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SMALL SATELLITE MISSIONS

Background paper 9

The full list of the background papers:

1. The Earth and its environment in space
2. Disaster prediction, warning and mitigation
3. Management of Earth resources
4. Satellite navigation and location systems
5. Space communications and applications
6. Basic space science and microgravity research and their benefits
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PREFACE

The General Assembly, in its resolution 52/56, agreed that the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) should be convened at the United Nations Office at Vienna from 19 to 30 July 1999 as a special session of the Committee on the Peaceful Uses of Outer Space, open to all Member States of the United Nations.

The primary objectives of UNISPACE III will be:

(a) To promote effective means of using space technology to assist in the solution of problems of regional or global significance;

(b) To strengthen the capabilities of Member States, in particular developing countries, to use the applications of space research for economic and cultural development.

Other objectives of UNISPACE III will be as follows:

(a) To provide developing countries with opportunities to define their needs for space applications for development purposes;

(b) To consider ways of expediting the use of space applications by Member States to promote sustainable development;

(c) To address the various issues related to education, training and technical assistance in space science and technology;

(d) To provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology;

(e) To strengthen international cooperation in the development and use of space technology and applications.

As one of the preparatory activities for UNISPACE III, the Office for Outer Space Affairs of the Secretariat has prepared a number of background papers to provide Member States participating in the Conference, as well as in the regional preparatory meetings, with information on the latest status and trends in the use of space-related technologies. The papers have been prepared on the basis of input provided by international organizations, space agencies and experts from all over the world. A set of 12 complementary background papers have been published and should be read collectively.

Member States, international organizations and space industries planning to attend UNISPACE III should consider the contents of the paper, particularly in deciding on the composition of their delegation and in formulating contributions to the work of the Conference.

In the preparation of the present background paper, contributions from the following organizations have been used: Centre national d'études spatiales of France; Centre royal de télédétection spatiale of Morocco; European Space Agency; International Academy of Astronautics; Subcommittee on Small Satellites for Developing Nations; Korea Advanced Institute of Science and Technology; Surrey Satellite Technology Ltd., located at the University of Surrey, United Kingdom of Great Britain and Northern Ireland and World Meteorological Organization.

The assistance of M. J. Rycroft (International Space University, Strasbourg, France, and Cambridge University, United Kingdom) as technical editor of background papers 1 to 10 (A/CN.184/BP/1-10) is gratefully acknowledged.

SUMMARY

Small satellites offer valuable missions with current and emerging technologies, for all fields of science and applications, for technology demonstrations and for education and training. This is not only true in industrialized countries, which already have established space programmes, but it is also particularly important for developing countries and countries emerging in space technology, which can then have access to space missions, applications and spin-off technologies. Together with reduced development times, the inherent reduction of launch costs offered by the reduced size and mass of the spacecraft and their more manageable proportions, small satellites become attractive ways to develop and establish a national expertise in space technology and to serve the needs of all countries in accessing new missions.

Small satellites have considerably augmented the range of possible space missions, thereby lowering the cost threshold of access to space for countries emerging in space technology. Small satellites are not a solution for all types of mission, but offer the possibility of performing ambitious scientific experiments and applications as a complement to large missions. Their capabilities increase with improvements in electronic processors and sensors.

Small satellites can be developed through international cooperation, at either the regional or higher levels. Cooperative programmes also offer opportunities for engineers and scientists to be trained in satellite design, production and operations. Small satellite missions are particularly attractive for so-called “space-emerging” countries—which are countries with a technical knowledge base and some space experience, striving for small satellite missions to exploit the new, cost-effective possibilities they offer.

The philosophy and roles of microsatellites and small satellites are examined here, as are also the economic aspects of small satellite projects, the roles of educational and research institutions and of the commercial sector, and the possibilities for cooperation at the regional and international levels.

I. PHILOSOPHY OF SMALL SATELLITES

1. In the early days of space exploration, most space missions were small, primarily because the launch capability was small. As the launchers grew, so did the satellites. However, it must not be forgotten that an incredible increase in human knowledge came from those early small satellites. As projects, mainly scientific projects, grew larger, there was a general concern in the global space community about the gradual decrease of the number of flight opportunities for any particular discipline, the increasing costs of more and more complex missions and their decreased flexibility (because of long development times, for example).

2. The need to return to smaller missions was therefore initiated by the space community, which was then being consolidated by the reduction in space budgets. However, the return to small satellite missions was also driven by advancements of technology. Thus, small satellites could be developed that not only provided valuable scientific returns, but also allowed completely new applications in remote sensing, environmental monitoring and communications.

3. There is no universally accepted definition of a “small satellite”. Usually, an upper limit of about 1,000 kilograms is adopted. Below that limit, satellites over 100 kilograms are frequently called “minisatellites”, between 10 and 100 kilograms “microsatellites” and below 10 kilograms “nanosatellites”. At the University of Surrey, United Kingdom of Great Britain and Northern Ireland, satellites having a mass between 500 and 1,000 kilograms are called “small” and between 100 and 500 kilograms “mini”. The European Space Agency (ESA) usually considers 350-700 kilogram satellites “small”, 80-350 kilogram “mini” and 50-80 kilogram “micro”. The cost of developing and manufacturing a typical minisatellite is between US$ 5 million and 20 million, a microsatellite between US$ 2 million and 5 million and a nanosatellite could be below US$ 1 million. In the present paper, the generic term “small satellite” is used for a spacecraft of less than 1,000 kilograms.

4. The small space mission philosophy can be stated as essentially a design-to-cost approach, within strict cost and schedule constraints and with, as far as possible, a single mission objective. This philosophy is supported by the following four trends.

Electronics miniaturization and growth of performance

5. Improvements in electronics technology have resulted in many of the items used in our everyday life (from computers to video cameras, portable phones, radios and watches) becoming smaller, more efficient and generally cheaper. This is also true for all satellite equipment affected by electronics and software. Mass-market devices drive technological developments. Non-space-qualified processors and mass memories, more powerful than their space-qualified equivalents, have been successfully flown on small missions. Micro-machining technologies have enabled bulky electro-mechanical sensors, such as accelerometers, to be replaced by very low-mass, low-volume semiconductor sensors.

Appearance of small launchers

6. The mass of geostationary telecommunications satellites has grown because of the need for increased lifetime, power and number of channels. Launch vehicles have grown accordingly; added performance has enabled double launches of telecommunications satellites and has been needed to support manned missions. This capacity has driven up the size of scientific missions, with some benefits in terms of economies of scale, but the downside is the long time involved in securing funding for such large, costly missions and the complexities of coordinating the conflicting requirements of the various instruments. To counter that trend, in the late 1980s the United States of America supported the commercial development of new small launchers (operational in the mid-1990s). Commercial, generally smaller and cheaper, launchers are now also successfully used to create “constellations” of small communications satellites in low-Earth orbits. The Russian Federation has promoted the use of modified military missiles to launch small satellites and could have a major influence on the small satellite market owing to the high

reliability, large stockpile and low cost of such launchers. Europe, with its Ariane launcher, is playing a major role with a special platform devoted to microsatellite launches (see para. 50).

Independence

7. A small satellite carrying a single instrument and a dedicated launch is often the affordable way for emerging "space-faring" nations to put their own satellite into orbit. Small satellites also enable individual countries to obtain a completely independent communications, Earth observation or defence capability at a rather low cost, so that they are not totally reliant on major space-faring countries. Even if the performance of the small satellites cannot match the larger satellites in all aspects, they are under that nation's direct control and that is a very attractive feature.

Mission complexity and cost of multi-instrument satellites

8. The growth in cost and complexity of traditional scientific missions has caused a parallel growth in the constraints and the management layers associated with those missions. Increasingly stringent safety regulations have been introduced to protect the investment, preventing the use of state-of-the-art technologies. The end-users then had less control over the mission and considerably more time to wait for the results. Small mission platforms can flight-demonstrate and qualify new equipment, sensors and systems cheaply and deliver meaningful results in a short time.

9. In the 1990s there has thus been growing interest in returning to the use of small satellites, which can be launched a few years after programme initiation. That small mission philosophy was also adopted by the National Aeronautics and Space Administration (NASA) of the United States of America, with its "faster, better, cheaper" approach. Scientific missions for near-Earth and planetary explorations are now conducted in accordance with that philosophy: several spacecraft in the new generation have already been launched and successfully operated. Along with the reduced size of the mission, the customer oversight has also been reduced, leading to further cost reductions, although the level of quality of the product must still be maintained to assure mission success.

10. An excellent case history is the programme of the Institute of Space and Aeronautical Sciences (ISAS) of Japan, where most, if not all, of the scientific spacecraft have been of the small class, providing valuable scientific returns, and also in cometary and lunar exploration. The reduction in the size of the satellites is now evident in more focused Earth observation missions, with fewer smaller instruments providing full services to specific or national user communities along with the larger land remote-sensing (LANDSAT) satellites, the ESA's Envisat and Meteorological Operational (MetOp) or the Système pour l'observation de la Terre (SPOT)-type satellites.

11. Most of these new missions are driven by the worldwide reduction in space budgets, but they are also made possible by taking full advantage of technological developments—the miniaturization of engineering components and the development of micro-technologies for sensors and instruments for well-focused and small-scale scientific and Earth observation missions. At its extreme, the miniaturization process leads to the integration of microelectromechanical systems using microelectronics for data processing, signal conditioning, power conditioning and communications, that is, the concept of the application-specific integrated microinstrument. Initial evaluations of micro- and nano-technologies have even led to the concept of nanosatellites with dimensions of a few centimetres and masses of only a few kilograms, constructed by stacking wafer-sized application-specific integrated microinstruments together, with solar cells and antennas on the exterior surface.

12. Thus small spacecraft do not imply low technology and short lifetimes: on the contrary, they may mean very advanced technology, offering larger payload mass in relation to the total mass of the spacecraft. In fact, the small satellites offer valuable missions, even with today's technology, for science and applications as well as for education and training. Together with reduced development times and the inherent reduction in launch costs offered by the reduced size and mass, the small satellite concept becomes an attractive solution to serving the needs of the new missions. This is particularly important for the developing countries, which can then afford to have access to space missions, applications and the relevant technologies.

II. COMPLEMENTARITY OF LARGE AND SMALL SATELLITE MISSIONS

13. Small satellite missions do not replace large satellite missions, as their goals and issues are often different. Small missions are complementary to larger missions. By developing new methodologies and techniques, small satellites can spearhead pioneering advances in experiments and technologies that are later flown on major missions.

14. Small satellites have several advantages over larger ones, for both large and small countries: more frequent and more varied mission opportunities; more rapid expansion of the technical knowledge base; greater involvement of local industry; and greater diversification of potential users.

15. Of course, one solution is not necessarily applicable to all problems. There are, for instance, good reasons why geostationary satellites are growing in mass: the number of positions available in geostationary orbit is limited and a longer lifetime increases the return on investment. In general, there is a similar relation between small and large satellites as between microprocessors and mainframe computers. Some problems are better addressed via distributed systems, for example, constellations of microsatellites or small satellites (typically for global coverage), while others may require centralized systems (e.g. a large optical instrument, as in a space telescope or a high-power direct-broadcast communications system).

16. Affordable small satellites require a very different approach to management as well as to technology, if cost, performance and delivery targets are to be met. Several attempts at using a traditional aerospace organization to produce such satellites have failed because of the rigidity of the management structure and conservative thinking. Small teams (25 persons), working in close proximity with good communications and well-informed and responsive management personnel, are essential. Such characteristics are best found in small companies or research teams, rather than in large aerospace organizations, which may find it difficult to adopt or modify the procedures necessary to produce affordable small satellites using staff and structures intended for large aerospace projects.

17. Specifically, a successful small satellite project requires:

(a) Highly innovative technical staff;

(b) Small, motivated teams;

(c) Personal responsibility, rigour and quality;

(d) Good team communications, close proximity;

(e) Well-defined mission objectives and constraints;

(f) Knowledgeable use of modern components;

(g) Layered, failure-resilient system architecture;

(h) Thorough testing of both components and the whole system;

(i) Technically competent project management;

(j) Short timescale (to prevent possible escalation of objectives).

III. SCOPE OF SMALL SATELLITE APPLICATIONS

18. Social and economic problems may be addressed by various applications of space technology, in particular those using small satellites. Such direct needs can be classified by geographical location, by type of services and products or by type of applications. Today it is usual to focus on problems such as communications or monitoring of remote areas, agricultural land use and environmental protection. In addition to those direct needs, it is also important to realize that small satellites can be the best way to test and validate new technology. Finally, the subject of academic training requires specific attention, as small satellites can play a significant role there, especially for developing countries.

A. Telecommunications

19. The subject of telecommunications has many space applications. For the purpose of the present paper, discussion will be restricted to remote and mobile communications (including messaging, electronic mail and localization) using small satellites in low-Earth orbits.

20. The use of low-Earth orbit communications systems allows many services, such as communications between a portable terminal, similar to that employed in cellular telephone communications, and a normal telephone of the existing fixed telecommunications network. In that case, the two users may be located anywhere in the territory, so that this is especially attractive in remote areas or in regions lacking communications infrastructures. On the other hand, communications are also feasible between a mobile user and a user of the fixed network system anywhere in the world. In that case, the final connection is completed through the existing network system.

21. The use of automatic data-collection platforms, in conjunction with the two-way characteristics of low-Earth orbit communications, allows the installation of a data-collection network that features a wide coverage and provides real-time service. In addition, the low-Earth orbit communications system can give the location of any user of a mobile terminal. The location accuracy, in the hundred-metre range, is adequate for most applications. The low-Earth orbit communications mobile terminal can also be coupled to a facsimile machine for the transmission of graphical data. Thus it will be possible, for instance, to send a facsimile of an electrocardiogram in the case of a medical emergency in a remote area.

22. Telemedicine is an application that will increase the efficiency of medical services by allowing the transmission of information obtained by cheap and simple sensors directly to complex processing units in large medical centres where it can be properly interpreted by specialized physicians. Thus, powerful and effective emergency services can reach poor and undeveloped areas, saving many lives and avoiding the unnecessary displacement of patients. The HealthNet project is a very good example of a telemedicine application: it uses a 60-kilogram microsatellite (HealthSat) in low-Earth orbit to relay medical data and information between a number of African countries and North America.

23. To increase the immunity to failure under disaster conditions, mobile communications may also play an important role in the case of a large natural disaster: help should reach the disaster victims faster than otherwise and the mobile communications provide logistic support to the rescue teams.

24. Low-Earth orbit communications could be the solution to communications problems for large remote areas in developing countries. It is necessary to concentrate efforts in that direction, while the currently proposed low-Earth orbit communications systems are oriented towards the large, sophisticated market in developed countries. The cost to end-users can become unrealistic for remote areas in developing countries, which is why they should make a significant effort to define their needs properly. This will then help the process of international coordination and regulation of the radio frequency spectrum. By their very nature, such missions become an important factor in bringing the benefits of education and social development to all people.

25. An example of such a dedicated mission for developing countries is the ECO-8 project, which was originally conceived by Brazil. Considering that most of that country is in the tropical zone, Brazil specialists realized that low-inclination orbits would be appropriate to cover their needs. This means that instead of a large number of satellites

such as in the Iridium (66) or Globalstar (48) programmes, only 8 (or possibly 12) satellites could provide the service. Such a much cheaper system could also interest other tropical countries.

B. Earth observations (remote sensing)

26. The Earth observation applications considered here cover the various aspects related to data collection and imagery. As for telecommunications, Earth observation may be examined from different points of view. With the special features of each country, different unique scenarios of applications can be identified. In any case, low-cost small satellites can now make affordable multi-satellite networks of Earth observation satellites to reduce observation intervals from 10 to 20 days to around 12 hours, anywhere on the Earth's surface.

27. Many countries have had early access to the benefits of satellite remote sensing, but still have a long way to go in order to maximize the benefits allowed by their existing capabilities. There are, however, unique needs at both the national and regional levels that demand new solutions. Brazil and the Republic of Korea, for instance, are already developing new satellite programmes to address their specific needs. Latin America, South-East Asia and other developing areas require special capabilities related to sensor parameters, such as specific spectral bands, spatial resolution, time resolution, cost of image, autonomy and investment level in ground equipment, and the expertise required for their utilization.

28. During the United Nations Conference on Environment and Development, held at Rio de Janeiro from 3 to 14 June 1992, sustained development and biodiversification were terms mentioned and defended in every speech made by the Heads of State. Careful and sustained development can only happen with provision for local monitoring and control of the use of natural resources. By obtaining regular, global and permanent information on its resources, as can, for example, be provided by small dedicated satellite, a country can plan its policy for the longer term. Remote observations from satellites and distribution of the remote-sensing data should thus help to slow the depletion of natural resources, including the rain forest. It is also important in sustained development that the logistics necessary to support settlement and employment be considered.

29. Remote sensing, with portable ground stations and low-cost space systems, has an important role to play here. A key feature of the space system is direct down-linking to numerous small ground stations, eliminating the need for a centralized processing and distribution system. The advantages are real-time access to observations, smaller databases and ease of information distribution, even in areas not well served by communications systems. In some cases—forest and brush fires, pollution, fishing and storms—monitoring in real time and decentralization are a sine qua non. In the area of disaster prevention, there are clear demands for earthquake forecasts, early detection of tropical storms and anticipation of volcanic activity. Scientific and system design activities should be carried out in those areas.

30. The present constellations of polar-orbiting and geostationary meteorological satellites allow for the sharing of common costs and for synergy between sensors (simultaneous data on a given area). The advancements in sensor technologies, in particular new types of active and passive microwave detectors, open up possibilities to consider small satellites with a specific payload and mission. In the near future, small satellite missions may be flown with only one instrument. There are many advantages for such a constellation, for instance, the decrease in vulnerability by moving away from a single point of failure.

31. Another philosophy being proposed by some private organizations is commercialization, whereby the private sector would assume the role of building, launching and operating environmental monitoring satellites. Scientific data obtained in that way could then be purchased by organizations, such as national meteorological and hydrological services.

C. Scientific research

32. One of the main advantages of small satellite scientific projects is the possibility to perform simultaneous measurements of physical parameters from different locations in space. The concept of a large (mother) satellite and a small (daughter) subsatellite has been used successfully to separate the time and space components of variations of geophysical parameters in the framework of the international projects Aktivny, Apex and Interball. The Czech-made Magion subsatellites of about 50 kilogram mass were able, from a controlled distance, to complement the data gathered from the mother satellite. There are many ongoing cooperative scientific programmes in the area of solar and space plasma physics which illustrate this advantage of small satellites to offer support in taking multi-point measurements of various phenomena, in particular in the International Solar-Terrestrial Physics programme, involving the Solar and Heliospheric Observatory (SOHO) of ESA, Wind and Polar (NASA), Geotail (ISAS) and the future Cluster 2 (ESA). Of course, not all parts of the project are small satellites (e.g. SOHO).

33. Examples of small scientific satellites from developing countries are FASat (Chile) for monitoring ozone depletion and the KITSAT project of the Republic of Korea, which uses an instrument for monitoring geomagnetically trapped particles.

34. During the last decade there has been considerable progress in understanding the global behaviour of upper atmospheric regions and their relationship with the interplanetary medium. Such studies have been heavily concentrated in the northern hemisphere of the Earth’s globe, however. It seems highly advisable, therefore, that developing countries, which are located in many cases in the southern hemisphere—and in particular in the tropical zone—should join the global effort towards improving the knowledge of their own space environment. It does not make sense that such important environmental studies, which are for the benefit of all humanity, should be restricted to the Earth’s northern hemisphere. The countries of the southern hemisphere certainly have the necessary human resources, skills and motivation to carry out such studies.

35. As a consequence of the relative lack of space science studies in the southern hemisphere, several natural phenomena that occur in the upper atmosphere in the tropical and southern hemisphere zone are not adequately understood. Examples are ionospheric plasma depletions, or bubbles, which occur over the South American sector and strongly affect radio communications as nowhere else in the low latitudinal region of the globe, or the South Atlantic geomagnetic anomaly, with its large fluxes of precipitating energy-charged particles from the inner Van Allen radiation belt, causing severe physical damage or even the complete destruction of satellite instrumentation (such as sensors, solar cells or photometric devices).

36. The southern hemisphere is also an important region for studies in the field of astrophysics, especially for studies of regions of the sky not directly accessible from the northern hemisphere; many developing countries located in the southern hemisphere have been engaged in astrophysical studies over the past few decades. Satellites would be an important means of complementing the ground-based studies that have been carried out so far by developing countries and a course for future studies.

37. Recent examples of small planetary missions are the highly innovative and successful Discovery and New Millennium programmes in the United States, the planetary and lunar missions developed by ISAS in Japan and the University of Surrey’s low-cost lunar mini-satellite proposal. They show the very high benefits of such new approaches, which fall into the category of “faster, better, cheaper” programmes.

D. Technology demonstrations

38. The demonstration of technology is an obvious application for small satellites, which are an attractive and low-cost means of demonstrating, verifying and evaluating new technologies or services in a realistic orbital environment and within acceptable risks prior to commitment to a more expensive, full-scale mission. Examples have been NASA’s Discovery and New Millennium programmes, the Japanese Hypersat class and ESA’s Project for On-Board Autonomy (PROBA). The Centre national d’études spatiales (CNES) in France is developing a universal platform, Proteus, aimed at various applications in space research, remote sensing and telecommunications, but also usable

for technology demonstrations. CNES is also developing a microsatellite (100 kilogram) family for technology, science and application missions.

39. The NASA Discovery programme is a typical example of missions designed to demonstrate technology for solar system exploration (Lunar Prospector, Mars Pathfinder, NEAR). While this programme is known because of the type of mission and the media coverage, other missions have been flown with success, leading to a collection of valuable data on material and equipment behaviour in the space environment, especially in the hazardous radiation environment in low-Earth orbit or even in the geostationary transfer orbit. Examples are the space technology and research vehicle satellites of the United Kingdom.

E. Academic training

40. The growing space industry and the many associated service and scientific organizations require a steady flow of enthusiastic, trained and competent young engineers and scientists to meet the challenges of the future. Indeed, countries emerging in space technology who wish to take their first steps into space also need to learn from more experienced space users and to generate a cadre of trained personnel before establishing their own national agencies and presence in space. Very successful small satellite technology transfer and training programmes have been completed between the United Kingdom and Chile, Malaysia, Pakistan, Portugal, the Republic of Korea, South Africa and Thailand.

41. Although small satellites are physically small, they are nevertheless complex vehicles that exhibit virtually all the characteristics of a large satellite. This makes them particularly suitable as a focus for the education and training of scientists and engineers by providing a means of direct, hands-on experience at all stages and in all aspects (both technical and managerial) of a real satellite mission—from design, production, test and launch through to orbital operation. Education in space technology is a most important item in many parts of the world.

42. Universities and schools of engineering in several countries have already developed, launched and operated their own small satellites: this has been the case in several countries in Europe. Others are currently engaged in the same process, for instance, Japan, where it has taken the form of a contest between students, South Africa and the United States (NASA's Office of Space University Explorer (UNIX) mission programme). A university environment is an ideal place for inaugurating space activities. Thus the usual spin-off of a space programme, that is, the acquisition of technology and the development of an industrial organization and management methods, will begin to accumulate at the national level as the students leave the university and start their professional lives.

43. The advantage of low cost, rapid timescale and manageable proportions makes this approach very attractive to countries wishing to develop and establish a national expertise in space technology. They can be either purely national programmes, but most generally they are cooperative programmes with a technology transfer content. They typically have the following content—academic education, on-the-job training and cooperation on the satellite and the ground station, and support for satellite operation.

IV. POSSIBILITIES OF LOW-COST LAUNCHINGS OF SMALL SATELLITES

44. The low-cost access to space is a critical enabling capability, in particular for developing countries with limited resources to expand their initial space activities. Launch opportunities for small satellites include launch on a dedicated expendable launch vehicle; launch as a secondary, or "piggyback", satellite on a large expendable launch vehicle; launch as one of two spacecraft launched on a dual mission on a single expendable launch vehicle; and launch carried in one of the small satellites services offered by the Space Shuttle (the so-called "get away specials" payload bay slots).

45. The choice of one of these involves an assessment of the unique mission requirements against the capabilities, costs and constraints of the launch options. The most important considerations are flexibility as regards date of

launch and orbit (in the case of a shared launch) and the value of the spacecraft. A second consideration should be the reliability record or flight history of the potential launch vehicle. Those launching a series of low-cost payloads may be willing to take the risk of a new lower-cost launch vehicle with an unproven record. Once a commitment is made to a particular vehicle, the spacecraft with its payload may require some modifications if it is to be launched on a vehicle different from that for which it was originally designed.

A. Dedicated launches

46. During the past 30 years, many countries have invested in the development of an indigenous launch vehicle capability, pursuing the lucrative commercial market or strengthening their own civil and national defence programmes. International space policies and programmes are emerging with commercial developments and advances in related technologies. The small class of expendable launch vehicles has experienced the largest entry of commercial entrepreneurial activity, both in the United States and abroad over the past few years (including airborne launchers like Pegasus). Also, the long-range and intercontinental missiles from military arsenals of the cold war rival super-Powers are now available for civilian space launches.

47. The specific cost per kilogram into orbit of small launchers is higher than that of larger launch vehicles, but their absolute cost is much lower. Some operators also offer lower prices for their launching services, especially on newly introduced launchers (the ride on a test flight might even be free of charge). Small-class expendable launch vehicles can deliver payloads weighing from as little as 25 kilograms to as much as 1,500 kilograms to low-Earth orbit. Launching two or more small satellites on the same expendable launch vehicle (“dual manifesting”) is a viable alternative (see para. 50).

B. Secondary/piggyback launches

48. In an effort to reduce the cost of access to space and to make use of surplus performance capabilities, larger expendable launch vehicle manufacturers are interested in offering the small payload community the option of flying as a secondary, or “piggyback”, payload on those missions where the primary payload does not fully utilize the vehicle capability. Such possibilities have been used during some United States Delta launchings and Russian Federation Soyuz and Tsiklon launchers associated with main payloads of the Resurs and Meteor satellites. The primary payload schedule and reliability remain unaffected by the companion payload and the small payload owner is provided with a potentially cost-effective alternative to the purchase of a dedicated small expendable launch vehicle.

49. However, piggyback launch opportunities in low-Earth orbit are relatively rare and the mission parameters and schedule are dictated by the main user. It may be expected that the multiple launches into low- and medium-Earth orbits required by the new telecommunication constellations may provide more opportunities for piggyback launches in the future.

50. For the European Ariane 4 launcher, a special supporting structure, the Ariane Structure for Auxiliary Payloads (ASAP), has been developed to launch several small satellites simultaneously. The mass of an individual satellite (up to seven per launch) is limited to 50 kilograms, while the new more powerful Ariane 5 launcher provides for several 50-100 kilogram satellites. This greatly facilitates launchings of small piggyback satellites into geostationary transfer orbits or, in some cases, into low polar orbits.

C. Ways to obtain launch access

51. There are several ways to obtain launch access, either on a purely commercial basis or through participation in international cooperative agreements. A country may also consider developing its own launch capability. A driving force in pursuing this approach is the lack of available low-cost launchers and an inability for the country to meet its launch requirements on a timely basis (if it views access to space as critical to its national development).

52. The acquisition of launch services from international commercial sources is sometimes preferable to cooperative arrangements, owing to difficulties in finding an appropriate exchange of opportunity. In particular, a country seeking its first launch may find commercial acquisition the most effective route open to it. Such launch services should be planned as an integral part of the country's long-term planning of its space programme. A country newly embarked on satellite activities and seeking to develop a national infrastructure (governmental and/or industrial) must also establish priorities for the development of expertise in managing launch activities.

53. Cooperative missions may be considered when a clear programmatic benefit is shared by more than one country with a mutual desire to maximize their unique national resources and available funding. International cooperative agreements vary from mission to mission and from country to country; most require each country to assume full financial and technical responsibilities for its portion of the cooperative effort. In addition, clear and distinct managerial and technical interfaces are described in the agreements.

V. GROUND SUPPORT NEEDED FOR SMALL SATELLITES

54. The ground segment fulfils three functions: (a) the operations, which include the status and health monitoring of the satellite, and the command preparation and validation; (b) the tracking, telemetry and command functions, which are ensured by the communications station, possibly combined with the operations centre; and (c) the reception and transmission of the mission data to the user(s) for processing and further distribution.

55. Depending on the type of mission, the ground station for small satellites can be based on a simple very high frequency (VHF) antenna, as is the case with many standard platforms, such as the University of Surrey satellite (UoSAT) series in the United Kingdom, or it could be more complex, as required, for example, by an Earth observation mission. The reason is that the latter typically require acquisition of a large volume of data. Small satellites tend to rely more on on-board autonomy and safe modes. This reduces the need for continuous monitoring from the ground, thereby simplifying and reducing the cost of the ground segment. Recent availability of on-board navigational autonomy (using the global positioning navigational system) is encouraging that tendency.

56. The cost of mission operations represents a major part of the programme cost and it is important to find ways to minimize it. Reuse of the major agency tracking networks should be avoided for routine operations, although they may be required for the launch and early operation phase. It has usually proved far more cost-effective to employ national facilities, ideally utilizing a single ground station when feasible.

57. In order to reduce the cost of operations, it must be understood that a prime cost is human resources. The high reliability of the computers and the power of modern personal computers make autonomy an affordable solution. Many items in the operations scenario may be candidates for automation: antenna tracking, pass set-up and close-down, data reception and storage, conversion of raw data, status checking and so on. In the future, it may be possible for small satellites with reduced telemetry and availability requirements to use the mobile communications constellations as a global data relay system.

58. Although a ground system for a small satellite programme should have the lowest cost possible, it should still be reliable so as not to miss satellite passes or data. It should also offer a fast return of critical data together with a rapid response for critical commanding. For bulk data a regular return could be adequate, depending on the application. However, direct down-linking to user terminals and portable ground stations may be considered beneficial, especially for remote-sensing data, as already indicated.

VI. ECONOMIC BENEFITS OF SMALL SATELLITES

59. Usually, two different types of benefits are considered, depending on whether they are a direct result of the field of application or the result of the development of space system development in the country.

A. Direct benefits

60. Direct benefits from the use of small satellites may be identified, depending on their field of application. However, it must be understood that those benefits result from the application, which could also be provided by larger spacecraft. Small satellites provide their own contribution in such areas as:

(a) Improvement of agricultural and animal productivity in medium- to large-size farms owing to better weather predictions, identification of soil characteristics, improvements in communications and transportation;

(b) Lowering of transportation costs, made possible through the optimization of truck, bus and ship routing, location and early robbery detection, with favourable impact on the price of goods;

(c) Provision of communications for the basic needs of small rural settlements in remote areas;

(d) Improvements in natural disaster detection and relief, made possible by systems that integrate scientific, communications and remote-sensing satellite networks;

(e) Educational programmes for populations of remote areas.

B. Indirect benefits

61. The indirect benefits are particularly relevant to developing countries or to smaller countries that want to initiate a space programme. Space systems are indeed expensive, in particular from the standpoint of a developing country. However, international experience has shown that investments in the space sector have a very high multiplier effect on the gross national product: a factor around seven has been suggested in the literature.

62. It may be highly desirable for a country to maintain within its borders growing portions of the investments in commercial space systems and services. This can be achieved through increasing the participation of national industry in the international contracts for the provision of systems and services. This is not only a matter of governmental policy but also of the existing local capabilities.

63. Projects to develop small and microsatellite systems, because of their reasonable costs and shorter duration, can be the best strategy towards acquiring the expertise that is considered necessary to bring parts of governmental investments in commercial space systems and services into national operation.

64. Too often in the past, the lack of appropriate knowledge and training have resulted in decisions that have not best suited the needs of a country. Education programmes and formal training are necessary steps to acquire the desired capability, which should be negotiated as part of a contract to acquire space systems; this has, for instance, been the case in the development of the Koreasat telecommunications satellite programme. Such formal training is put to good use by working directly on space projects and, as noted earlier, small or microsatellite programmes may prove to be an affordable initial step for developing countries.

65. A coordinated interchange of information among countries in the same region of the world might be a proper way to increase expertise in defining the precise objectives of space programmes. In-depth studies to evaluate the actual needs can increase the chances that every country will choose the best alternative to suit its unique and changing needs, including through cooperative agreements with neighbouring countries.

66. The deployment of mobile telecommunication constellations will further benefit small missions. The production in series of small satellites for constellations is dramatically lowering the cost of off-the-shelf satellite equipment.

VII. INTERNATIONAL COOPERATION AT THE REGIONAL AND HIGHER LEVELS

67. According to those tenets established by the Charter of the United Nations and other agreements concerning international cooperation for the exploration and peaceful uses of outer space, each country has the right to have the opportunity to participate in space activities. In addition, each country has the obligation to cooperate in those efforts and to share existing information and adequate technology in order to help others to plan, develop, launch and operate satellites.

68. Although cooperative space activities have existed for a number of years, in particular as specific scientific endeavours, they are only now beginning to include small satellites. It is therefore highly desirable to define opportunities to widen the scope of cooperative efforts so that more countries have access to space and the resultant benefits to be derived from space technology. The small satellite option is undoubtedly the best opportunity available for developing countries to initiate their own space programmes in the most cost-effective way.

69. Examples of such programmes where engineers are trained on small satellite design, production and operations are numerous. Companies in the United Kingdom have for instance provided assistance to Chile, Pakistan and the Republic of Korea in the development of small satellites of less than 100 kilograms and even to small countries in Europe that had decided to initiate a space programme. Some countries, like the Republic of Korea, have initiated more ambitious programmes using small Earth-observation satellites of several hundred kilograms with the support of industrialized countries. The Technical University of Berlin is providing the Tubsat-C platform for a Moroccan project to build the first experimental national microsatellite for messaging and remote sensing. More classical cooperative programmes for the development of small satellites also exist, for instance between Argentina and NASA, or between Argentina and Brazil on a more regional basis. Other countries are already contemplating similar arrangements in order to develop a national space programme.

70. Cooperative space activities are often supported by some kind of technology transfer. A successful technology transfer in the development of small satellite activities implies a process by which a team acquires sufficient momentum to be able to produce the next generation of a small satellite. There are several mechanisms whereby technology transfer can be achieved, but, to be successful, the transfer should be a transfer of understanding, not the transfer of a technology package (“know-why” as well as “know-how”).

71. Considering that all technology transfer processes typically involve people from different countries, it is necessary to meet some minimum conditions for successful implementation:

(a) Successful technology transfer can only be made to persons of sufficient technical and scientific background;

(b) Access to appropriate infrastructure to support the application of the technology should be available;

(c) A long-term development plan with scheduled objectives and proper financing should be in place, in particular because technology transfer is a long-term process.

72. Cooperative programmes, with some kind of technology transfer, when undertaken in an appropriate manner, are achievable and provide the key to accelerating access to space for those countries which elect to implement such a programme.

73. In the Asia and Pacific region in particular, there is no previous experience in cooperation in space fields and a wide range of economic and technological diversity. It is therefore very difficult for developing countries even to join an existing cooperative space project when some financial contribution is involved. In order to ease the situation, a framework has been proposed by the Economic and Social Commission for Asia and the Pacific (ESCAP), which has been subsequently acknowledged by member countries as a very feasible and appropriate approach at least at the Asia and Pacific regional level. Its modus operandi is based on the principle of percentage contribution, with participating countries sharing project expenses flexibly, based on their level of participation.

74. According to ESCAP, the technology required in pursuit of a project can be divided into two categories: published technology and new technology. When published technologies are involved, they can be used freely for the project (no technology transfer fee is involved). When new technologies are to be developed for a project, the cost for research and development activities should be covered by the project. Participation can take place on four levels:

(a) Host-level participation is for countries that have the technologies to build common payloads and are willing to offer such technologies for the project, without making a financial contribution to it. However, host-level countries should not charge for the use of their technologies within the project;

(b) Owner-level participation is for countries that will put common payloads on their own satellites and operate them, covering all the necessary expenses for manufacturing such payloads of their own. If new technology is required, the owner-level country should cover expenses for the necessary research and development activities;

(c) Partner-level participation is for countries that participate in manufacturing all or part of common payloads. Once common payloads are in orbit, host-level, owner-level and partner-level countries can use the constellation of satellites freely, based upon prior arrangements;

(d) The analysis work-level is for countries that do not participate in manufacturing common payloads but perform analysis and research using data gathered from the common payloads; access to data and other related information is guaranteed free of charge. If specific hardware or software is required, it should be developed at the expense of each participating country.

75. Expenses involved in attending meetings and seminars for the project should be covered by each participating country. When host or owner countries need to provide training for manpower from participating countries, this could be done at marginal cost and covered by the participating countries.