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Joint Project on European Space Policy
APPLIED SCIENCE IN OUTERSPACE

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1) State of art.

Environmental conditions which are typically encountered by vehicles in orbit around the earth include, among others: lower gravity, the presence of a vacuum, and the relative absence of impurities. These conditions have permitted the carrying out of a series of scientific experiments not possible to conduct in the earth's environment.

Reduced gravitational forces affect the behaviour of materials in both gaseous and liquid states. Sedimentation, convection and hydrodynamic pressure are considerably reduced if not completely eliminated. Today, the most significant research activities in this area include work on: crystal growth, metallurgy,, containerless processing, fluid physics and chemistry. Biological separation through mechanisms such as electrophoresis, in which materials are isolated from mixtures according to the different electric charge of their constituent particles, is also being investigated.

With regard to crystal growth, weightlessness permits scientists to grow large, near perfect crystal. This is possible because in the absence of gravity little or no distortion or deforamtion of the crystal occurs. Crystals can be processed in microgravity conditions without a container in space. Containerless processing permits scientists to melt and solidify crystals without the crystals absorbing impurities from a container. The industrial applications of pure and near perfect crystals are many. They are required in computers, lasers and numerous other optical and electronic devices.

Microgravity conditions offer scientists an opportunity to investigate and improve methods for creating advanced metals, glass and ceramics. Another important benefit of space processing may be the development of lower-attenuation glass fibre for use in optical communication. These fibres would allow more signals to be sent over a larger distance than do conventional fibres.

Another important process that can be studied extensively in space is rapid undercooling. In this process a metal is solidified so rapidly that its atoms cannot organize themselves into their normal metallic structure. The result, a disordered structure similar to that of glass, gives the material unusual properties. The absence of gravity may shine new light involving undercooling and therefore contribute to advanced casting technology on earth.

One of the most promising areas of microgravity research is in the field of biological material processing. On earth, one of the most widely used analytical technologies is electrophoresis. In electrophoresis a gel or another supporting medium is used to suppress convective flows. To apply this process to cells, cell components or other particles the supporting medium must be eliminated. This is possible in the near free gravity environment of space where gels and other supporting media are not required.

Separation techniques such as continuous flow electrophoresis permit separation of biological materials in quantities and levels of purity unattainable on earth.

There is, nevertheless, a wide gap between scientific experimentation and possible industrial application.

The first step in bridging this gap is the research stage which involves experimentation verification to identify possible useful products worth developing. This activity can be conducted on earth using drop tubes, drop towers or research aircraft (1). To conduct such experiments on earth at present is less expensive than in space but at the same time these experiments are subject to a very restricted time limit of from 1.7 to a maximum of 20 seconds. The cost of experimentation can also be kept down, relatively speaking, with the use of sounding rockets. These rockets launch a small payload into space. As the payload coasts upwards and falls back to earth the contents of the payload are motionless, i.e. weightless in relation to one another. This low gravity condition can last for three to five minutes permitting scientists to explore a wide range of phenomena. The SPAR sounding rockets, for example, provided a large data base which served as the foundation of the low-g program aboard the Shuttle.(2)

The second stage, the "development" stage, requires the use of the spacial infrastructure and of the necessary hardware to conduct a long-duration experiments. In this stage, the first pilot units are produced.

The third stage is that of commercial demonstration and serves to show that the processing concept works on a larger scale, that processing is economically attractive and that the market exists for the corresponding product.

After this stage the routine production stage would normally follow but at the moment it seems to be very far away. Actually, the research stage is presently underway, while we have not yet fully entered the stage of commercial demonstration. The prospects of such commercial demonstration are difficult to predict. They seem primarily to depend on the cost of the earth-space transportation, on the reliability of the carriers and in general on all of the prerequisite infrastructures.

The Space Shuttle, a manned system, is at the moment the only vehicle which enables long-duration experiments to be conducted in space. As far as experiments in a low gravity environment are concerned, the best results are obtained today with the utilization of the Shuttle/Spacelab combination. The Spacelab is a pressurized module lodged in the cargo bay of the Shuttle which can host a team of four research scientists. The same Shuttle provides the module with all necessary support to the mission (e.g. electrical energy, monitoring of the enviromental conditions, telecommunication systems and data elaboration).

The Spacelab, designed and constructed by the European Space Agency , (E.S.A.) can carry out seven to thirty day missions and should be able to be utilized for fifty missions over an operative life of approximately ten years. The combination Shuttle/Spacelab has three important limits (3). One, the movement of the members of the crew cause micro-accelerations which can compromise the results of certain experiments. Two, the length of the stay (sojourn) in space is about ten days while many experiments require a significantly longer time. Three, the Shuttle does not produce enough energy for some application of microgravity.

Some of these inconveniences can be avoided by utilizing free flying platforms such as the Eureca, an unmanned system, which will permit precise microgravity experiments to be conducted without disturbance. The Eureca, a

European project, can be released into space from the Shuttle and recovered and returned to earth by an orbiter after completing its long-duration mission (the duration of the first flight is expected to be nine months), but could also be put in orbit by an expendable launcher. Eureca will include on board material processing facilities, furnaces and the like.

. Some American space companies are already thinking of beginning the marketing of an industrial facility which would be launched by the Space Shuttle. This launch is projected to take place two or three years before the space station is ready and would be unmanned during the free flight mode, but would have a pressurized workroom where astronauts could work in a "shirtsleave" environment, during the two or three days it would take to service the facility.

The space structure which best responds to the needs of low-g activities is however, without a doubt, a manned space station. This would permit experiments of a long duration to be performed directly by a team of scientists who would have the possibility of working in an envirorment whose microgravity level is certaily better than that of the Shuttle/Spacelab and of better quality. The space station would be the ideal structure within which routine production could be initiated. NASA has begun a project to build a structure of this type which, if current plans and funding are maintained, should be operational sometime in the nineties.

Europe, Japan and Canada have joined the USA space station program. Their participation will permit them not only to remain abreast of research in low-g experimentation but will also allow them to participate in the development of new technology necessary for the construction of space facilities. European participation in the station, i.e. the Columbus program, corresponds directly to developments in the Spacelab program. The main elements in the Columbus program include a pressurized module, a man tended free flyer, a polar platform and a resource module.

2) <u>The costs.</u>

At the end of the nineties, if everything proceeds as planned, the Western space industry will have built all of the basic infrastructures necessary to begin the process of the industrialization in space. But what are the costs of the infrastructures and will they be reliable? Today the cost of transportation by way of the Shuttle is around three thousand dollars per pound. According to some specialists, this sum must be reduced to approximately three hundred dollars per pound in order for it to be commercially feasible to produce new materials in space (4)

In effect, the investments which industry must make in order to operate in space are too high at the moment, when compared to the amount industry spends on related research on earth. A report published by OTA explains that: "A Delta-class MPS payload including integration expenses may involve flight costs in excess of $15 million. This additional expenditure, incurred well before commercial feasibility has been established, is a departure from normal product development on earth. The recurring costs associated with payload integration and space flight, added to the costs of starting materials, flight hardware (potentially tens of millions of dollars) and personnel, suggests that a commercial space venture would have to be assured of very high revenue before it became an attractive investment" (5). Furthermore, there is always the risk that some activities which today are believed to be possible only in a space environment may one day become feasible on earth at a significantly lower cost.

A significant example of discuraging economic prospects is the fact that Johnson & Johnson ended its proposed collaboration with MacDonnell Douglas in the production of the first pharmaceutical products in space. The decision on the part of Johnson & Johnson seems to have been based on the fact that it is still more economical to produce these products on earth (6). Another factor of uncertainty is constituted by the fact that the investors cannot count one hundred per cent on a stable and continued transport system. Changes in the Administration policies, budjet cuts by the Congress or a serious accident may cause long gaps in the earth-space transportation service.

This was dramatically evidenced in the case of the Challenger accident with the resultant schedule delays in prospects for the next Shuttle flights. It would seem that the American space program needs to be substantially revamped. Changes must be made both regarding the space station and the Spacelab scientific program. "Fewer Space Shuttle launches will be available to support the station because of a flight rate constrained by flight safety and payload manifest full of defense and other missions expected to require Shuttle launch".(7) All of these considerations "are forcing NASA to reconfigure the US international space station to a much smaller initial facility that will be built and operated differently from the one originally envisaged".(8) These changes will involve the use of heavy-lift expendable launchers to put in orbit space station modules. "Use of expendable boosters for station resupply is also a growing priority. Instead of relying exclusively on the Space Shuttle for station resupply, NASA is now planning a significant space station supply role for existing unmanned US boosters, the European Ariane and Japanese H-2 vehicles, a change that also foresees redesign and replanning of station operational concepts"(9).

As far as the Spacelab is concerned, it seems that NASA feels compelled to cancel fifteen to eighteen Spacelab missions that were planned to fly during the next five years, greatly reducing the frequency of space experiment opportunities for scientists in the US, Europe and Japan. According to Aviation Week and Space Technology: "As a consequence of the Challenger accident, NASA is likely to fly only three more Spacelab missions by the end of the decade, with only one of those using a pressurized module...". These changes "are likely to convince many scientists that they are better off flying their experiments on an unmanned launch vehicle."(10) All of this is likely to revive the debate over whether manned or unmanned flights are preferable. According to a study put out by NASA, experiments in low-g environments would be far more expensive if they were to be automated. When one is at the experimental stage the instruments are not necessarily completely reliable and man's presence is essential for repair work and handling unexpected developments. Human presence can make the difference between a successful experiment and an unsuccessful one (11). For the most part it can be said that initially the presence of man during experimentation is desireable if not essential. At a later stage it is possible, instead, to reduce costs through the extensive use of automated procedures especially when moving from experimentation to the actual production. In reality, however, one must beware of easy generalizations. The choice between manned and unmanned vehicles depends mainly upon the type of activity to be performed and the actual level of technology reached by the robotics in each particular type of operation required. When possible, it is more advantageous to send up an unmanned vehicle because it is certainly less costly and dangerous.

The problem of manned or unmanned space flight has been voiced also in Germany. In discussing the Hermes and the Columbus projects, positions have been expressed clearly in favour of unmanned and chiper projects . "Pressure continues to build from scientists who believe Columbus will absorb too much of the space budget and the national research budget as a whole. They believe Germany would receive more benefits from supporting a larger number of smaller, unmanned projects."(12)

Manned and unmanned options appear to be still an "open issue" as it was already underlined by OTA in its 1984 Civilian Space Stations and the US Future in Space: "It could turn out that most or all functions of space infrastructure that utilize a human crew could eventually be performed by one or several automated systems. This certainly seems to be true whenever a single specific activity is under examination: material processing in space, for instance, could perhaps be adequately performed in an operational production mode by an unmanned platform ...". (13)

Considering the high cost of space transportation the conditions necessary for the commercialisation of products or profitability are twofold: firstly, the product produced or the service rendered must have a sufficiently high intrinsic value and, secondly, there needs to be a large enough market for the products or services. As far as the first condition is concerned one must take into account the value to weight ratio. It is obvious that candidate materials for commercial manufacturing in space should be sufficiently light to minimize transportation costs, while valuable enough to ensure that the market price offsets the costs attributable to transportation.

An example of such a product is pharmaceuticals whose prices range up to billions of dollars per kilogram. The MacDonnell Douglas and Johnson & Johnson pharmaceutical venture planned to use space processing for production of new medicines and expected to generate one billion dollars in annual sales by the early to mid 1990s. The venture focused on the use of the electrophoresis separation process in space to obtain mass quantities of a hormone. The Ortho pharmaceutical division of Johnson & Johnson expected to begin human patient testing in early 1985 with the material produced on shuttle mission 41D. MacDonnell Douglas astronautics, however, had encountered problems in making the product in the quantity required for clinical testing. At that point Ortho decided to cancel the agreement with MacDonnell Douglas. This demonstrates that technical difficulties have not been successfully resolved and this in a type of microgravity activity which is more advanced than others.

Up to this time only one product has been obtained, the monodispersed Latex spheres. The spheres are used as tiny rulers to determine relative sizes of objects under microscopes and to calibrate filters, particle counters and porous membranes. Spheres smaller than one microns and up to three microns can be produced successfully in ground laboratories. Producing spheres of a uniform diameter larger than this is very difficult because of adverse gravitational effects. The spheres which have been produced in space by seeded emulsion polymerization are 10 microns (10 thousandths of a millimeter) in diameter. In spite of this good track record, the production of monodispersed Latex spheres on the Space Shuttle stopped in 1985 because of lack of demand.

Another sector in which private companies are interested is that of crystal growth. Microgravity Research Associates Inc., together with Grumman Space, has planned to manufacture gallium arsenide semiconductor crystals in space. Gallium arsenide has properties far superior to silicon, which has been the basic electronic industry semiconductor material for several decades. Supercomputers that will perform billions of computations every second, strategic defence systems and advanced satellite communication systems will have requirements that will surpass silicon technology and open the market for new semiconductor material. Raw material on earth is able to yield only 2% of gallium arsenide as an end product while in space it is possible to obtain a much purer product at 10%. The cost of the production of four chips on earth with a yield of eight good gallium arsenide chips (2% yield) is approximately $300. In space there is a yield of 10% so that from 400 chips we obtain 40 good chips. The operating processing cost, however, amounts to $4500 (evaluation before the Shuttle accident) because of earth-space transportation (14). Even though the total cost is higher on space, the profits overcome greatly those available by the earthbound production. But will there be a market ready to absorb the growing number of microchips?

Some marketing forecasts are decidedly optimistic for the future. The Center for Space Policy, an organization which specializes in estimating commercial or industrial opportunities in space, has predicted that by the year 2000 the annual revenue produced by the processing of material in a low-gravity environment, will be circa 41.5 billion dollars (15). It is, however, difficult to judge from such assessments, because of the high number of variables involved and lack of substantial reliability or applicability. The unreliability of certain studies is also confirmed by NASA circles. Besides, according to John J. Egan (16), a business planning group manager who heads commercial space studies at Cooper & Lybread, "many people are going to get 'burned' financially and some businesses are going to fail" (17). And, as Mr. Hansulrich Seiule, Spacelab D-1 project manager for DFVLR, pointed out years ago:"we have a long way to go before any of these microgravitational experiments have a potential to be marketed.(...) The DFVLR believes its continuing emphasis on basic research into microgravity and material processing will give it a long term edge in commercializing space, even though that edge may not become apparent until well into the 21st century." (18) At the beginning of the next century new space vehicles such as the British Hotol and the American transatmospheric vehicle (TAV) might be operational.

3) Organization

In most of the industrialized world there is a marked and growing interest in micro-gravitational experimentation. Activities of this type are mainly undertaken by governments and by space agencies, which is quite natural since we are in the initial stages. Only in the US has the private sector become involved to a relevant extent. NASA, through its Material Processing Space Policy Program, has tried to identify a certain number of scientific phenomena that may be suitable for commercial applications. Up until now the results have not been particularly encouraging (19). In an effort to interest the private sector in micrograyitational activities, NASA has formed the Office of Commercial Programs. In addition, NASA established the Joint Endeavor Agreement (JEA) and the Technical Exchange Agreement: contractual agreements which provide for the exchange of information, sharing of investment risks and free flights on the Shuttle. Although only a small portion of NASA's overall budget has been dedicated to experiments in microgravity, the American space agency has vigorously conducted a promotional campaign, making ample use of the media. According to OTA, this publicity is geared to increasing or maintaining NASA's support. Such publicity has, on the other hand, given rise to severe criticisms on the part of those who feel it premature to emphasize the commercial value of a space venture which is yet unproven (20).

In Europe, a low Gravity Research Association (ELGRA) has been set up with the sponsorship support of ESA and the Council of Europe in order to coordinate national activities in this sector. In 1982 the Microgravity Program was established by ESA for basic research. The main program involves the launching of "sounding rockets" for experimentation in fluid physics and in material science. A series of experiments have been planned to be conducted on the Spacelab and on the Eureca. The program is conducted in phases and has a limited financial resources. In Europe the highest interest in microgravity experimentation has been shown by Germany, where the Ministry of Scientific Research and Technology spent approximately 150 million dollars between 1978 and 1985 for microgravity activities. The FRG material processing program is not purely scientific in orientation. It is interested in encouraging the industrial sector in exploring the potential applications of space processed metals, composite metals, chemicals and crystals.

France is also carrying out a research program to evaluate material processing applications. Some years ago, CNES designed a specialized automated "manufacturing-in-space" system named SOLARIS. An effort to promote interest in SOLARIS among other ESA member states has not been particularly successful.

Great Britain has not shown a marked interest in low-g activities.

As far as the participation on the part of private companies in microgravity activities is concerned, a new organization called "INTOSPACE" was formed by the German MBB/ERNO and Italy's Aeritalia. This multinational marketing organization is designed to bring potential microgravity users together with the producers of European space hardware and systems. So far, the European private sector involvement in low-g activities is, however, very limited.

4) Why it matters to Europe.

The industrialization of space, should it occur, would provide a number of important opportunities to those involved. On the one hand, the construction of orbital stations and space transportation systems is resulting in significant technological spin-offs in other strategic sectors. On the other hand, the development of new materials, whose production is possible only undermicrogravity conditions, could prove to be an extremely important factor, not only commercially but strategically as well (e.g. high speed microchips for ultrasophisticated computer systems).

It is still far from certain, however, that space low gravity activities can be made commercially sound whatever the technical, economic and institutional framework. Assuming that the potentials of these activities remain attractive despite some recent reassessment both in the infrastructure and in the market evaluation, and considering the large investments necessary to make possible the production of materials under low-g conditions, international cooperation appears to be the best way to share the risks inherent in such an endeavour.

The most important project in this sector remains the space station to which the US has allocated $8 billion, while contribution of Japan and ESA are expected to be $1 billion and $2 billion respectively.

In this initial phase, three major divergencies have arisen between NASA and ESA: 1.disagreement over Europe's role in the space station, 2.the technology transfer issue, 3.the right to the patents and exploitation of discoveries made through the the space station.

For example, NASA refused to accept the ESA project for the detachable module for autonomous operations, because the infrastructure for a free-flier could be a significant additional cost for the US. Besides, Germany wants to equip the permanent attached module as an advanced space laboratory for microgravity experiments. NASA has never agreed to that and NASA officials have discussed using it primarily for life sciences and related activities. The question of proprietary rights to exploit discoveries has not yet been addressed in negotiations but NASA is likely to have the final decision also in this matter. One of the objectives of NASA has always been to channel funds "and technical capabilities dedicated to space in other countries away from activities which are competitive or not compatible with US interests, but involving them in a program dominated by and largely defined by the United States." (21)

To proceed with the immediate objective of establishing an independent European capability in the field of space industrialization would appear to be very difficult, unless Europe is ready to act on its own by developing its own infrastructure so that it can control access to it. Europe is technically capable of achieving such a goal but the costs would be enormous. As we have seen before, material low-g processing activities do not appear commercially promising at the moment. Therefore it may be wise for Europe to create the conditions which will enable future exploitation of commercial applications such as scientific research on earth, the utilization of sounding rockets, or unmanned platforms, and possibly the development of new technologies such as Hermes. It will be desirable in any case to continue cooperating with the US in the construction of the space station.

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15. G. Virgilio/E. Vallerani, "Economical & Industrial Aspects of Industrialization", III Conferenza sulle attività spaziali e le esigenze assicurative", p. 3.

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17 Aviation Week and Space Technology, June 25 1984

18 Ibidem

19 OTA, op. cit., p. 337.

20 Ibidem, p. 344.

21 OTA "Civilian Space Stations and the US Future in Space", p.179

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