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Centre National D'Etudes Spatiales

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16. Abstract A strategy for keeping the Common Market's space effort independent of and competitive with NASA and the Space Shuttle is discussed. Limited financing is the chief obstacle to this. Proposals include an outer space materials processing project and further development of the Ariane rocket. A manned space program is excluded for the foreseeable future.			
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SPACE PROSPECTS

Centre National D'Etudes Spatiales
(CNES)

Part I: Introduction

A long-range forecast predicts the prospects for a specific subject in the relatively distant future. The purpose is three-fold: /1*

- To reveal the underlying political forces at work, shorn of any temporary constraints.
- To establish a basis for choosing programs which lead toward the long-term objective.
- To direct present technological research.

In contrast with medium-range policy making, this paper attempts, as far as possible, to analyze the political, economic, and technological constants in a specific field of activity, space exploration.

The Priorities

France and the European Economic Community (EEC) in general have carried on a determined effort over the past twenty years to acquire an independent capability to construct, launch into space and operate earth satellites. These satellites have been used for telecommunications and earth surveys. In addition, they have military potential.

This independent capability has been attained, and our level of technological sophistication is equal to that found elsewhere. This /2

*Numbers in the margin indicate pagination in the foreign text.

is proved by the development of the Ariane rocket, the organization of the support structure for this program at the Guyana Space Center, the MARECS and ECS communications satellites now under construction (as well as the future French Telecom 1 and Television Directe satellites), the success of the Meteosat weather satellite, and, finally, the smooth progression of the Spot earth survey satellite project. The first objective of the space program is thus to keep pace with the technical innovations that occur in order to maintain its autonomy.

The sale of the first operational rocket, the Ariane, to the international organization Intelsat demonstrates the fact that European space hardware is competitive in the world market. Competitiveness is not a priori necessary for independence. However, the negotiations leading to the production agreement Arianespace (Transpace) shows that it is not practical to establish an industrial organization to produce only a small amount of materiel. A reasonable share of the world market and the almost complete domination of the western European market are practically preconditions for the survival of our space industry. These conditions can only be fulfilled if the products of the industry equal those available elsewhere. Thus, creating an industry which meets international standards is a second priority which is just as essential as and is inextricably linked to the goal of independence. This report will reveal how this second objective influences future planning.

One should take into account the fact that per capita expenditures for space research in the United States are about four times higher than in western Europe. NASA will spend 4.5 billion dollars (20 billion francs) this year to insure, as its charter states, "the dominance of American industry in aerospace". The total space budget of Common Market members is on the order of only 5 billion francs, including 3 billion for the ESA (the European Space Agency), in an average year. Whatever happens in the next decade, it is clear that the national and EEC space efforts cannot compete on all fronts with the Americans. Based on the American experience, we will have to choose the route with the least technical and financial

risk to follow to maintain a competitive position in the industrial and strategic areas considered essential.

Space Science

Scientific research has been the major focus of French and EEC activities in outer space. It will continue to play a significant role in the decade to come. The programs carried out and the results obtained in this area rank second to none in terms of quality and originality. The generous cooperation of the Soviet Union and the United States has allowed French scientists to participate in the most ambitious missions, notably in astronomy (the Space Telescope, the High Energy Astronomical Observatory, etc.) and planetary exploration (the American Pioneer probe to Venus and Galileo Jupiter probe, the Russian Venera launchings, etc.). At the same time, international cooperation within the framework of the ESA promises to result in advanced projects in astronomy and geophysics.

/3

Our long-range perspective continues to reserve a major role for scientific projects because:

--Space research is one of the most powerful tools for investigating the basic scientific questions: the origin of the universe, of the solar system, and of life itself.

-- Scientific missions are bold undertakings, frequently at the limits of technical ability and therefore stimulators of progress in space technology.

As the Minister has stated, France must be continually pre-occupied with "maintaining our scientific, technical, and technological ability at its present high level" (A. Giraud, Nov. 6, 1979). Achieving unbroken progress in space science is thus also an important element in planning for the future. However, the pursuit of this objective does not mean that we should not take advantage of multilateral cooperation or ignore American and Russian discoveries. This is the reason why this article will not make reference to an exclusively

national or regional strategy for technical development.

The Rockets

It is possible to envisage a program concentrating on a single pilot project that could generate a whole new generation of space apparatus, including new means of propulsion, new space vehicles, and the associated infrastructure. This is exactly what happened at NASA when the president of the United States assigned it the mission of landing on the moon within ten years. To reach this single objective, NASA developed a vast ensemble of technologies to solve the problems posed by landing on the moon, the lunar rendezvous, and reentry into the earth's atmosphere. NASA also had to construct the awe-inspiring Saturn I rocket, which was specifically designed for manned flights to the moon. At the conclusion of the Apollo project, however, the Saturn rocket had to be abandoned because it was too powerful and too costly to be used in other programs. A switch was made to a new type of vehicle that could be reused in successive missions, the Space Shuttle. /4

It is for this reason that it has not been considered practical to devote all our efforts to building the means to carry out a single type of mission, such as a manned space flight or a permanent space station. The technology of propulsion has special characteristics. A prolonged period is necessary for development and testing. The evolution of rocketry must progress at its own speed, guided by the following underlying objectives:

-- The defense and strengthening of a competitive position in the areas of cost and performance in relation to other systems of space transport (of obviously different design) placed on the world market by the United States, as well as potentially by the USSR, China, Japan, and other countries.

-- The expansion of production of the Ariane rocket to meet international demand.

-- Complete compatibility with the satellites built to take advantage of features of the Space Shuttle.

In the not too distant future, the following developments will take place:

-- The completion of the modifications for the Ariane II and III by 1983.

-- The construction by 1984 of a new launching site for use by the Ariane IV. This rocket will allow for a greater orbiting mass and a larger payload than previous models.

-- The completion of the necessary preliminary research for the Ariane V. This launcher should be in service as soon as possible and no later than 1990 if we are to maintain our position when faced with satellites built for the Space Shuttle and other advances in space flight. The preparation required for the Ariane V mainly involves work on the HM 60 high thrust liquid hydrogen engine.

Man in Space

/5

The greatest decision that must be made in terms of long-run space policy is whether or not to develop the capacity for manned space flights. It is clear that this capacity has been judged important enough to make almost irrevocable national commitments to it on the part of the United States and the Soviet Union. One result of the competition between these two countries has been that citizens of other countries have been granted easy access to these programs. As part of the Spacelab program, NASA has agreed to launch European and probably Japanese astronauts and specialists into orbit. NASA will charge 40 million dollars for this, the cost of launching the Shuttle. The Soviet Union has already opened its astronaut program to east Europeans and has proposed including a French cosmonaut.

The "normalization" of manned flight reduces the purely political attraction of creating an independent capability in this area. This would duplicate Soviet and American resources that are already available for scientific research under certain circumstances.

It remains to be determined whether the activity of human beings in outer space constitutes a key element in the missions planned for the years 1990-2000. These missions include the erection and maintenance of orbital space stations and the repair and modification of space satellites to make them usable in new programs. The current opinion of the CNES is that manned flight would facilitate a rather large number of activities, especially on the experimental side of the space program. It does not, however, represent a crucial factor in the evolution of commercial applications. In any case, preliminary studies recently conducted have concluded that the technology needed to put human beings in space would require ten years to obtain, given the current state of the western European space industry. The reader is referred to the Hermes study of a manned satellite launched by an advanced version of the Ariane and gliding back to earth at hypersonic speeds.

With these considerations in mind, the following course of action is proposed:

- (i) To make the greatest possible use of cooperation with the United States and the Soviet Union to place French specialists in orbit to perform scientific research and gain technical expertise, particularly in fabricating and processing new materials in a weightless environment.
- (ii) To independently develop ground-controlled mechanical means of working in space in anticipation of the time when the maintenance, refueling, and modification of equipment will be necessary for making economical use of spacecraft.
- (iii) To keep the option of embarking on a manned space program open.

The space program requires a long-term investment of considerable size and risk. We have to rely almost totally on the western European space market and on the influence EEC members have in such international organizations as Intelsat. A commitment on the part of as many Common Market countries as possible is therefore required to make the program viable.

It is essential in preparing for the future to reach a consensus in the Community in favor of a project which could take form quickly and make use of the resources available in the 1980's. At the same time, this project would have to be sufficiently ambitious to make for a real technological breakthrough in western Europe.

The broad outlines of such a project are described in this report and are justified on the basis of key technological developments which will be mentioned here. The situation no longer calls for promoting a wide variety of miscellaneous satellites (meteorological, navigational, communications, etc.) as was the case at the founding of the ASE. Rather, the problem is to use a demonstration project to acquire and check out all the techniques essential to a range of future spacecraft in low altitude or synchronous earth orbit. A program of this sort might be one that concentrated on the processing of materials in low earth orbit. This would require three distinct space systems:

- (i) An orbital module equipped with mechanisms for remote control.
- (ii) An automatic vehicle that could rendezvous and dock with the aforementioned module. It would also have to return to the earth's atmosphere to deliver its cargo.
- (iii) A system of relays in synchronous orbit for the real time television, telemetric, and telecontrol systems needed to operate the two preceding pieces of equipment.

Such a project could be completed in the latter part of this decade. It would mark a truly significant step forward for the EEC. The ability to use several orbiting spacecraft in complex operations in outer space would be demonstrated for the first time. We would be following in the footsteps of the lunar rendezvous of the Apollo flights. The lag behind the United States and the Soviet Union is obvious. Even so, this know-how would be acquired in time to keep us abreast of developments in industrial applications. It is precisely in this period that NASA plans to experiment with a low altitude orbiting platform guided by remote control. A similar satellite in synchronous orbit is planned for later, in 1990. This proposal therefore constitutes a goal worthy of the consideration of the other Common Market partners and around which each one's long-range planning could be coordinated.

Part II: Future Programs

Evolving Needs

/8

A remarkably fruitful period of technical innovation has just ended. It has led to a revolution in national and international telecommunications. More specifically, the 4-6 and 11-14 billion Hertz frequency ranges were opened up for communications use, long distance television transmission via satellite was introduced, and a world-wide system of weather satellites was created. We now seem to have entered a period of consolidation. An examination of the projects proposed by organizations engaged in space research reveals an emphasis on continuity and security. Innovations with unforeseeable risks are avoided.

The most elaborate proposals concern the state of communications satellite systems ten years from now. Thus, Intelsat plans to increase the number of telephone channels per satellite from the present 24,000 in Intelsat V to 320,000 in Intelsat VII, which will be launched around 1999. Of course, this progression will be accompanied by various technical refinements. Examples of projected improvements include the use of intersatellite relays, the introduction of multi-beam antennas, advances in modulation and multiple access techniques, and increased activity in the 11-14 BHz band along with possible expansion to the 20-30 BHz range. The field of space communications will thus continue to hold the lion's share of the commercial market for space hardware for a long time to come.

As for the commercial application of earth survey satellites, the most often expressed desires involve establishing a service that regularly furnishes data useful in weather prediction, the management of natural resources, etc. The introduction of high frequency cameras is obviously envisioned. This would eliminate interference by clouds which block the visible and infrared parts of the spectrum. Farther down the road, the increasing use of satellites in synchronous orbit will provide constant observation of various regions of the earth. The most stubborn problem that remains to

be solved is that of rapidly processing, interpreting, and disseminating data.

Real technological breakthroughs could occur in two fields. These /9 are the perfection of industrial processes for fabricating new materials in weightless surroundings, and the introduction of new types of communications services as improvements in space transports make them possible.

The Benefits Obtainable in Materials Processing

The greatly reduced gravity on board orbiting vehicles opens the door to the study and application of physical processes in which transfers of mass and thermal energy are disassociated. The first attempts in this new field were made on the Skylab and had spectacular results. Giant metal "whiskers" were produced, and, on a more fundamental level, very important phenomena involving surface tension were discovered.

Contrary to what had been thought initially, it rapidly became apparent that application to industry was not yet within sight. A period of basic research was needed first. This research represents one of the most important investigations now being undertaken in outer space. At the same time, applied research into materials processing is also going on. Two new developments which open the way to new products can be cited:

-- Procedures for handling products not confined in containers, for use in cases where chemicals would react with the crucible in which they resided. These procedures could be used for the production of glass or ceramics, including rare earths and special metal alloys.

-- Procedures using heat to process gases and liquids and which would avoid separation due to gravity or convection that occurs on the ground. Products of exceptional purity and structural quality (metal whiskers, in particular) as well as alloys that

cannot be produced on earth (because of immiscible components, for instance) could thus be obtained.

Some of the new substances that have been produced are very promising. They include semiconductors, superconductors, and magnetic and optical materials. One of the experiments performed by the materials science section of the CNES has been the synthesis of HgI_2 crystals. These crystals might be useful in the construction of X- and gamma ray detectors that would be very sensitive in ordinary surroundings. Another example is the magnetic alloys that have been the object of exploratory experiments on board the Salyut (Elma 1) spacecraft.

There is no doubt that space flight makes possible the production of exceptionally high quality or entirely new materials. However, the profitability of fabricating these substances in outer space has not yet been established. The cost of space transportation is a crucial factor. /10

At present, the only items that would be competitive with their terrestrially produced equivalents are the so-called "strategic materials". The only considerations in purchasing such materials are their quality and performance. At the present time, a few hundred kilograms of them are produced each year for the technologically advanced nations. Their increasing popularity could result in an annual production of a few metric tons in ten to twenty years.

The highly competitive market for specialized high technology materials is much larger. It amounts to hundreds of tons per year. This market could be entered as soon as the cost of space transport has decreased to the level of 15 to 20 thousand francs per kilogram. The projected cost of using the Ariane V to launch payloads into low altitude orbit falls exactly within this range. (See Part III.)

The Benefits Obtainable from Satellite Communications and Broadcasting

In the years to come communications and broadcasting will continue

to be the main commercial use of outer space. Two factors are at work: the growing needs of numerous nations will force them to purchase new communications facilities, and new types of service will probably be introduced.

For the majority of countries, whatever their level of development, economic growth brings with it increased pressure on telecommunications networks, added telephone traffic, more data transmission, and greater demand for telephone/computer hookups. A survey of these needs shows that telephone use remains the most important demand. It will represent about 75% of total satellite capacity in 2003, as compared to 80% in 1983. The same survey also indicates that many countries will need to use communications satellites. Two possibilities are open to them. They can either rent channels on existing international networks or they can construct their own domestic or regional systems.

We have a double role to play in this context. We must be able to meet our own needs and also establish new communications satellite networks for others.

The appearance of new types of service could change the situation considerably. If one increases the dimensions and therefore the power of a satellite in orbit, the sensitivity and size of ground stations can be reduced. This very simple idea will allow the introduction of microreceivers early in the next century. Miniature receivers could be used as mobile telephones, in alarm and security systems, as paging and locating devices, etc. Our position as a supplier of space equipment will be threatened unless we can provide these new types of services. /11

This brief analysis has made two things clear. In the first place, the expressed needs of present satellite users requires no great technological breakthroughs. Secondly, the industrial market for space equipment is essentially limited to telecommunications and materials processing.

2. The American Perspective

The qualified conservatism that is apparent when talking to present or potential space equipment customers contrasts sharply with the overflowing enthusiasm evinced in NASA's proposals. (See NASA Five Year Plan, Fiscal Years 1980-1984.) NASA's plans are not limited to the development of automatic and piloted spacecraft for use in orbital transfers. The astronomical future mapped out in these proposals is based on permanent space stations in low and synchronous earth orbit and the construction of gigantic structures for gathering solar energy or radar observation of the atmosphere. This difference in viewpoint demands an explanation.

The first reason for the race towards giantism lies in NASA's own dynamic. NASA is explicitly charged with promoting new developments. The ability of the American economy to introduce new products for domestic consumption before imposing them on the world market cannot be underestimated. A classic example of this is in one of our areas of interest, satellite communications. Until recently, this field was practically monopolized by the Americans. The design of large multipurpose space stations could be viewed as a means of out distancing growing European and Japanese competition in the conventional satellite market. It might reestablish the Americans' monopoly by shifting the confrontation to an area where competitors would be handicapped by a lack of appropriate launch vehicles and manned spacecraft. This should be kept in mind when reading the following critique of the future projects found in the NASA plan.

/12

Three features distinguish this plan:

- The development of apparatus to maintain and repair vehicles in orbit (the service satellite).
- The design of new generations of space stations.
- A fascination with large dimensions.

The Service Satellite

The goal of this program is to recover, maintain, repair, or destroy satellites in orbit. Achieving this depends on the development of certain types of equipment and tools.

The first necessary element is the RMS manipulator arm attached to the Space Shuttle. This arm enables the crew to deploy and retrieve satellites in the immediate vicinity of the spacecraft without leaving the cabin. For maintenance and repair operations, NASA has devised a number of tools (mechanical hands) and a platform that can be connected to the RMS. Early versions of this platform will consist of an exposed "cherry picker". Later, a pressurized compartment will be added on. NASA plans to perfect this equipment by 1983 or 1984.

NASA is designing a remote controlled service module to perform operations at a greater distance from the spacecraft. The service module is a direct result of research done to save the Skylab (Teleoperator Retrieval System). It will be able to function within a thousand mile radius of the Space Shuttle and will be adjustable to perform various repairs on satellites in orbit as well as to retrieve whole satellites. All that is necessary to service satellites in synchronous orbits is to fit this module to a transfer vehicle (OTV).

In another field, NASA plans to improve its inhabitable Spacelab /13 orbiter so that it can function as a permanent space station positionable in either low or synchronous orbit. The objectives pursued here involve the two subjects we have been concentrating on, materials processing and communications.

Materials Production Stations

NASA also wants to adapt the current Spacelab model to create a family of materials science experiment capsules (MEC). The first

will be automated and be able to remain up to sixty days in space. They will perform research of a more applied nature that that planned for the Spacelab.

The second generation will be capable of functioning permanently in orbit. Such models will carry two to eight metric tons and have a power supply of 10 kw. They will permit loading, maintenance, and repair in orbit.

A more advanced, full-scale industrial stage has also been sketched out. It will make use of even larger, possibly pressurized spacecraft. However, no work on these vehicles has yet been planned.

Space Platforms in Synchronous Orbit and Solar Energy Plants

Large space stations could present great advantages by providing for the simultaneous use of a wide variety of equipment for weather observation, natural resource management, telephone and television transmission, etc. An improved communications system could reduce the interference problem by using large aperture antennas, multiple and/or narrow beam broadcasting, and circuits for switching beams between various antennas. This would make for a more efficient use of synchronous orbiting and the high frequency end of the spectrum.

Some preliminary study has been done in the U.S. on large solar energy collectors. However, the NASA plan shows more interest in 200 to 500 kw solar generators to power spacecraft than in solar energy stations to transmit energy back to earth.

Research into the orbital assembly of structures with dimensions of several hundred meters was related to proposals for large-scale solar energy plants. For the moment, NASA seems to have its sights set on more modest assemblies in space: /14

-- Assembling and testing of a model space platform and of the instruments needed to perform the different functions of

this platform (in preparation for a multimission space station).

-- Testing unfolding antennas (in cooperation with the Department of Defense because of the military interest in this field).

-- Demonstrating the possibility of fabrication in orbit.

This quick examination of the NASA plan, which concretizes the American strategy for outer space, has revealed two essential points:

-- NASA is going to try to develop the apparatus for servicing, resupplying, and modifying satellites in orbit.

-- NASA is trying to make communications technology evolve in the direction of large orbital space stations.

3. A Possible Approach to Long-Term Development

Given the weaknesses in the American plans, and the economic and military significance of the space industry, the possibility of a renewed technological challenge cannot be discounted. This would involve either low altitude orbiting satellites for exploring new metallurgical processes or automated or manual assembling and servicing in space of much larger orbiting structures for purposes not yet foreseen. However, western European space programs are of a smaller size than NASA's. We cannot explore all promising lines of research, as NASA does. The only reasonable strategy is to first enumerate all the technologies currently central to space missions. We could then establish an experimental project that would permit the development and trial of these technologies in as concentrated a manner as possible.

The Key Technologies

/15

Numerous technical improvements are to be expected and will be gradually introduced in future satellites, even those of conventional design. The progress of these basic technologies is the object of

the general R and D program and is not at issue here.

However, the range of new missions that can be predicted for the coming years necessitates the introduction of technologies entirely new to the Common Market space program. Experience in the following key technologies must be achieved before proceeding with future projects:

Satellite to satellite communications: Wide band communication between satellites in low earth orbit and relay satellites in synchronous orbit are necessary in two situations. The first is in making up for the limited capacity of the recorders on board earth survey satellites. The second instance is in experimentation on orbital manoeuvres, which require constant contact between the spacecraft and the ground command. In addition, links between satellites in synchronous orbit is an obvious technique in improving future global telecommunications systems.

Orbital rendezvous: Rendezvous and docking have been mastered by both the United States and the Soviet Union, with or without a pilot on board. Automatic docking has been demonstrated particularly by the Progress program. Techniques for interconnecting electric and hydraulic circuits are indispensable for servicing permanent space stations.

Reentry and recovery: The majority of nonscientific missions in outer space can be accomplished by nonrecoverable spacecraft, which could even be destroyed on purpose to vacate their position in orbit. However, the production of materials in a weightless environment requires the recovery of samples from the space station. The recovery of space capsules, minimally involving the simplest techniques of aerodynamic breaking of an unmanned reentry vehicle, therefore figures among the technologies central to this type of program.

Remote controlled manipulation: Performing complex operations in orbit without the direct involvement of human operators presupposes

/16

the development of robot-like appendages. These adaptable tools will either be controlled by a preestablished program or by the instantaneous intervention of an operator on the ground. Robots have already aroused great interest for use in terrestrial applications where direct access by human beings is costly or impossible. Independently of this, the implementation of techniques of telecontrol is vital to the construction of spacecraft designed to be supplied and serviced, if not modified, in space. This is the only way to attain a really prolonged operational life, comparable to that of industrial facilities on earth.

Electric power: Applications envisioned in the fields of high power telecommunications and materials processing demand a source of electrical energy on the order of 10 kw. This is considerably more power than is available on present spacecraft (1 kw). The use of solar cells presents no difficulties here. However, the introduction of large size solar generators raises new problems of deployment and rigidity that will have to be surmounted.

The Role of Human Beings

Human beings can carry out activities in space either by remote control, as in interplanetary probes, or by direct participation, as in the Apollo lunar expeditions. In considering the options, the difference between the highly diversified and evolving investigations planned for the Spacelab and the Russian Salyut orbiting station and repetitive industrial processes must be taken into account. It is the second group of activities that holds our attention here. In general, there are three practical modes in which humans could perform work in space:

- (i) The direct effort of an astronaut in a pressurized suit. This is most satisfactory when there is a solid structure to support him. The astronaut would move objects and tools around manually ("Extravehicular Activity").

(ii) The indirect effort of an astronaut inside an orbiting vehicle and using direct visual and/or tactile contact to help him operate devices by remote control.

(iii) Long distance manipulation operated in real time or simply preprogrammed by a computer on the ground.

In the more distant future, work accomplished by completely automatic robots can also be foreseen. Such robots would either be programmed or would be capable of independently responding to stimuli received by their own receptors. We will not delve into this question here.

The difference between modes (i) and (ii) lies only in the differing effectiveness of the hand and the tool. The tool can be shown to be superior each time that a standardized task is to be done in which specific tools for the job have been constructed. The programmable machine tools and robots used today in mass production are evidence of this. On the other hand, the distinction between modes (ii) and (iii) lies in the delay in transmission of information between machine and operator. This delay in the command loop is a constraint whose effects must be studied experimentally. It has already been demonstrated that this obstacle can be overcome if the telecontrolled apparatus has sufficient autonomy. This is the conclusion that can be drawn from the success of the Soviet ground crew in operating the Lunokhod vehicle on the surface of the moon despite a transmission delay of one second in each direction.

We can provisionally conclude from this rapid analysis that any work performed to modify, check up on, or maintain an industrial process or commercial service in space can be broken down into a series of standardized actions. Furthermore, these actions can be carried out automatically under the control of operators working in obviously more comfortable surroundings with many more resources available than would be the case for an astronaut. Under these conditions, it appears for the moment that an independent manned space flight capability is not essential for participating in advancing

space technology in the coming decade.

The technologies required to accomplish different types of future missions can be summed up in the following table: /18

	: Large Telecommuni- : : cations Stations :	: Materials : : Processing :	: Earth : : Survey :
Intersatellite communications:	X	X	X
Rendezvous	X	X	
Recovery		X	X
Remote control:	X	X	
Electric power:	X	X	X

A Demonstration Program: the Trisat Project

One possible way to gain experience in the technologies necessary to future development is to carry out a program based on one type of demonstration or model mission. The members of the Common Market would have to agree on what kind of missions to carry out.

Telecommunications is not the best theme for a project of this sort within the framework of the Common Market. This is because of the immediate commercial implications of this technology and also because experimental maneuvers at high altitudes would require very expensive rocketry. Earth survey satellites are also unsuitable because of strategic considerations. Experimental materials processing, on the other hand, is very attractive for the following reasons:

- It explores a field with long-run, significant industrial

applications.

-- All the technological capabilities listed above are needed in this field.

-- For the most part, the mission would take place in a low altitude orbit.

/19

Preliminary study has suggested a relatively complex mission, which would include coordinated maneuvers involving two satellites in a low altitude orbit and a relay satellite in synchronous orbit. This is the Trisat project. The satellite system will be made up of these elements:

- (i) A service module which would house a model materials production facility. It would include all the usual support services: electric power plant, attitude and orbital stabilizers, information processing circuits, and implements for docking with other spacecraft and manipulating tools and substances inside the module by remote control.
- (ii) A partially recoverable automated vehicle including a means of propulsion and an automatic pilot for performing rendezvous and docking. It would transport new equipment (furnaces, for example) raw materials, and consumable fluids to the service module. This vehicle would also have to be able to send a recoverable capsule containing finished products back to earth.
- (iii) One or several relay satellites in synchronous orbit to provide permanent (?) contact between mission control on the ground and the two spacecraft in low altitude orbit. Such relay satellites would closely resemble NASA's TDRS (Transmission and Data Relay Satellite).

When the Ariane project was approved, critics complained that the Ariane was overpowered and that a rocket able to put only 350 to 400 kg in stationary orbit would have been sufficient. This was the size of the majority of satellites at that time, which was in turn closely related to the capacity of the two stage Thor Delta rocket. With the financial help of its users, the Thor Delta's performance was improved and a whole new class of synchronous satellites with a mass of 500 to 600 kg was created. Examples of these satellites are the OTS, MARECS, and their derivatives, the ECS and Telecom I. Outside the EEC, Anik C, SBS, Satcom, and others also belong to this group. Another class of heavy satellites to be launched by the Atlas Centaur rocket was under development at the same time. These were primarily for use in international communications (Intelsat IV and IVa). Later on, Comstar and Westar III served the needs of American common carriers.

The development of the Space Shuttle has not radically altered the division of the market for two reasons. In the first place, constructors of space equipment wanted to be able to use conventional launchers should the Space Shuttle run into difficulties or long delays. Secondly, the Space Shuttle is equipped with a solid fuel orbital maneuvering system that does not allow for a continuous variation of payload mass.

One can make two observations from this very brief summary of the situation when the Ariane was put into service:

-- The capacity of the Ariane, which can launch 1000 kg into a synchronous orbit, is slightly greater than that of the Atlas Centaur. It satisfies the requirements of all EEC satellites, which range between 600 and 1000 kg in mass. The lift requirements of practically all known projects outside the Common Market also fall within this range.

-- Historically, there has been an undeniable tendency for weight

to be constantly increased within a given category of satellite.

Since Ariane must continue to be competitive with the rockets of /21 other countries and since there is a large number of satellites in the 500-1000 kg class planned for the coming decade, it is necessary to modify the Ariane so as to carry two of these satellites at once. Its lifting capacity must be increased by 40%, and a system for launching two satellites simultaneously must be introduced. These improvements can be made at a cost equal to less than 7% of the total cost of development. The increase in construction costs will also be approximately 7%. We would thus be in possession of a rocket capable of putting 1400 kg in stationary orbit by 1983.

The long-term future of EEC launching vehicles will be an issue as soon as this version of the Ariane III is available. Taking account of the time required to complete any redesign or modification, we must begin to study the situation soon. Otherwise, we will not be able to meet users' requirements after 1985.

1. The Details of the Problem

1.1 Mission Imperatives

The forecast presented above does not include any radical break with past conditions, for which the Ariane rocket was conceived. Completely new projects will therefore not be a determining factor in designing new western European rockets in the coming decade. This is true even if the performances required by any conceivable new projects are taken into account as much as possible.

On the other hand, the increasing weight of different types of satellites, especially synchronous communications satellites, will be a constant factor in technical progress. In cases where the satellite only uses half the capacity of the Ariane, the extra space can be used to send supplementary equipment into orbit to perform related services, or extra fuel can be carried. This fuel could

maintain the satellite in synchronous orbit for a longer period or supply it with more stored electric energy for times when the sun is eclipsed.

The capacity of the Ariane III is designed to meet the projected needs of the years 1982 to 1985. For "heavy" satellites whose weight equals the maximum allowable for the Ariane III, mass limitations have already become a serious constraint. For example, Intelsat V, which will be first launched in the beginning of 1980, has suffered severely from the restrictions imposed by the Atlas Centaur. Even though future models, which will be launched by the Ariane or the Space Shuttle, will have a little more room, the introduction of new services, such as in maritime communications, will be hampered. The more advanced Intelsat Va and Intelsat VI will need greater lift-off capacity. The construction of television satellites means that the capabilities of the Ariane III could be used immediately.

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1.2 The Competition

The Space Shuttle is the basic competition for the Ariane. Although the difficulties encountered in developing the Space Shuttle have caused long delays, the planned levels of performance and reliability will be achieved. As for the exact length of the delays, the situation is less clear. Budgetary restrictions have forced the production program to shoulder the burden of the financial risks involved. At least until the middle of 1982, only a single vehicle will be in service. These delays, a greater interval than originally planned between flights, and the necessity of reserving some flights for the military have meant that the calendar is already filled up through the middle of 1984. It is certain at this point that no satellite launchable only by the Space Shuttle will be introduced before 1985, except for experimental purposes.

The costs involved are also uncertain. The proposed prices announced in 1971 and revised in 1975 have not been readjusted to take into account the final specifications of the Space Shuttle. These prices can only give an indication of what the Space Shuttle will actually cost. NASA has decided to charge an introductory price

for the first three years and then to change it according to what experience has shown the actual costs to be. Thus, it will not be until 1985 that the true economic conditions of the competition will be defined. It is already known that in addition to technical reasons, the reduction in the number of scheduled flights will cause a considerable increase in costs. A hypothetical 25% increase has been made to try to compare the prices of Space Shuttle and Ariane flights. NASA has in fact already announced a price rise of 15 to 20% for flights after the first three years.

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1.3 The Common Market Investment

The Ariane project represents the largest investment ever made in space by members of the Common Market. Beyond creating an independent satellite launching capability (its first goal), the program has also resulted in the establishment of research teams capable of carrying out a sophisticated program in rocket technology. Complicated research facilities also have been built. It is natural that the Common Market will want to recover its investment by taking advantage of the potential of this research organization. The planning for the evolution of rocket launchers in the coming decade has thus been guided by a desire to optimize this investment. The result has been the concept of the Ariane series and the exclusion of any radically new system. The development of the improved Ariane II and Ariane III models is a first step in this direction. The American experience with the Space Shuttle has shown us that this type of spacecraft is only justifiable when there is a very large number of flights per year. Even in the United States, this level will not be reached before the end of the decade. The implementation of a similar system will not be economically feasible for the Common Market in the foreseeable future.

2. The Near Future: Ariane III

We shall quickly summarize the major features of the program to improve the Ariane rocket. This program entered its preliminary phase

in August, 1979 and final approval is expected in the beginning of 1980. It is expected to be completed in 1983. The improvements being considered generally fall into one of four categories:

-- Increases in the payload capacity of the Ariane obtained by increasing the thrust rating of the engines in the first two stages (by raising the pressure in the combustion chamber), by adding two booster rockets, each containing seven metric tons of solid fuel, and finally by lengthening the third stage to allow 25% more fuel to be loaded. This rocket, the Ariane III, will be 40% more powerful than the present version. A modified model, the Ariane II, which is lacking the booster rockets, will be available for use by those who do not need the full capacity of the Ariane III. /24

-- Recovery of the first stage from the ocean. The cost of recovery is only 45% of replacement cost. Reconditioning and reusing the first stage would lead to a significant reduction in the cost of a launching.

-- Efforts made to increase the reliability of certain assemblies and subsystems.

-- A reduction of costs by making efficient use of new techniques, both in the design of assemblies and in the methods used to construct them.

3. The Medium-Term Outlook

The modifications proposed for the Ariane III were limited for several reasons, in particular:

-- The necessity to reach as rapidly as possible a payload capacity of 2400 kg so as to simultaneously launch two Space Shuttle generation satellites along with the orbital maneuvering engine PAM D.

-- The limitations imposed by the launch pad, particularly the height of the gantry scaffold. The gantry scaffold was inherited from the Europa program and cannot be improved more than it already has been. Progress beyond the Ariane III requires a new launching site. There also exist functional problems that make a new site necessary.

3.1 The New Launch Site

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The availability of a single launch pad reduces our ability to utilize the Ariane. The design of the installation causes a lengthy period of preparation for each firing. Only five or six launchings a year can be made. Repairing and rebuilding the present launch pad would necessitate a more or less prolonged interruption of the schedule. It seems necessary for the reliability of the program and for reducing the interval between flights to construct an entirely new facility. A new launch pad would alleviate the obstacles to putting the Ariane III into operation while at the same time making maximum use of existing logistic systems.

A preliminary study that includes a consideration of the requirements of satellite customers has been done by the CNES. Among the requirements noted, the following stand out:

-- Flexibility: the new launch pad will have to be adaptable to all the different versions of the Ariane without extensive work or long delays.

-- The reduction of the lead time needed to launch a satellite. In the future, this will be an important condition in making space systems profitable. In order for reliability of service to be comparable with that found on earth, satellite users must be able to quickly replace satellites which break down in orbit. The ability to quickly make available replacement satellites and launchers is becoming an important economic factor in the success or failure of the Common Market venture.

3.2 Ariane IV

/26

It is probable that by 1985 there will be a growing number of heavy satellites to meet the needs of television transmitting networks (whose first elements will be launched in 1983) and communications systems. At the same time communications systems using lighter synchronous satellites of 500 to 600 kg will be fully operational and will require a large number of launchings. Extensive research has been made into reducing the costs of putting satellites into orbit and in predicting the evolution of the market. It seems apparent that the ability to simultaneously launch two satellites of this type is an important goal to reach. To be specific, this would require that the Ariane IV have the capacity to place a payload of 3500 kg in a parking orbit. This is double the capacity of the original version of the Ariane.

The modifications proposed for the Ariane IV will follow the principles of gradual evolution defined above. They will consist of adapting elements of the Ariane III. The principal improvement planned is to increase the amount of rocket fuel carried by the first stage from 145 metric tons to approximately 200 metric tons. This will be accomplished by increasing the length of the cylindrical part of the fuel tanks by 2.5 meters, which should not present any particular difficulty. The number of booster rockets will also be increased. The exact number (from 4 to 8) of boosters will depend on how much the thrust of the Viking engines could be increased for the Ariane III. The booster rockets will carry 7 metric tons of solid fuel and be identical to those on the Ariane III. It should be noted that this approach is similar to that followed in making the American Thor Delta rocket more competitive.

There will be almost no change in the second stage, and the third stage will be identical to the Ariane III's. However, an enlargement of the nose cone and changes in the system for double launchings will be necessary in order to offer a volume equivalent to that of the Space Shuttle for satellites of this class. Placing satellites in the nose cone ahead of time will greatly facilitate

preparations for launchings and considerably reduce the lead time when relaunchings are needed.

4. Long-Term Evolution

/27

4.1 The Market beyond 1985

The Space Shuttle should be fully operational by 1985, and the technical and economic calculations that went into implementing the system will have been verified in practice. If the Space Shuttle is successful, there will probably be a gradual expansion of satellite diameter up to the limit of 4.5 meters imposed by the dimensions of the hold of the Space Shuttle. This is because:

- The price list in effect for the Space Shuttle encourages the design of satellites with the shortest possible length.
- The rotational stability of satellites during orbital transfer is maximized by a small length to diameter ratio.
- The increase in the number and in the diameter of antennas, especially for multiple beam switching circuits and relaying broadcasts, will cause all available space to be filled.

In addition, it is expected that the design of commercial satellites, freed from the constraints imposed by the performance of traditional rockets, will evolve toward heavier and heavier multipurpose systems, in anticipation of large adaptable space platforms.

The size limitations of the Space Shuttle will be in effect for a long time because it will not be replaced by a larger vehicle at least until the year 2000. The high thrust rocket programs of NASA are for launching very heavy payloads and will not compete with the Ariane series.

4.2 The Prospects for the Common Market

If the EEC is to maintain its competitive position in relation to the Space Shuttle, two conditions have to be met. Approximately the same technical features must be made available and the cost per kilogram in orbit must be lowered. Moreover, this must be accomplished within a reasonable time period and with a level of financial backing within the reach of the members of the Community. Will it be possible for the Common Market to have a launch vehicle in the 1990's that can place satellites 4.5 meters in diameter in orbit at a cost close to that of the Space Shuttle?

In terms of payload size, low altitude missions must be distinguished from those in synchronous orbit. For the first type, there is no possibility of competing with the Space Shuttle, which can carry more than thirty tons per flight. For synchronous orbits, on the other hand, the capacity of the Space Transport System is limited by the thrust developed by supplementary rocket stages or orbital transfer vehicles to a mass of 2900 kg.

This is within the range of possibilities for the Ariane program. Around 1990, a model capable of lifting three metric tons into synchronous orbit at 40% of the present cost could be introduced.

4.3 The Ariane V

The Ariane V would be a multipurpose rocket. It would be specifically designed for launching objects into parking orbits, like the versions preceding it. However, it would also be able to transport payloads of up to ten metric tons directly to low earth orbits and smaller payloads to higher altitudes. Finally, it could be called upon to launch a Hermes-type manned spacecraft.

Even though it would represent an important stage in the evolution of the Ariane series, the Ariane V would remain well within the traditional framework of this series. It would be a conventional nonreusable rocket (except that the first stage could be recovered at

sea and portions of it reused). The design would be simple. The first stage would be the same as the first stage of the Ariane IV. Thus, the launching facilities could be used unchanged. Modifications would be confined to the upper stages. These would include:

--The second stage, unchanged in all previous models, would be replaced by a liquid hydrogen powered rocket carrying 40 metric tons of fuel and developing a thrust of 60 tons. This stage would be constructed of light alloy material, following the techniques developed previously in the Ariane program. Its diameter would be 3.8 meters, which would create a continuity of form with the first stage.

--The third stage would also be powered by liquid hydrogen. It would have a capacity of about 6 metric tons of fuel. This stage would be a modification of the third stage of the present model Ariane and would use the same propulsive system. The fuel tanks, on the other hand, would have to be rearranged because of the new configuration and also to take the most advantage of new structural assemblies that will already have been developed or that would be developed in the course of the Ariane V project. Thus, the hydrogen tank would have a design based on that of the second stage and the oxygen tank would be an adaptation of the present design.

If the Ariane V were constructed in this way, it would have several uses:

/29

In its three stage version, with a nose cone large enough to carry satellites built for the Space Shuttle, it could put approximately 5.5 metric tons in parking orbit. This corresponds to a satellite of about 3 tons in synchronous orbit. It could also carry an additional rocket engine as part of the payload. This would allow missions to be placed in orbit which require a very large amount of energy, such as long-distance space probes, interplanetary probes, and the ejection of radioactive wastes from the solar system.

--In its two stage version, with the same nose cone, the Ariane V could transport 3.5 metric tons to a parking orbit, the same capacity as the Ariane IV. This version could also place approximately 10 metric tons directly in a low altitude orbit. This means that it could launch a space station subassembly or a large automated laboratory for fabricating materials into space.

--Finally, a manned spacecraft of the Hermes type could be placed on top of the first two stages. This spacecraft could then be launched into a 200 km high orbit, inclined at 60° to the equator. This mission would, however, require additional development to raise the reliability of the launcher to the levels required by manned flight.

IV.4 The HM 60 Engine

The design outlined above is realizable with the techniques already mastered by the Ariane program. Strains caused by simultaneously introducing new basic technologies and a new rocket system would be avoided.

The propulsive system proposed for the second stage is the only element that would represent a substantial step forward. This is the liquid hydrogen engine of 60 tons thrust that has been designated the HM 60. It is true that the basic technology necessary for this type of engine was introduced in the third stage of the Ariane. However, the increase in scale (thrust is multiplied by a factor of 10) is such that the construction of the engine must be undertaken as if it were a new program. If the choice of an engine of relatively powerful design is supported in further studies, it would be realistic to predict that it would take ten years to develop the HM 60 and put it into service. In order to complete the Ariane V by 1990, a preliminary program lasting three years must be started in 1980. This program would include the detailed design of the engine and the propulsive system, initial experiments on the most critical elements, and design work on testing equipment.

IV.5 The Hermes Manned Shuttle

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Preliminary studies have been carried out on the design of the inhabitable Hermes space shuttle, a hypersonic vehicle that would be launched by the Ariane V and would reenter the atmosphere under its own power. These studies tried to answer the question of whether the EEC could produce a manned spacecraft if the evolution of space flight demanded it. The initial restrictions, in particular the use of the Ariane, have limited the spacecraft to modest dimensions. Nevertheless, it would be large enough to service a manned orbital station. The Hermes space shuttle could carry five astronauts and a load of 200 kg or two astronauts and a load of 1500 kg. Such a project appears feasible even though it would require many new techniques. There are, meanwhile, two fields in which previous experience would be necessary before the Hermes spacecraft could be built. These are thermal insulation for protection during reentry and the generation of electricity by fuel cells.

IV.6 Economic Considerations

In order to make the Ariane competitive with the Space Shuttle, the thrust of the rocket must be increased with the least possible increase in the cost of launching satellites. The choice of improvements is based on these criteria. Thus, in introducing the Ariane III, only the booster rockets contribute to a slight increase in the cost per kilogram of payload. The other two modifications have no effect on the cost. Similarly, lengthening the first stage to build the Ariane IV does not increase the launching costs at all, while the extra booster rockets cause only a slight augmentation. For Ariane V, the second stage is certainly more expensive than the present one, but the increase in launching capacity is such that the price per kilogram placed in orbit is significantly less. In all, a reduction of 2.5 times in launching costs can be hoped for in advancing from the present version of the Ariane to the Ariane V.