

IAA

Position Paper

Inexpensive Scientific Satellite Missions

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1. INTRODUCTION

1.1 MOTIVATION AND HISTORY OF STUDY

Initially, all space programs were small. The early Sputniks and Explorers are typical examples of small and, in some way, in-expensive space missions if one omits the overall investments for developing the infrastructure. As time went by, scientific projects grew bigger, not only in the US and the Soviet Union but in other regions having come later into this field, like Western Europe. Lately, a general concern has been growing within the world-wide space science community about the dramatic decrease of the number of flight opportunities for any particular discipline.

This has led the Committee on Space Sciences of the International Academy of Astronautics to consider the initiation of activities aimed at quantifying this problem area and to assess measures apt to help to overcome it.

Preliminary discussion, including working meetings at Vienna and Heidelberg in 1986, Brighton in 1987 and Bangalore in 1988 showed that in some countries, like Japan, India or China, the space program is structured in such a way as to allow each major discipline in space sciences to receive a flight opportunity every few years. Furthermore, during the last two years, a number of parallel initiatives have been taken, at different levels, by the major space agencies that are directed at restoring, or investigating restoration, of a higher frequency of scientific missions.

In deciding to convene a workshop for the analysis of this issue, the Academy acknowledged that the present budgetary environment calls for innovative approaches, not for just another demand of increased funding, however well supported by an assessment of needs. The workshop was therefore instructed to address the following aim:

"to assess the feasibility - based on applicable experiences - of reducing the cost of moderately-sized scientific missions, as a way to increase the number and the rate of such research flights".

This document summarizes the results of the study conducted by a Working Group of Scientists and Engineers during 18-20 May 1989 at Bordeaux (F) and sets forth a number of technical and procedural suggestions and recommendations for the implementation of future inexpensive missions satisfying the needs of the space science disciplines.

The document has been prepared to foster the development of scientific knowledge about the universe, for peaceful purposes and through international cooperation. Its aim is to provide a contribution to the space plans and the science policies of the concerned ministries of the fifty-six countries represented in the membership of the Academy. In the same spirit, it is also addressed to the space agencies of those countries, to the space research institutions and space industry throughout the world.

1.2 BENEFITS

The name of this study contains in brief a summary of the potential benefits of this approach. To be able to offer a larger number or lower-cost, moderately-size, but fully valid, scientific missions has natural advantages. A set of institutional advantages covers general governmental concerns, aspects related to the mandates and aims of space agencies, on the one hand, and research institutes and universities, on the other.

Foremost are obviously the benefits to the scientific community, even if they do blend with the institutional ones. The major themes have been identified. Lower-budget missions can be formulated to look at "new" aspects and phenomena, thus preparing the ground for future, larger missions, if such more exploratory work is successful. Then, such an approach offers a fast-reaction capability for the study of unexpected or sudden astrophysical events. Finally, long-term observations and monitoring become economically feasible.

From these research aspects, advantages for academic formation can be highlighted. The envisaged duration of the development of small scientific satellites of a few (2-4) years creates the possibility to phase the educational cycle with the development and operation of such research missions. Secondly, a number of research institutes inside or outside the universities possess or could (re-) develop the capability to build substantial parts of or even the entire scientific payload or spacecraft of small dedicated space missions. This would naturally lead to heighten-ing the standards of education for both scientists and engineers and technologists.

Finally, one can mention improved opportunities for technology transfer between academy and industry, as well as for technical assistance in the space field to less developed countries.

2. FEASIBILITY

This section presents some examples of the lower cost or alternative approaches that have been applied to programs in the past and to certain current programs. It is not intended to provide a complete survey of such activities throughout the world, but rather to demonstrate feasibility and existence of low-cost concepts.

2.1 EXAMPLES OF THE PAST

2.1.1 The AMPTE Ion Release Module (IRM)

The Active Magnetospheric Particle Tracer Explorer (AMPTE) was originally conceived as a 2-spacecraft mission to trace the passage of ions from the solar wind into the Earth's magnetosphere. The German Ion Release Module (IRM) would release canisters of barium and lithium which would be ionised and accelerated by the solar wind, and hopefully find their way into the magnetosphere, where they would be detected by the American Charge Composition Explorer (CCE). It was subsequently decided to convert the adaptor cone, which linked the two spacecrafts during launch, into a third spacecraft, the United Kingdom Subsatellite (UKS), for observing the local in-situ effects of the release.

The IRM was designed and implemented by the Max Planck Institute for Extraterrestrial Physics in Garching having a number of innovative approaches which ensured that costs were kept to a minimum.

Many of the spacecraft subsystems were produced in-house, and those which had to be obtained externally were not necessarily procured from companies with existing space experience. For example the deployable S-band antennae were based on the Mercedes deployable automobile antennae.

The IRM spacecraft, designed for a one-year mission was operated highly successfully for 2 years and together with the other AMPTE spacecraft has contributed to the production of large quantities of world-class scientific data. The cost of spacecraft and instrumentation was somewhat in excess of DM 30 M, of which one half was spent on the spacecraft.

2.1.2 The AMPTE United Kingdom Subsatellite (UKS)

The UKS was designed and implemented by the UK Rutherford Appleton Laboratory (RAL) and the Mullard Space Science Laboratory (MSSL). The adaptor cone which linked the IRM and CCE spacecraft was converted from a nugatory piece of hardware into a highly sophisticated third spacecraft, by the addition of 5 plasma diagnostic instruments and a full set of spacecraft support subsystems. Most subsystems were constructed in-house at the two institutes whilst others were put out to "non-space" companies. The solar arrays were manufactured by a US solar energy company which had been involved previously only in terrestrial solar panels. Many examples of innovative engineering were exploited, including the use of a system of thermal flaps for control of a variety of hostile thermal conditions which could otherwise have been achieved only by an expensive system. The total mass was 78 kg.

For a cost of approximately 5M Pounds the UKS has served a UK scientific community of more than 60 scientists in 10 institutes, and many more world-wide. It has resulted in UK authorship of around 100 papers published to date.

2.1.3 The Swedish Viking Satellite

The decision to develop a scientific satellite devoted to auroral plasma physics was made by the Swedish government in 1979. The launch of Viking, originally planned for 1984, was postponed until February 1986 because of the schedule of the SPOT satellite of France with which it was launched in a piggy-back configuration (SPOT on Viking).

The Viking project was managed by the Swedish Space Corporation (SSC), and the satellite, based on a Boeing spacecraft, was built by the Saab Space Company. The scientific payload consisted of 5 major experiments (comprising several subunits) and was in part procured from scientific institutes outside Sweden. The mission was operated in scientific campaigns, with real-time data reception and active control from the Science Center at ESRANGE/Kiruna, where all scientific teams were represented, and in close coordination with ground-based support. During its 9.5 months operation outstanding scientific data were received which led to many discoveries. The spacecraft (not counting experiments) was procured for the costs of 80 MSEK. Its dry weight was 286 kg. Strict adherence to the resources envelope, a design lifetime only 8 months, virtually no redundancy, and use of off-the-shelf equipment characterized its development.

2.1.4 The UOSAT Program

The University of Surrey (UOSAT) microsatellite program has resulted in the highly successful design and production of two spacecrafts which are currently operational, after 8 and 5 years respectively, and two more

due to be launched on the first flight of the Ariane Structure for Auxiliary Payloads (ASAP) in October 1989. The spacecrafts are used for research into cost effective spacecraft engineering techniques and for space education, with a world-wide user community of more than 3 000. They are controlled by a ground station at the University which is able to operate in a largely hands-off mode, covering typically 12 passes per day.

The first two UOSATS were produced for costs of around 250k Pounds and 450k Pounds, whilst the latest two ASAP spacecrafts cost approximately 700k Pounds in total.

2.1.5 The VEGA Program

In the framework of the VEGA project (from the Russian form for the name VENERA-HALLEY) France has been able to produce, either totally or partially, 10 experiments for the study of the Venusian atmosphere and Halley's comet.

The payload of more than 100 kg was produced by a combination of small industry, scientific laboratories, international cooperation, and a significant contribution from CNES. The overall cost of 120 MFF for 2 launches was equivalent to a cost per kg more than 3 times lower than in classical space industry. The scientific objectives were achieved at more than 70%.

2.1.6 The AMSAT Program

Projects like the AMSAT OSCAR Series of radio amateur satellites show an excellent record of spacecraft flights based on low cost. Since 1963, a total of 14 satellites were built using, to a large extent, donated volunteer labours and secondary payload launch opportunities. The satellites range between 40-150 kg with considerable capabilities (bipropellant motor, powerful on-board processing and attitude control, autonomous satellite operation without ground control). The satellites performed well, their lifetime extended the expectations despite incorporating innovative technologies.

2.2 EXAMPLES OF ON-GOING PROGRAMS

2.2.1 Large Space Agencies

On-going programs show a constant trend to find in any frame, periodic, interesting and quite relatively low cost flight opportunities.

With its Small-class Explorer Program, NASA has already made an important step in realizing many of the ideas promoted in this study. We can only applaud to this development. The objectives of these missions are, in brief, to conduct scientific research in the space disciplines traditionally served by the already existing Explorer Program, but at lower costs and shorter lead times. The specific characteristics of this new class of satellite projects in NASA's program are: a scientific scope that can be controlled by a single principal investigator, a lead-time from selection to launch of typically three years, an overall flight frequency of two per year (initially one per year) launches by Scout-class vehicles, and total costs for spacecraft and scientific instrumentation on average not exceeding 30 M\$. Four missions have already been selected. Although it seems that the spacecraft development is being entrusted to the NASA field centers such as Goddard Space Flight Center, it is conceivable that in some cases one may return to the approach of the early years of space

flight during which universities were given the chance - quite successfully - to develop the entire spacecraft in-house.

The European Space Agency has at present no program element comparable to NASA's Small-class Explorers. The Yellow and Blue Missions of the Horizon 2000 program are by scientific scope, programmatic approach and anticipated costs outside this category.

The NASA/CNES bilateral MFE/MAGNOLIA project, if undertaken, may become an example of a relatively low-cost Explorer program with another satellite on ARIANE.

In the Soviet Union one has entrusted the development of a new type of spacecraft to the Institute of Space Research (IKI). Under the name REGATTA they will constitute an important element in the International Solar-Terrestrial Physics program (ISTP). It offers new scientific and technological opportunities in international cooperation. However, by complexity and size of the planned spacecraft they hardly qualify as small and probably also not as inexpensive satellites.

2.2.2 Other Major Space Programs

2.2.2.1 The Japanese Space Science Program

In Japan, eighteen scientific satellites have been launched in inexpensive ways by ISAS (Institute of Space and Astronautical Science) over the nineteen years up to 1989. This pace, roughly one satellite per year, has contributed to the realization of the flight opportunity for one scientific discipline every five years and the continuity of the field of research by educating follow-on research staffs in a university framework.

For the last five launches of ISAS, the average cost for satellite and for vehicle are 26 M\$ and 27 M\$, respectively. Realization of these inexpensive satellite is due mainly to the administrative structure for space development, namely, the application satellite program with a larger budget, which are controlled by separate organizations, NASDA (National Space Development Agency of Japan) and ISAS respectively. Programs of these two organizations are coordinated by Space Activities Commission, which belongs to the cabinet.

Japanese industries have expressed their willingness to cooperate with ISAS at the cost of their present expense, if they judge that the know-how accumulated through the cooperation with ISAS could be transferred to bigger systems such as application satellites and space stations.

2.2.2.2 The Indian Space Science Program

The Indian space science community consists of about 600 individuals and is spread over about 50 work centers. Primary interests of these scientists cover aeronomy, astronomy as well as atmospheric sciences including meteorology.

The capability for astronomical and aeronautical observations from space platforms became a reality in 1975 with the launching of the first Indian satellite "Aryabhata" which carried three experiments. Also the second satellite, "Bhaskara-1", carried on-board an astronomical instrument. As an example of a payload that utilized a piggyback flight opportunity in an international mission, we can cite the cosmic ray experiment ANURADH which was flown on the Space Shuttle's Spacelab-3 mission during April-May 1985.

A launch vehicle called the Augmented Satellite Launch Vehicle (ASLV), that can launch a satellite of 150 kg weight class, called Stretched Rohini Satellite Series (SROSS) into a low earth orbit is presently being developed by ISRO. Within the constraints of weight and payload envelope allowed by the fourth stage of ASLV, the SROSS configuration has been worked out to suit a variety of experiment requirements. From considerations of reliability, turnaround time and cost effectiveness, a common bus configuration has been adopted for the platform. Both 3-axis stabilised and spin-stabilised versions are under development.

The first two missions of SROSS carried instruments for the investigation of celestial gamma ray bursts and for remote sensing applications. One of the future SROSS missions will have on board an aeronomy experiment, another one will be devoted to X-ray astronomy.

The Indian Space Research Organization is presently developing a Polar Satellite Launch Vehicle (PSLV) that can launch a one ton-class of satellite (like the Indian Remote Sensing Satellite IRS 1A) into a polar sun-synchronous orbit. It is conceivable that the IRS platform can be modified to accommodate major science missions.

2.2.2.3 The Chinese Space Science Program

There are 25 satellites that have been launched in China since 1970; it includes the scientific programs of ionospheric and magnetospheric physics, remote sensing, meteorology and atmospheric physics. In addition to these special satellite programs, scientific payloads are carried on the special and technological satellites for promotion of research of solar physics, microgravity sciences, life sciences and other fields.

In the next few years, China will develop and launch several types of satellites for the meteorological research and scientific explorations. The national program including the research and development on space science and technology for peaceful purposes is planned since 1986 and will persist into the next century. With regard to the scientific research related to the exploration and utilization of space resources, it covers many fields and will extend to many decades in the future.

2.2.3 Further Examples

As mentioned above, this brief survey of on-going programs of small scientific satellites is not intended to be complete. Many efforts are being made in countries not (yet) belonging to the major spacefaring nations to develop scientific satellites which by necessity are inexpensive, although they may consume a considerable fraction of those nations space budget. Examples are Brazil and Argentina. Furthermore, among the ESA member states there are some which devote (a small) part of their budget to low-cost satellite programs. The Swedish-German satellite project FREJA may serve as an example for this category.

The already discussed radio amateur satellite series of the AMSAT organization is being continued with a new generation of spacecraft. A further example is TUBSAT, a technological micro-satellite with an instrument capability in the range of about 20 kg. It will be launched by STS as part of NASA's "GAS" program. Its characteristics fall in the class which can be adopted to the ASAP structure. The s/c is based on a 3 axis attitude control system.

3. MEASURES FOR ACHIEVING INEXPENSIVE SATELLITE MISSIONS

3.1 COST DRIVERS

The cost of a mission is influenced by a number of factors and operations like: cost of the spacecraft and its payload, launch vehicles and operations, management approach, etc.

In the course of this study, mission requirements, organization and management, and political considerations have been identified as those cost drivers which are more easily controlled by either the sponsoring organizations or the scientific institutions.

3.1.1 Mission Requirements

The mission requirements are derived from the scientific objectives. Conventionally those objectives are translated through a number of managements layers in the process of becoming requirements, some of which are more stringent than necessary. This may cause the development cost to move into an area of exponential growth.

For the large and ambitious projects a very high level of requirements, standards, procedures and configuration control is justified in order to meet the mission success. Risks are not acceptable due to the large impacts and cost involved. In addition, the programs are necessarily lengthy and infrequent which further justifies, high quality control, reliability and component standards as well as a tight configuration and project control. This adds to complexity and impacts on the qualification, test program, operation, etc.

3.1.2 Organization and Management

The organizational structure of complex missions includes many interfaces and communication chains in order to distribute the program complexity and work load based on a world-wide level of cooperation including the international constraints and communication overhead which adds to complexity. This often results in delayed program definition and changes which impact on the overall schedule. In addition, the availability of experienced personnel in the expanding space activity is a matter of concern. Limited experience of personnel, which may result from present educational limitations, causes considerable difficulties and has management impacts throughout the programs.

3.1.3 Political Considerations

The adoption of the approach outlined in this document will provide the opportunity for each country independent of its size to initiate and conduct scientific missions at moderate cost.

The efficiency of implementation would be increased even more by using the know-how and experience resident in major agencies, for instance if it was possible to have them as consultant.

3.2 PHILOSOPHICAL APPROACH

The development of inexpensive satellite missions requires a change in several aspects of the organization of the work which industry usually carry out for space agencies. A small dedicated team, avoiding geographical spread, in charge of all aspects of engineering and hardware integration is a possible approach. This should be able to minimize documentation and administrative expenses which are not directly productive to the project. Integration of this technical team with the scientific one has been found useful in the past for assessment of, and decisions on, technical issues and for proper assessment of risks taken. Also, both engineering and scientific teams must fight against "nice to have" requirements which may dramatically increase the cost of its mission. Early in the payload definition all major cost drivers of this nature have to be identified and eliminated. Similarly, the scientists should be prepared to accept that maximum reuse of existing equipment may lead to some reduction of the scientific return of the mission.

In most instances, space industry is not structured to accommodate such innovative approaches and new dedicated structures may need to be created. However it is believed that such an approach can only be followed by industry if it can expect continuity and growth of activity over the years as such projects develop. This should be reflected in a long-term policy by the space agencies.

3.3 MANAGEMENT APPROACH

There is no unique way of carrying out a space mission at low cost, neither on the technical, nor on the managerial side. In the following sections measures are addressed that were adopted in past projects and that were found instrumental in the desire to reduce costs. For any individual mission some procedure named below may be replaced by a modified one. The main point is flexibility of approach, i.e. adaptation to the specific scientific goals to existing resources.

Among the management measures adopted in previous inexpensive missions the one that breaks perhaps most drastically with the "agency approach" is the formation of an integrated science and engineering team as discussed in the preceding section. This does not mean, however, that strict management rules should be abandoned. The need for control remains unaffected, but the means vary. Small projects handled by integrated teams can replace much of the paperwork by communication inside the regular group meetings.

Quality assurance is one of the most critical items in the overall costs of a space project. Elaborate procedures worked out for control of the supply of various systems and subsystems from widely distributed contractors can be replaced by strongly simplified ones in a low-cost approach. However, basic measures like careful incoming inspection of parts and qualification of non-space-qualified items are indispensable. Again, there is no simply describable way of reduction of quality assurance procedures. But there is much experience with individual procedures, like, for instance, replacing high tech parts by suitably screened mass production components from other than space industry, when no substantial risk increase is foreseen. Another important measure for achieving enhanced reliability is the introduction of redundancy wherever

feasible. Thorough and, in some cases, long term testing of systems and subsystems can to some extent replace costly parts selection and tracing procedures.

In some past projects the prime industrial contractor has been replaced by a scientific institution or a government-controlled agency or company (e.g. Swedish Space Corporation). However, also the classical approach, of having an industrial prime contractor should not necessarily raise the costs drastically, if the same flexibility would be applied as characteristic for scientific research institutions. However, there seems to be little experience with such an approach in satellite manufacturing, although in the development of sounding rocket payloads it has been proven to work.

Table 1 condenses in short phrases many of the management experiences suited to keep the cost of a mission at low level. Ultimately, it is the scientific objectives which decide whether such rules are applicable or not.

3.4 TECHNICAL ASPECTS

This subsection gives examples of the type of cost reduction measures which can be considered when planning and implementing a mission. In no sense is it intended to be exhaustive, nor does it imply that programs must be conducted in a particular manner. We just point out what measures have already proven to be successful or are likely to be so in the future.

3.4.1 Spacecraft

To achieve the objective of inexpensive scientific satellite missions, several technical considerations must be highlighted. It is clear that the cost of satellite will, in a first instance, be driven by the scientific mission and experiment complexity. Requirements related to pointing accuracy, modes of operations, data rates should be given careful consideration as they will affect not only the spacecraft design but also the testing and validation program as well as the operational phase.

In fact, programs need to be based on a constant scrutiny and review of all elements, identifying sources of major cost impacts sufficiently early to enable full review to define alternative solutions. Introduction of new and/or enhanced requirements should be severely restricted, financial and effectiveness considerations should be the dominant factor throughout program implementation.

It is believed that the reuse of existing spacecraft buses is very effective to reduce the cost of the spacecraft, and such an approach should be encouraged wherever appropriate. However, it is recognized that scientific missions usually have unique features which may prevent reuse of existing buses: in such cases the reuse of existing subsystems and equipment should be pursued as a major design objective.

Passive stabilization modes are known to provide the most cost effective approach. Spin stabilization has been used successfully for many missions, and gravity gradient control with magnetic control can provide coarse 3-axis stabilization. It is recommended that such approaches be implemented should the mission permit. However if more complex 3-axes stabilization modes are required, sensors and actuators covering the whole range of requirement already exist and can be selected, thus avoiding the cost of new expensive developments.

Management Recommendations· Start a program with clearly identified specifications· Minimize program duration· Reduce number of models· Avoid technical risk in mission-critical areas· Minimize team size· Minimize number of external interfaces· Avoid unnecessary administrative loads· Find new methods for achieving geographical distribution e.g. by multiple sub-satellites· Adopt innovative engineering solutions· Don't be constrained by existing methods (but don't reject them simply on principle)· Be innovative without pushing the frontiers of technology (interact with technologists)· Adopt simple, well-defined subsystems interfaces· Use off-the-shelf equipment· Encourage modular design· Make use of multiple-satellite or piggyback launch opportunities· Identify reliable flight opportunities· Adopt standard mechanical interfaces· Use a well-proven primary structure in which other users have confidence· Streamline launch campaign to minimize impact on primary payloads· Make use of local expertise and centres of excellence· Research establishments· Small industrial companies· Product Assurance (PA)· Develop a PA plan which is just technically adequate· Avoid hi-rel components unless justified· Restrict documentation to the absolutely necessary· Avoid component level testing and inspection unless really necessary· Emphasise box-level and system-level tests.

Management Recommendations

- Start a program with clearly identified specifications

- Minimize program duration
 - Reduce number of models
 - Avoid technical risk in mission-critical areas

- Minimize team size
 - Minimize number of external interfaces
 - Avoid unnecessary administrative loads
 - Find new methods for achieving geographical distribution e.g. by multiple sub-satellites

- Adopt innovative engineering solutions
 - Don't be constrained by existing methods (but don't reject them simply on principle)
 - Be innovative without pushing the frontiers of technology (interact with technologists)

- Adopt simple, well-defined subsystems interfaces
- Use off-the-shelf equipment
- Encourage modular design

- Make use of multiple-satellite or piggyback launch opportunities
- Identify reliable flight opportunities
- Adopt standard mechanical interfaces
- Use a well-proven primary structure in which other users have confidence
- Streamline launch campaign to minimize impact on primary payloads

- Make use of local expertise and centres of excellence
- Research establishments
- Small industrial companies

- Product Assurance (PA)
- Develop a PA plan which is just technically adequate
- Avoid hi-rel components unless justified
- Restrict documentation to the absolutely necessary
- Avoid component level testing and inspection unless really necessary
- Emphasise box-level and system-level tests.

Lile for attitude control, use of the simplest design approach should be encouraged for any subsystem: passive thermal control and minimization of the number of mechanisms are typical examples of low-cost design objectives.

Measures to reduce the cost of electronic equipment may comprise the replacement of space qualified components by screened commercial or MIL-standard components. Such an approach combined with adequate redundancy schemes, may results in reliability and risk levels which are acceptable considering the

associated cost savings. New technologies may also be avoidable to reduce mass thus improving operational capabilities without necessarily encountering severe cost increases.

Another important cost element is the testing program. Reduction of spacecraft models, such as protoflight approach, have already been implemented. Extensive system tests versus extensive subsystem tests should be reviewed; both solutions have been implemented successfully in the past and potential cost reductions must be assessed versus risks taken.

3.4.2 Flight Opportunities

As of 1990 several opportunities exist to fly individual experiments and small satellites as piggyback payloads combined with single or dual Ariane launches, on a stand-by mode basis.

Available platforms include:

- for individual experiments of mass of 20 kg max., the free flying Ariane Technology Experiment Platform (ARTEP) developed by ESA, attached to the ARIANE 4 SPELDA* structure, offers up to 150 kg payload capability, once or twice a year, in dual launch, essentially into GTO. The 1st flight is scheduled in 1990 for the ESA In-Orbit Technology Demonstration Program (TDP),

- for small satellites up to 50 kg such as UOSAT, the Ariane Structure for Auxiliary Payloads (ASAP) developed by ARIANESPACE, to be attached to the ARIANE 4 equipment bay inner cone offers up to 200 kg payload capability about once every 18 months, in single launch, and most likely into SSO. The 1st flight is scheduled in November 1989 with 4 MICROSAT (4 x 12 kg) and 2 UOSAT (2 x 40 kg) associated with SPOT 2.

ASAP and ARTEP flight opportunities could be offered at particularly attractive financial conditions (i.e. not more than 1 M\$ per mission).

For small satellites, in the range of 150 to 600 kg, the BOEING VIKING or the ESA APEX-ARIANE 4 structure** to be mounted as the carrying structure of a main passenger of an ARIANE 4 launch, could offer a solution. However, this is far more expensive, since it implies the use of an upgraded version of the ARIANE 4 L/V family (i.e. launch costs in range of 10 M\$ to 20 M\$ would have to be faced).

* Structure Porteuse Externe de Lancement Double Ariane

** - Viking was launched in February 1986 with SPOT 1

- APEX-401 was launched in June 1988

For the time being, and with exception of the above-mentioned ASAP, there is no systematic solution that would allow small satellites to be flown at low cost and with a sufficient number of opportunities. There is however a growing offer of possible small launch vehicles. The availability of a dedicated small launcher such as PEGASUS, AMROC, LITTLEO, Improved Scout, EPAC, CONESTOGA, Starfire and Orbital Express, would constitute an attractive expansion of launch opportunities, characterized by enhanced flexibility in comparison with piggyback launches.

In addition one could expect to have available in the future many other launchers. Apart from Europe and the USA, other countries appear able and eager to propose dedicated, shared or piggyback flight opportunities: e.g. USSR, China, Japan, Brazil, India.

3.4.3 Ground Operations and Ground Based Stations

The cost of mission operations clearly represents a major part of the program costs and it is important to find ways to minimize it. Reuse of the major agency tracking networks, such as NASA's Deep Space Network, or the ESA ground station network, should be avoided for routine operations, although their support will often be required during the Launch and Early Operations Phase (LEOP).

It is usually proven far more cost effective to employ national facilities - ideally utilising just a single ground station. For instance, the two European AMPTE spacecraft were controlled from single stations in Germany and England, respectively. The UK station was developed at very low cost by updating the original IRAS control centre to the requirements of the AMPTE mission. Although new software and operational procedures were necessary, very little new hardware was required.

Any mission which utilises data relay satellites, whether the US TDRSS or the forthcoming Japanese or European systems, will obviously incur severe cost penalties, originating from the high gain tracking antenna required on the spacecraft and from the actual operations. If no compelling reasons exist for their employment, they should be avoided for low-cost scientific missions.

Another important element is to avoid costly centralized data processing, if distributed processing with strong involvement of the experimenters themselves appears feasible and appropriate.

4. SCIENTIFIC NEEDS AND TECHNOLOGICAL DEMONSTRATION

During the course of this study, it was not possible to conduct any survey of existing instrument or mission proposals suited for a low-cost approach. Nevertheless, it would be easy to name examples from those proposals made, but not selected during the last ten years of program definitions of the major space agencies. A good demonstration of the scientific needs was the response to NASA's Announcement of Opportunity for the Small-Class Explorer Program. 51 proposals were received, 19 from the side of space astronomy and 32 from space physics. A call for proposals of this kind, if released elsewhere, is likely to create a similar response.

Scientific and technology demonstration missions have a set of common concerns. In both cases there is a conflicting situation between the request for frequent flight opportunities and the limited budget for paying spacecrafts or flight costs.

It is deemed that scientific missions, launched in piggyback configurations and with high demands on performances, are good opportunities for in-flight test of new and promising technologies, provided a certain level of risk is acceptable and safety constraints can be met.

On the other hand, the push towards new and ambitious missions are forcing the major agencies to study and define performant, coherent and low-cost in-orbit Technology Demonstration Programs (TDP). These programs are open to various solutions like piggyback launch or payload, low-cost spacecraft. This means that future scientific programs could be enabled to derive benefits from cooperation with the TDP's by co-sponsoring flight opportunities and simultaneously using technologies.

The typical need of more and more sophisticated scientific instrumentation could be met in a most appropriate fashion by long-term programs proceeding step-by-step from technological advancement to verification and application, whereby each step could be realized by a low-cost approach. In many fields of space science, not necessarily excluding space astronomy (which typically calls for larger and larger observations), this rhythm of development and verification almost demands existence of more frequent and low-cost flight opportunities.

5. RECOMMENDATIONS

The term "inexpensive" scientific satellites has no precise definition. We used it here in the sense that such satellites are apt to fill the gaps between the major programs of the great space agencies, that they can be developed with short lead-times, and that the rules of management and technical implementation differ considerably from those applied in the major programs. The advantage of such a class of satellites is obvious: it allows for higher flight frequencies and shorter times in implementing new technological developments. Ideally the lead-times can be made to correspond with the educational cycle of space science students. For many countries, no other than "inexpensive" satellites in this sense are conceivable for budgetary constraints. Hence there is a commonality between the programs of such nations and those which have the possibility of sending man into space and explore other planets. This document addressed governments, space agencies, industries and scientific communities mainly, but not only of those countries which have great space programs or share them with other nations (ESA) and which seem to have lost sight of the possibilities of such inexpensive program elements over their efforts to realise their ambition of conquering and exploring space. This document is intended to contribute to the creation of an awareness that other, more cost effective ways are still possible at this time that they can coexist with methods developed for big programs, and that they are highly recommended for the implementation of the many more modest objectives that exist in great abundance in the scientific community.

The development of such an awareness should lead scientists and industry to rediscover their common interest in such inexpensive programs, since scientific and technological advances more often than not proceed hand-in-hand, and higher flight frequencies should offer advantages for both sides.

In order to implement a satellite project in an inexpensive fashion, one has to identify the common enemy of science and industry, which we see in exaggerated and rigidly applied specifications and control methods. Such procedures often originate from a principle of mutual mistrust. We recommend to rediscover ways in which integrated teams of scientists, engineers, technicians and managers perform their work in an atmosphere of openness, in which unexpected problems are not being hidden as long as possible, but are readily identified and attacked in a common effort. Much of the way towards inexpensive solutions consists in finding the appropriate "philosophical" approach.

Some practical steps that have been found helpful in the past are described in this document and condensed into Table 1.

Finally, a few specific recommendations are made:

- the introduction of a Small-Class Explorer Program by NASA is seen as being perfectly in line with the spirit and objectives of this study. To proceed along this path by even increasing the number of flights per year and by involving, wherever feasible, the scientific laboratories in the spacecraft development is our recommendation,

- with regard to ESA's scientific program the situation appears to be quite different. We do not recommend the introduction of a program similar to NASA's small class explorers, since we feel that this would imply an augmentation of the corresponding budget. To develop inexpensive satellites would be within the capability of the ESA member states, either alone or in bilateral or multinational collaborations. However, ESA could play an important role in such efforts in making available its technical expertise in the conceptual and design phases, as well as during spacecraft development by offering help in mission, mechanical and thermal analysis and testing while charging only marginal costs. This would lead to better exploitation of the common investments of the ESA nations and could save costly national investments*.

- In general, we do not plead for increasing the space budget in order to accommodate a new class of albeit inexpensive satellites. We believe that their introduction requires only a slight modification of the spirit in which the scientific space programs are being defined. And this is not only addressed to the governments and their space agencies, but equally to the scientific community and its industrial partners.

* NOTE -

Elements of this study have found entry into the reports of the 1989 Science Programme Review Team to the Council of the European Space Agency (1990) and its recommendations. In response, ESA has just recently issued a Call for Ideas for Small Missions, in order to assess the priorities for a program consisting of one launch every two years with an ESA contribution at a level of 20 MAU per flight.

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