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The commercial potential of large orbital space platforms

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The commercial potential of large orbital space platforms or space stations is a key factor that must receive serious attention during the early feasibility and concept study phases. It is recognized that the total development cost will be very great and thus it is essential to identify potential users and their likely investment interest at an early stage. However, the development time of a space platform, say ten years, poses clear problems to both builders and potential users. Some typical problems are mission cost, operational effectiveness, commercial security, ownership and operational responsibility of the platform. Another very important issue is whether the platform should be manned, man-tended or unmanned. All these points are important factors to the commercial potential. The paper will review some of these aspects by using results gained during current studies being made for the European Space Agency.

INTRODUCTION

Space operations including spacecraft, launch vehicles and the ground segment are already in their third decade and a number of major milestones have been passed.

(i) The potential of the unmanned satellite and space probe is being fulfilled in a variety of roles such as space science, communications and Earth observation.

(ii) The highly successful commercial use of communications satellites is accepted.

(iii) Manned operations in space are now becoming almost routine after the success of the Space Shuttle.

(iv) The commercial potential of Earth observation satellites is now being developed.

(v) The ability to place and retrieve very large payloads into low Earth orbit (l.E.o.) has been demonstrated.

Most of these milestones have been achieved by using expendable launch vehicles such as Delta, Atlas Centaur, Saturn and Ariane. Perhaps the most significant achievement is the reusable launcher system known as the Space Shuttle, which has been demonstrated so successfully. This development has encouraged the consideration of space activities and related facilities for the next decades. Of particular interest is the study of the potential and architectural concepts of the manned space station and large orbital space platforms.

The space station concept envisages the following facilities: a permanent manned laboratory in space for scientific research in astronomy, Earth observation and life sciences; a base for manufacturing activities in space, which would exploit microgravity for the production of new materials for use on Earth; a transport node for spacecraft destined for high Earth orbit, which would integrate spacecraft and upper propulsion stages, and provide a base for an orbital transfer vehicle that would enhance the use of the Shuttle launch capacity. As a consequence, the Space Station is not seen simply as an updated version of the Skylab orbital laboratory but as a complex of components, some of which form the ‘core’ manned facility and some which form related elements. If the U.S. programme is approved it would be expected to develop

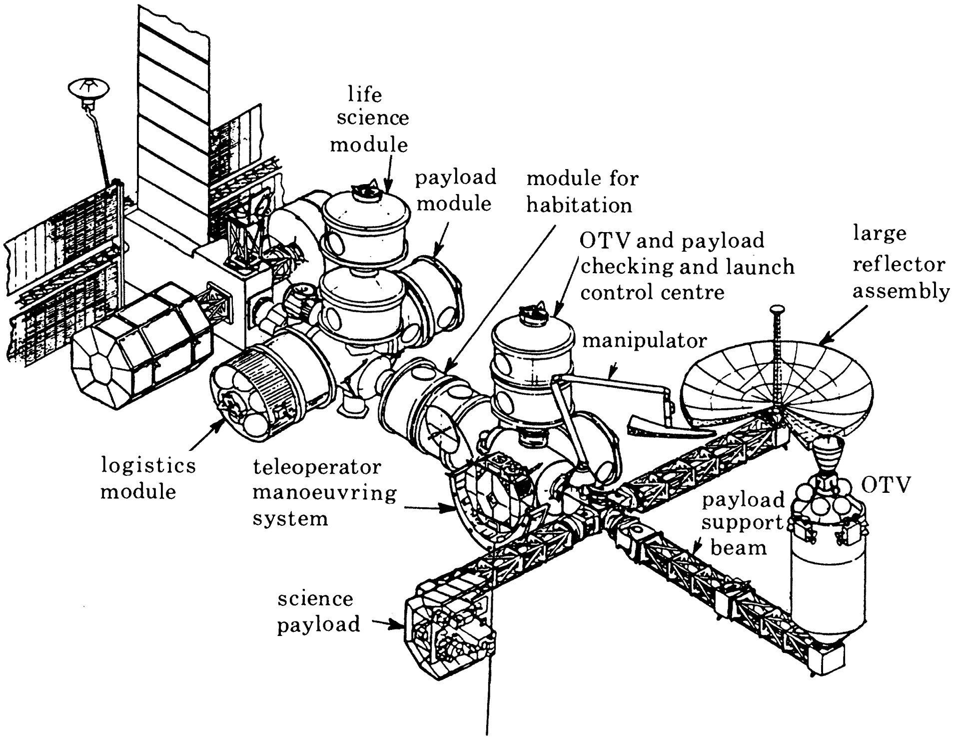

FIGURE 1. Concept of a baseline space station configuration.

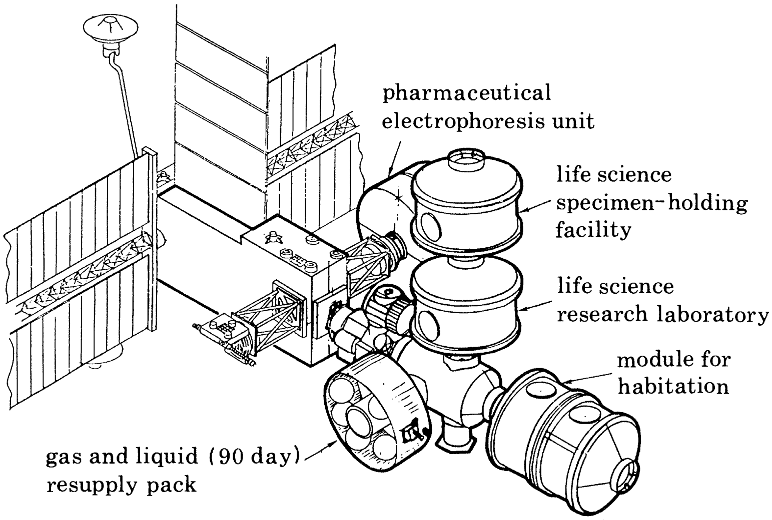

FIGURE 2. Initial space station with minimal logistics capability.

and evolve throughout the decade of the 1990s, beginning with a minimal four person facility in a 28.5° low Earth orbit in 1991. These major components will probably include: a baseline manned platform; a free-flying teleoperator servicing vehicle; a modular unmanned platform with space station elements but in other orbits (for example, polar); a reusable space based cryogenic orbital transfer vehicle (OTV); propellant storage and refuelling facilities and a vehicle servicing hangar associated with the manned station.

At this comparatively early stage it should be recognized that there is no definitive space station design but a number of concepts are being used for system assessment purposes. A typical concept that is being used in a European study (to be described later) is shown in figure 1. This concept has many of the features being used in the N.A.S.A. and U.S. industrial studies. Each of the basic elements or units shown in this concept can be carried into low Earth orbit by using the standard Space Shuttle, which gives a rough indication of the station size. The station will be assembled in space by using robotic and astronaut operated manipulators working out of the Space Shuttle. Figure 2 shows a concept of a much simpler platform, which can be unmanned or man-tended from Shuttle visits. These two basic concepts lead to the point that a space station can be manned, unmanned or man-tended, depending on the type and scale of mission to be undertaken.

A very significant milestone is the acceptance that space activities and operations should now offer a useful commercial potential whenever possible.

Space Station characteristics and environment

In all novel concepts and their working environment there are both advantages and disadvantages and some of the more important ones are given in table 1.

Table 1. Advantages and disadvantages of space station concepts

advantages	disadvantages
access to the unique environment of space for a wide range of users and equipment	high development costs and long development programme
a much greater payload capability in both mass and volume than can be provided by an unmanned automatic satellite	considerable crew safety constraints
flexibility of mission types and operational modes	potential users do not have control of the availability of the space transportation system
opportunities for non-astronaut participation in space activities for example, scientists, engineers and other technicians	the need to maintain independent commercial security for industrial users on a common space station
comparatively low recurring costs when compared to unmanned satellites	international political situations can have a serious influence on users' programmes
very long lifetime of basic hardware, together with the capability to regularly replenish consumables such as fuel, food and water	inevitably complex financial arrangements for development and use, particularly when considering international involvement
the ability to repair and replace worn or damaged major components	
the ability to make 'hands on' experiments and processing using man's unique abilities for subjective judgement, tactile skills and response to unusual situations	

Why put people in space?

In this age of highly developed automation and robotic operations in a wide variety of industrial activities, it is proper to ask the question, 'why put people in space?'. The point is that man should only perform tasks that use his unique skills and not be used in functions that machines and automation can do better. Some examples of such abilities are: the ability to make real-time subjective decisions based on direct observation and the facility to deal with the unexpected; that man can provide the application of continuous intelligence with an in-built adaptive logic and programming ability; the ability to assess situations and communicate.

The space environment

It is appropriate to include some of the more significant characteristics of the space environment that have relevance to the operation of a space station. It is not often realized that space is a comparatively benign and predictable environment. There is no climate, no bad weather, no natural disasters of the type experienced on Earth.

Some of the characteristics are: a continuous microgravity level of 10^{-3} to $10^{-5}\,g$; a continuous hard vacuum; a solar and ultraviolet radiation not subject to atmospheric attenuation; a unique experiment base for work that is impossible in a normal terrestrial environment; the capability to provide facilities for the remote observation of Earth at all latitudes and longitudes, i.e. global coverage; free solar energy, which after photovoltaic conversion by solar arrays can provide the station's electrical power supply.

Related disciplines and potential users

Most potential users may be expected to be identified within the following broad disciplines: materials science and associated processes; life sciences; space sciences; environmental observation from space; space technology and testing; satellite repair and replacement and mission support services.

Table 2. The disciplines in materials science and life science that could use the space environment

- metal composites
  - solidification of metal melts, also with dispersed additives
  - metal foams
  - measurement of physical parameters
  - improvement and testing of technologies in space and on Earth

- crystals
  - basic study of melt zone crystal growth
  - growth of new types of semiconductors
  - growth of monocrystals with finely dispersed inclusions
  - growth of crystals by precipitation from solution
  - developments in glass, ceramics and refractories

- interface and transport phenomena
  - basic study of cellular and Marangoni convection
  - studies of boundary and transport phenomena at and in interfaces and surfaces
  - measurement of transport parameters

- physical chemistry and process engineering
  - measurement of thermal and caloric state functions
  - studies on reaction kinetics
  - containerless processing
  - measurement of physical parameters
- pharmaceuticals and bioprocessing

life science

- human physiology and medicine
- gravitational biology
- radiation biology
- exobiology
- biotechnology

Preliminary surveys have indicated that initial potential users of space station or platform facilities are in the many subdisciplines of material and life sciences. These interests are a direct consequence of the inherent availability of the microgravity environment. An indication of the range of these interest for materials science is given in table 2. The lists in table 2 show that the potential commercial users can be expected to be found in the companies responsible for producing very high quality metals, crystals, ceramics and pharmaceuticals. It is stressed that there is no intention of proposing materials processing in space for products that can be produced simply on Earth; it is reserved for the exploitation of processes and materials that will benefit significantly from manufacture in space. Indeed, the current situation in the U.S. is that a major pharmaceuticals house, Johnson and Johnson, in close collaboration with McDonnell Douglas, have already flown a continuous flow electrophoresis experiment on four Shuttle flights with very encouraging results. The results have shown that an increase in yield of over five hundred times has been achieved with quantitatively repeatable separation. The flights have also demonstrated the value of manned participation as well as validating the design concepts.

The main driver for the interest in materials science is the very low gravity environment known as microgravity, although the actual levels lie between $10^{-3}\,g$ and $10^{-5}\,g$ depending on the operational requirements and facility. Microgravity leads to some interesting physical and engineering phenomena such as convection free conditions in liquids and gases, and no gravity-dependent separation of materials with large differences in density. These two characteristics can be used for the production of more perfect homogeneous materials or materials that cannot be produced under normal Earth gravitational conditions. Continuous flow electrophoresis is a typical process that benefits dramatically by the elimination of gravity.

European potential users

As part of its Long-Term Preparatory Programme (L.T.P.P.) on space transportation systems the European Space Agency (E.S.A.) has identified a number of areas for study by selected European industrial and establishment teams. Of particular interest is the recently completed first phase of one of those studied, which is called ‘European Utilisation Aspects of a U.S. Manned Space Station’, a title that has been abbreviated to EUA-1. This E.S.A. study was led by D.F.V.L.R., the German Space and Aeronautics Research Establishment with an industrial team comprising ERNO, Aeritalia, Matra, Dornier System and British Aerospace, all of whom have been involved in Spacelab. The main objectives of the study were to identify the level and type of European interest in using a manned space station; to identify potential European payload candidates, which will be beneficially supported by a manned space station, and to assess the required operational support from the Station; to discuss alternative approaches and identify the impact if no manned space stations were available to support the missions.

The plan was for each industrial company to make personal contact with companies and institutions working in the relevant fields to establish the level of interest in the potential offered by the space station. The contact was followed up with a requirements questionnaire and a short descriptive brochure of a typical space station and its facilities. From these contacts and questionnaires it was hoped that a reasonably well defined set of candidate payloads and their requirements from the station would emerge.

This approach identified a fundamental problem. It was a comparatively simple matter to work with scientists who were already familiar with space activities, but it was much more difficult to contact and communicate with potential users outside the space community. The problem was bilateral; the understanding of what space could offer and what industry needed demonstrated a requirement for mutual education that could not be achieved quickly. This problem was particularly acute for the pharmaceuticals industry. It is worth noting that fundamental research into exotic metallurgy and crystallography in a microgravity environment has been proceeding for several years by using the very successful Skylark sounding rocket, which gives several minutes of microgravity, which is often sufficient for proof of concept tests. The programme, known as TEXUS, is strongly supported by the German D.F.V.L.R.

The first phase of the EUA study provided valuable lessons, particularly on user contact, which have been incorporated into the second phase of that study, which has recently started. It is also hoped that symposia of this type will help to bridge the gap between potential users and those who understand the space environment and can provide the facilities. However, despite the difficulties, some 35 materials science payloads were identified and, as had been expected, these were mainly in basic research. Twenty five of the proposed payloads were German. During the study it was observed that there was an interest by potential users in doing materials and processes research in orbit, but an understandable reluctance to speculate about the potential for large scale space production until the essential research is completed. Another viewpoint was that useful experiments could be done in space, which would lead to a better understanding of terrestrial processes. Many other payloads were identified in the other fundamental disciplines described earlier, but as they have less commercial potential at this time they will not be discussed further.

So, the basic objectives of the study were met, useful lessons were learned, which have been recognized in the second phase activities, and the broad summary and conclusions of the European study are now given.

Summary

(i) A manned space station is necessary for selected European payloads in material and life sciences.

(ii) Manned space station operations need to be complemented by free-flying unmanned platforms for automatic materials processing.

(iii) Most payloads identified were for basic research.

(iv) Commercial opportunities at this stage were only identified in communications, where the space station is used for orbit staging and assembly.

(v) Identification of possible materials-processing payloads will be largely dependent on the flight results obtained from the Spacelab mission.

Conclusions

Participation in a U.S. manned space station programme will promote European scientific and technological progress. The usefulness of people for representative candidates from all user disciplines was identified. The identified trends in use result in increasing payload requirements to be met by future space systems in both technical and functional capabilities. Human assistance is important for the development of these capabilities even if in the long term they may be provided by automatic systems.

Participation in a U.S. manned space station will, in the long term, open the way for increased operational and commercial use of space by Europe. As well as a working research base, the space station can be a service centre, transfer station and warehouse supporting future space missions. It will simplify access to space and increase the cost-effectiveness of space operations, both of which are of considerable importance to the successful commercial use of space.

COMMERCIAL POTENTIAL

The industrialization of space, and its related commercialization, has already started; it is no longer science fiction but is rapidly becoming science fact. As other papers have shown, the communications industry, both suppliers and users of equipment, were quick to realise the great commercial benefits that fast, high quality, high capacity space communications could offer by using satellites. In this business sector, the use of space facilities is no longer a novelty. Although space station studies are at a comparatively early stage, there is a growing feeling that there is great scope for their commercial potential. In this context commercial potential should be associated with cost benefits. The absolute assessment of cost benefits is extremely difficult and will not be attempted here, but it is possible to indicate trends and growth areas. In this third decade of space activities it is clear that unless the space station can demonstrate a significant commercial potential, then its future, at least for civil applications, may be limited.

It is important to understand that cost benefits or commercial returns are not immediate and will require those who wish to invest in such a large scale advanced programme to accept that the development of an operational manned space station will take about nine years. There is no quick return on investment, which is true of most high technology industry. To develop and maintain the interests of potential users it is essential to demonstrate the ability of space facilities to provide the services required. Commercial growth and product development will be strongly dependent on the results to be obtained from early flights, which will be concentrating on research and development. In Europe, for example, much depends on the success of Spacelab, which is being flown in the Space Shuttle. This is a typical example of the type of space laboratory that is an essential tool for space processing experiments in both science and technology. The current experience of McDonnell Douglas and Johnson and Johnson in their continuous-flow electrophoresis equipment for achieving very high purity production indicates a time of five to ten years to develop from concept to implementation, for the introduction of a new product to the commercial market.

It is recognized that the use of space systems in an industrial process will inevitably carry a risk, particularly for commercial ventures, and the space industry must provide a continuing public relations service to encourage potential users. Further, very important points are concerned with protection of proprietary rights, intellectual property rights, access to the facilities, the potential for private ownership, and crew training for company operatives working on the station. To encourage commercial interest for space-developed products and services, space facilities must be easily accessible by dependable and regularly scheduled space transportation systems with a clearly defined tariff.

Economic benefits of research and development are relatively difficult to quantify. One method of evaluating these benefits is to consider a function such as the 'cost per kilogram hour', which is based on two factors, namely payload capability and mission duration. Some figures have been estimated in the U.S. space station studies. With the basic assumption that the space station can operate on a 90 day production cycle on materials processing, the costs have been estimated at about $2.00 per kilogram hour, as compared with $17 per kilogram hour for Space Shuttle processing operations and very much higher costs for other methods of materials processing in space. However, at present this is a highly speculative area and much will depend on the outcome of the relevant Shuttle flights.

One U.S. estimate of space station economic benefits, made in 1983, is $1.6 billion and does not include any income or benefits from commercial materials processing in space. The benefits come from the use of a space-based orbit transfer vehicle (69 %), satellite servicing (14%) and research and production (17 %). For all three categories the space station mission costs were compared with both the economic value of the mission (when quantifiable) and the projected cost of alternative means for accomplishing the same mission. Conservative estimates were used throughout. The potential benefits of materials processing in space are believed by some experts to be of the order of billions of dollars per year but much more evidence is required before these claims can be substantiated.

The mass of European microgravity payloads transported into low Earth orbit in the decade beginning 1995 is likely to increase owing to the availability of orbital facilities such as Eureca, the European retrievable carrier, and the manned space station, and a growing awareness of the commercial potential for space materials processing. At this time an analysis of experimental payloads identifies something like 6.5 t of materials science payloads and 5.6 t of life science payloads. How many will actually fly depends on funding availability, but equally as facilities become available and experiments are successful the demand might be expected to grow.

Two factors may limit the rate of growth of microgravity payloads in the post-1995 period. The first is the time delay between the inception and completion of an experiment indicated earlier, and the second is the specific cost of material processed in a space facility, which may limit its commercial exploitation. Several iterations may be required to bring a commercial process to maturity. The specific cost of processed materials determines which products might show commercial attractiveness. The relation between specific cost and demand may be as powerful as an inverse cube relation, so that cost reduction in this period may be very important indeed.

Conclusions

At this early study stage it is not possible to give many firm conclusions, but certain points have emerged from both the U.S. and European studies.

(i) Candidate commercial users do exist, but it is essential that there is mutual involvement and continuing dialogue to sustain and foster the interest.

(ii) There is a gap between potential users and the space industry and strong efforts must be made to bridge this gap.

(iii) A manned facility is essential for research and development, operations and commercialization.

(iv) The manned space station must be evolutionary and affordable, and benefits should repay investment.

(v) Management aspects, both commercial and operational, need careful consideration.

(vi) The ultimate space station system must include both manned and unmanned elements in various orbit locations.

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