered as the configuration to have more merits of both the 500 kg class and the 750 kg class, and less their demerits, but the result of feasibility study turned out to have the same demerits as the 750 kg class. Characteristics of these 6 major configurations are given in Table 1. The final decision will be given by the Space Advisory Commission, and the decision may vary depending on which criteria and conditions they may adopt. However, the trade off studies show the strong favor for the 500 kg class configuration with the liquid first stage and 9 SOBs. Especially the development schedule given in Fig. 1 will be a little difficult to be met with by the other configurations but the 500 kg class with the liquid first stage.

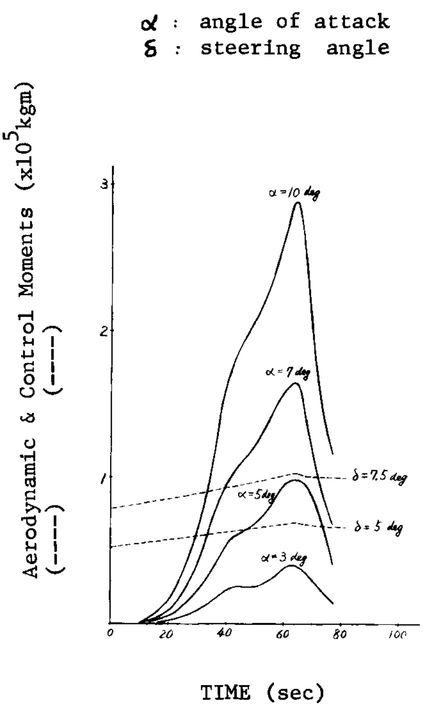


Fig.3 Controlability of 750kg class

TABLE 1 Characteristics of Typical Configurations

TOTAL WEIGHT	(ton)	140	171	227	134	240	308
LENGTH	(m)	39.6	39.6	41.5	31.0	42.0	34.0
DIAMETER	(m)	2.44	2.44	2.44	1.1mϕx3	3.0mϕ	2.44mϕx3
1st STAGE PROPELLANT		LOX/RJ-1	LOX/RJ-1	LOX/RJ-1	1.1mϕSRM(4/2/1)	3mϕ SRM	2.44mϕ SRM
PROPELLANT WEIGHT	(ton)	80.9	80.9	80.9	101.5	178.0	81.0
THRUST AT SEA LEVEL	(ton-f)	78.0	78.0	78.0	142/72/36	393	291
SPECIFIC IMPULSE "	(sec)	254	254	254	230	264	264
STRAP ON BOOSTERS		9 Solids(6/3)	9 Solids(6/3)	8 Solids(4/4)	---	---	2.44mϕSRMx2
PROPELLANT WEIGHT	(ton)	33.7	60.0	100.0	---	---	162.0
THRUST AT SEA LEVEL	(ton-f)	142.2/71.1	136.8/68.4	196.7/196.7	---	---	582.0
SPECIFIC IMPULSE "	(sec)	238	229	229	---	---	264
2nd STAGE PROPELLANT		LOX/LH2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2	LOX/LH_2
PROPELLANT WEIGHT	(ton)	8.33	8.33	8.33	8.33	21.0	8.33
THRUST AT ALTITUDE	(ton-f)	10.0	10.0	10.0	10.0	10.0x2	10.0
SPECIFIC IMPULSE "	(sec)	430	430	430	430	430	430
3rd STAGE PROPELLANT		Solid	Solid	Solid	Solid	Solid	Solid
PROPELLANT WEIGHT	(ton)	1.85	2.1	2.7	1.85	2.1	2.6
SPECIFIC IMPULSE "	(sec)	285	285	285	285	285	285
FAIRING WEIGHT	(ton)	0.6	0.6	0.85	0.6	0.6	0.85
DIAMETER	(m)	2.44	2.44	3.00	2.44	2.44	3.00
PAYLOAD:200Km PARKING ORBIT	(Kg)	3220	3718	4829	3160	3396	4684
GEOSTATIONARY ORBIT	(Kg)	550	635	830	540	580	800
APOGEE MORTOR PROPELLANT		Solid	Solid	Solid	Solod	Solid	Solid
PROPELLANT WEIGHT	(ton)	0.53	0.6	0.79	0.53	0.56	0.77
SPECIFIC IMPULSE AT ALTITUDE	(sec)	290	290	290	290	290	290

OUTLINE OF THE 500 kg CLASS VEHICLE

The configuration is not pin down yet, but as we mentioned in the previous section, the 500 kg class configuration with the liquid 1st stage engine could be one of the most possible configuration as a result of the detailed feasibility study undertaken in FY 1977. Therefore we will describe this configuration briefly in this section.

1st Stage

As a first stage propulsion system we use a gimballed NLV first stage engine or equivarent as a main engine, along with 2 vernier engines, which use LOX/RJ-1(Kerosene) as propellants. A 2.44 mϕ tank with iso-grid pattern wall is used as a propellant tank. Pitch and yaw, and roll control moments are generated by gimballing the main and vernier engines respectively. The on board guidance computer is mounted on the top of the 2nd stage and sends control command to an electrical package (E-pack) to drive the gimbal actuators.

As augmented boosters, we use 9 same solid motors as NLV, 6 of which will be fired at the lift off and the rest of 3 solids will be fired just after the first 6 solids burnout. They are dropped together after the burnout of the last 3 solids. Most of the telemetory data are managed by the on bord computer and are sent back to a tracking station as PCM signals.

2nd Stage

The second stage is a cryogenic stage with a cylindorical integral tank made of Aluminum alloy iso-grid plate which is separated by a honeycomb sandwich common bulkhead. Its demension is about 5.5 m long and 2.44 m diameter, and its dry weight is 700 kg. A sectional view of the second stage propulsion system is shown in Fig.4.

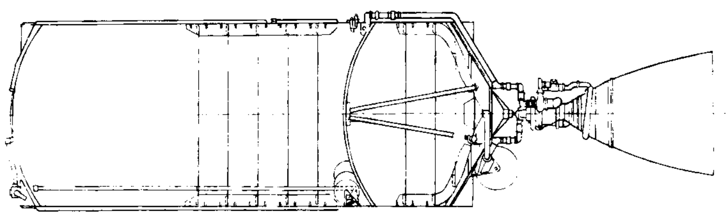


Fig.4 Sectional view of second stage propulsion system

At the top of the 2nd stage, there is a so called guidance section packed up with the on board equipments, such as guidance computer, inertial measurement units, batteries, power and sequence distribution boxes, telemetory systems and E-packs. A roll control of a powered flight and an attitude control of a coast flight are done by the gas jet system. Parts of this gas jet system are also used for actuation system of an allege control system. Pitch and yaw of powered flight phase are controlled by the gimballing of the 2nd stage engine by the command of a guidance computer. The functions of the guidance system are shown in the block diagram (Fig.5). The major role of the on board computer (guidance computer) is also defined in Fig.5. The major cycle consists of a navigation, a guidance, an event control and propulsion system controls. Details of the guidance system components will be given in the next section.

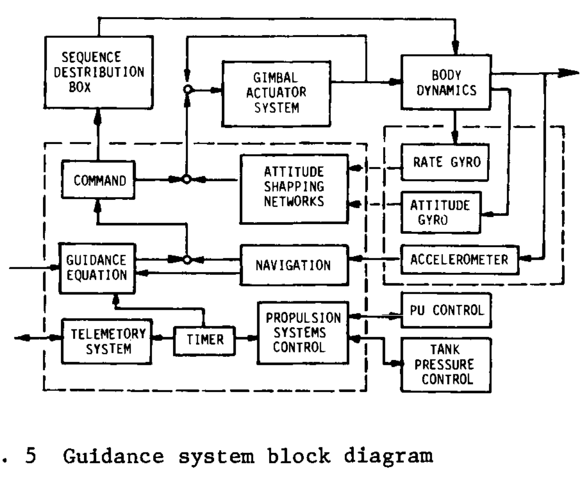


Fig. 5 Guidance system block diagram

The second stage propulsion system is equipped with 10 ton-f thrust (at altitude) LOX/LH2 engine, a schematic diagram of which is given in Fig.6. As shown in diagram it is a regeneratively LH2 cooled engine with a gas generator cycle. LOX and LH2 pumps are driven on separate shaft 2 turbines in series. This engine has a restart cap-

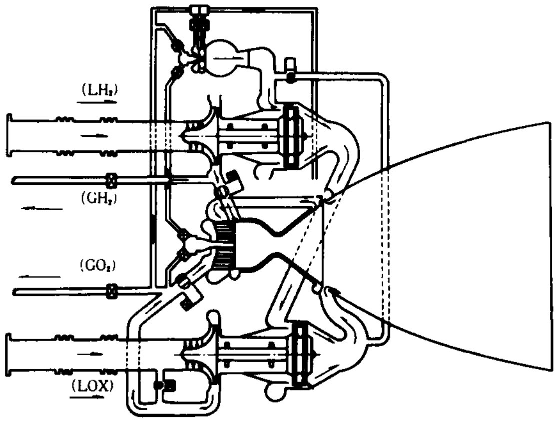


Fig.6 2nd engine flow diagram

ability, and thrust and mixture ratio (see Fig.7) are controled to ensure the required high performance. Specifications will be given in the later section.

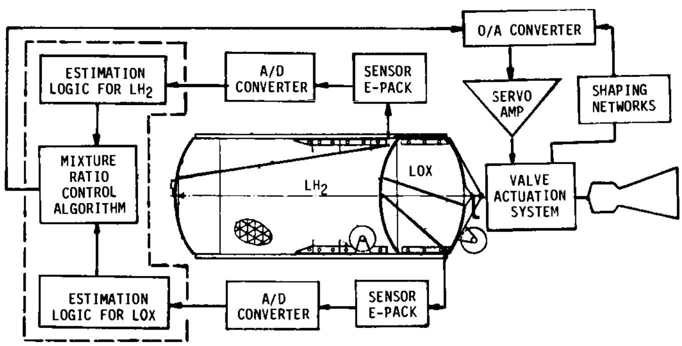


Fig.7 Propellant utilization control diagram

3rd stage

An optimally sized spin stabilized spherical solid motor is expected for the 3rd stage motor. Preliminary component tests are under way at the Nissan Motor Co,Ltd.

GUIDANCE AND CONTROL SUBSYSTEM

After the two years of intensive study about the proposed three guidance system, the H-I guidance system was selected and general concept was fixed in 1976. The system is a stable platform type inertial navigation system with an explicit guidance law. The system consists of four major elements, i.e. an inertial measurement units (IMU), a guidance computer (IGC), a data adapter unit (DAU), and a guidance program (IGP).

Components tests of gyro elements and accelerometers were completed in 1972. The basic configuration of IMU is adopted from the inertial navigation system of a high performance aircraft assembled by Japan Aviation Electronics Industry, Ltd. Main check points were in the modified platform mechanism and the acceptability in space environment. Design requirements for IMU are summarized in Table 3.

The applicablity of a large scale integrated circuit (LSI) was investigated in 1976. In 1977 a small size light weight micro computer was assembled and tested as BBM of IGC based on the general purpose mini computer NEAC 3200 of Nippon Electric Co.Ltd. Fig. 8 shows the outlook of this BBM. Design requirements for IGC are given in Table 2.

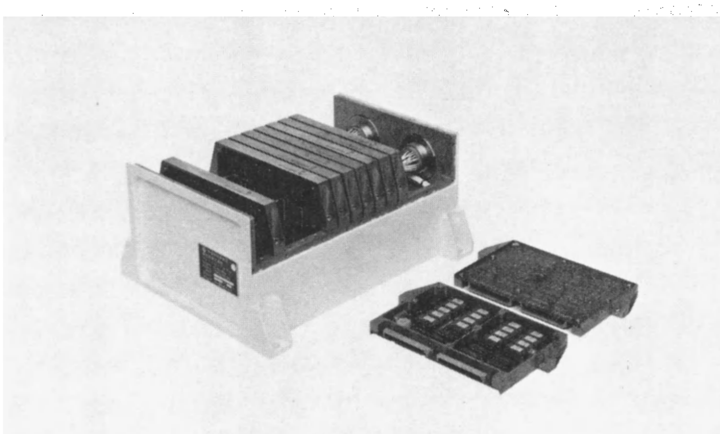


Fig. 8 BBM of guidance computer

TABLE 2 Characteristics of IGC

Programming	Micro programming
Word length	16 bits (binary)
Memory capacity	16K words
Clock signal	4M Hz
Number of statements	76 kinds
Computing speed; Add	4.5 us
Multiply	9.5 us
Division	11.5 us
DMA channel	1 channel
Direct accessible address	1K words
Interraption lines	8 lines
Environment (Temperature)	-25°c to 60°c

TABLE 3 Characteristics of IMU

Sensor	4 gimballed space stabilized platform
Alignment	Self-alignment by gyro compassing
Alignment accuracy; Tilt	1 arc min.
Azimuth	6 arc min.
Accelerometer range; Axial	-5G to 15G
Normal	-10G to 10G
Accelerometer error; Bias	$2x10^{-4}$G
Gyro errors; Non G sence drift	0.01 deg/hr
G sence drift	0.15 deg/hr/G
Environment (Temperature)	-25°c to 60°c

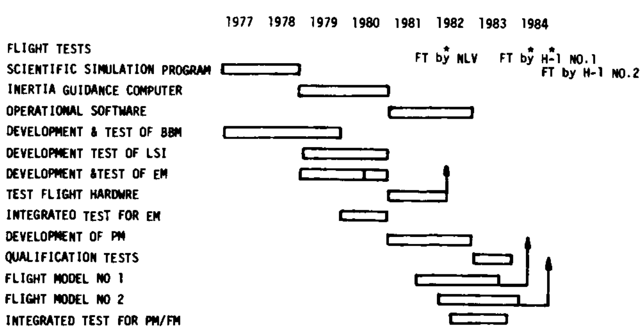


Fig. 9 Development plan for guidance system

As a guidance system software, a navigation method, a guidance equation, and flight control logics had been studied since 1975. From 1977 the development of scientific simulation program was started to help quantative evaluation of a guidance software by the Mitsubishi Space Software Co.,Ltd.

Beside the two test flights by H-I in 1984 there is one more chance of a test flight by NLV in 1982, where only open loop system test (mainly a navigation) will be executed. The development plan for the guidance system is given in Fig. 9.

PROPULSION SYSTEM

Tank system

The tank sytem for H-1 2nd stage consists of tanks and components. Among components are a dump cooling subsystem before engine starts,level sensors and their filters for mixture ratio control, tank pressurization and pressure release devices. Cryogenic tanks are insulated in different ways depending on their parts. A cylinder parts, made of 1.15 mm iso-grid Al-2219-7871, will be insulated by Polyurethane form from outside. While the dome parts, made of Al-2219-T6, are insulated in different ways. An about 20 mm multi layer insulation and a 50 mm insulation bug method are adopted for LH2 and LOX dome parts respectively. A common bulkhead, made of about 35 mm honeycomb sandwitch, are super insulated. Inside the tanks are unti-slosh buffles, and are liquid helium accumulators in LH2 tank to save the space and weight. Some other data about the tank system is given in Table 4.

TABLE 4 Characteristics of Propulsion System

Burn time	370 sec	Propellants	LOX,LH_2
Thrust at altitude	10 ton	Tank dry weight	440 Kg
Specific impulse "	430 sec	Tank diameter	2.44 m
Engine weight	200 Kg	Tank volume	
Engine length	2700 mm	LOX Tank	6400 liter
Engine diameter	1650 mm	LH_2 Tank	20200 liter
Nozzle area ratio	136	Tank pressure	
Chamber pressure	35 Kg/cm^2A	LOX Tank	2.4 Kg/cm^2A
Mixture ratio	5.5	LH_2 Tank	3.1 Kg/cm^2A
Turbo pump shaft speed		Propellant weight	8333 Kg
LOX	15000 rpm	Propellant flow rate	
LH_2	50000 rpm	LOX	19.1 Kg/sec
Gas generator		LH_2	3.5 Kg/sec
Chamber pressure	25 Kg/cm^2A	Coast time(max.)	80 min
Mixture ratio	1.0		

A damp cooling test and estimation of thermal insulation effects by experiment have been conducted so far. Also some strength tests of materials and welded parts under the cryogenic condition have been completed successfully. Development of an engineering model has started in this year considering the result of tests and experiments. The tank system development schedule is set to facilitate the propulsion system tests and it is given in Fig.11 with that of the engine system.

Engine system

Since outline of H-I 2nd stage engine system was given previously, only its some other additional aspects will be given here. The ignition of both a thrust chamber and a gas generator are done by torch like fashion to ensure the engine start. The torch of burning mixture are brought from a precombustion chamber which is ignited by a spark plug. An expander cycle is adopted only for the start period to prevent the unstable combustions and pump stole particular to a gas generator cycle. Turbine and pump are connected directly to form a turbopump, and two of them are spritted and driven independently to avoid the complicated gear couplings. The propellant utilization control is adopted to minimize the residual propellants. To attain this end the mixture ratio are controlled by adjusting the by-pass valve set in the down stream of a LH2 turbine. Thrust control is achieved by controlling the by-pass valve set in the down stream of the gas generator. Nozzle wall with expansion ratio of up to nine is regeneratively cooled, while the nozzle part after that to the end is cooled by dumped gas through open end tubes. Further information are given in Table 4, the propulsion system characteristics. The mock up model is given in Fig.10 and shows the expected outward view of the propulsion system.

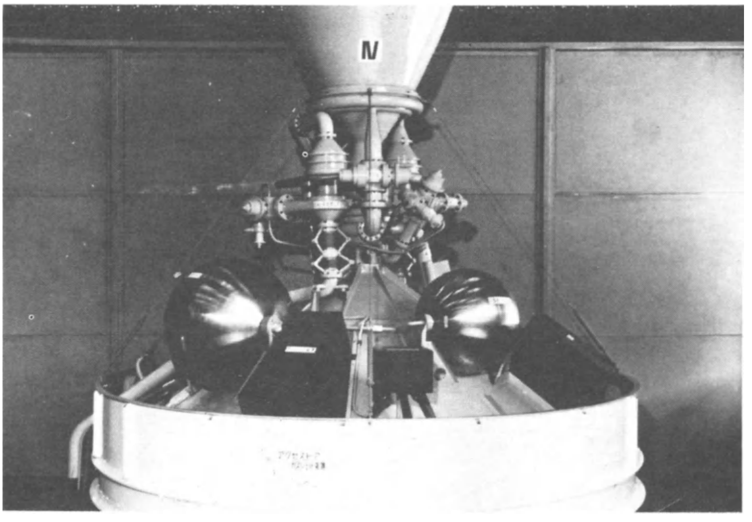


Fig. 10 Mock up model of 2nd stage engine

Development of 2nd stage engine system is divided into two parts. One is mainly the thrust chamber and the other is the propellant feed system. To know the combustion and cooling characteristics, the firing test of 500 kg-f thrust chamber had been conducted in three steps, i.e. with the chamber without the cooling devisse, with water cooled chamber and with LH2 cooled chamber. The results of these tests showed good agreement with the analyses. Further water cooled 10 ton-f thrust chamber tests are planned in this year. All these experiments has been taken place and will be taken place at the Tashiro Test Site of the Mitsubishi Heavy Industry Co.,Ltd. (MHI). Now LH2 regeneratively cooled 10 ton-f thrust chamber is under development for the tests in the next year. From 1975 to 1977 LH2 pump characteristics are investigated by using a 7.5 ton-f pump with LN2 as substitute for LH2, and the results were compared to the results of LH2. From 1977 the tests for LH2 pump and turbine have started by the Ishikawajima Harima Heavy Industry Co.,Ltd.(IHI). The results using the substitutes LN2 and GN2 for LH2 and GH2, were satisfactory and the tests using LH2 and GH2 respectively will follow. The development of LH2 turbopump is now under way and will be ready for test in next year. The other experiment conducted by the IHI from 1977 to 1978 are gas generator tests and engine control components tests. The result thus obtained and will be obtained are utilized to determine the final design of elements and components. Meanwhile the BBM of LOX turbopump is now under development at the National Aerospace Laboratory based on their research about them. NASDA will take over the development from FY 1979. The overall engine test and then the propulsion system test of EM will start in FY 1980. Further schedule is given in Fig.11.

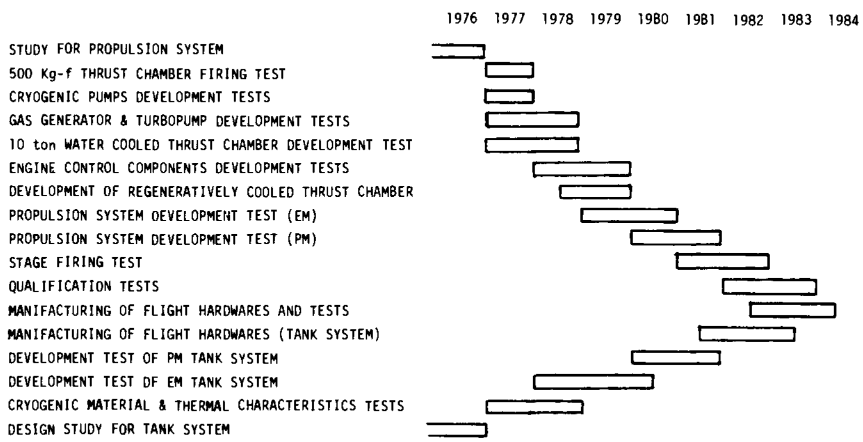


Fig. 11 Development for propulsion system

TEST FACILITIES

The test facilities for the guidance system are gathered at the Tsukuba Space Center of NASDA, 50 km south east of Tokyo, while the propulsion test facilities are gathered at the Kakuta Launch Vehicle Test Center of NASDA, 300 km north of Tokyo. Due to limited capacity at the Kakuta, some firing test facilities are placed in the MHI's Tashiro Test Site. The new launch site is also planed in the Tanegashima Space Center. The constructions and operations of all these facilities are planed to be in time for their use.

CONCLUDING REMARKS

As we outlined H-I project and briefly explained background and status of the project, it is only at its start line and has to face many difficulties in the future and may subject to innevitable change. Some part of this report bear the information which are tentative in nature and might be revised in near future. The report is as of September 1978. Another progress report will also be issued along with the development somewhere. Finaly we thank all those engineers who are working towards the reality of H-I launch vehicle.