PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A
MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Overview of the Industrialization of Space

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Overview of the industrialization of space

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[Plate 1]

This overview paper will set the scene by reviewing the totality of the framework of commercial opportunity. Several mainstream areas such as communications, Earth observations, navigation and the use of space stations will be dealt with in detailed papers later, and this paper will seek only to put their timescale and prospects into perspective. Other areas that have not yet matured to major levels of activity in the process of industrialization will be discussed, to provide a balanced viewpoint. The inter-relations of technology with finance, industrial relations, national and international policies will be reviewed in the framework of the complex nature of the development and exploitation of space projects, particularly highlighting those aspects that relate to the developing countries of the world, who are already deeply involved, and will become increasingly so, in the space business.

The manner in which the world community organizes itself in space activities will have a profound effect on the level of benefits we can gain in the future from our technical achievements. Some of the options will be described and the implications considered of how we move further into the industrial future in space.

1. Introduction

A century or so ago, the countries we now refer to as 'industrialized' displayed an extraordinary degree of innovation in creating, at a remarkable rate, a multitude of factories and service industries. The process accelerated into the twentieth century with new forms of transportation, communication, energy generation and distribution and so on. The rate of progress of the industrial revolution was accelerated further by the stimulae of the two major global wars and now, indeed since the the middle of this century, the process of industrialization has spread with wide implications to the so-called 'developing' countries of the world.

In October 1957, a new era began in the evolution of mankind, when the domain of space was added to the others as one where new commercial and industrial processes could flourish. It is fortunate that space developments are clean compared with the smoke polluted developments of the last century, and are certainly dramatic and exciting. The whole effect has been visibly enhanced by the remarkable advances in global communications made possible by the use of space.

We have today a world community that addresses the equipment supply and operations in the medium of space to generate business of many billions of pounds a year, much of it as revenue from the sale of services. Projected business levels in future years are many times that amount as the whole process takes root even further, and widens its effect worldwide.

The objective I had in mind for this meeting was to pause and take stock of where we have reached in this process, and more particularly to explore where we can, and should, be going in the future. My task in presenting this overview is to put the overall scene into focus, particularly for the non-aerospace related members of the business and industrial community, to assist those who have not so far, perhaps, been deeply involved in the subject, to see some of the linkages and relations between the many sectors of activity and the growth potential in general.

In a subject where the applications of space technology are widening dramatically, a two-day meeting is too short to give full opportunity for certain projects to be presented as separate papers, and therefore I also propose to touch upon a few such projects to ensure that a balanced overview of what is happening in this field is available.

There is of course a clear implication in the use of the word 'industrialization' that commercial benefit is involved, and that is indeed both true and desirable, bearing in mind that the economy of any country depends on the profitable operation of its industry in both the manufacturing and service sectors. The redeployment and investment of profits so earned into the continued improvement and expansion of its industries is for the good of all concerned.

In space we find two distinct categories of operations: one starting and continuing in the field of science wherein immediate commercial return is not appropriate; the other being where technology has emerged already in its application to practical uses, which involves the sale of equipment and services and results in a corresponding revenue from such operations. We are now well into this process already, and it is timely to consolidate our position and drive forward with clear vision towards the right objectives for the future.

2. Present status of evolution

Space system elements

It would seem appropriate to start by reminding ourselves just where we have reached in the evolution of practical uses of technology in space. Table 1 simply lists the full range of subject matter that we must include now in our review of this subject. This range of elements involves either the provision of the equipment itself or the sale of services via that equipment or in support of that equipment, or the first together with one of the last two. There are already

Table 1. Industrial and commercial elements in space: a list of equipment and services

- space transportation vehicles
  - reusable
  - non-reusable
- communication satellites (space segment)
  - point-to-point
    - global
    - regional
    - national
  - mobile
    - maritime
    - aeronautical
    - terrestrial
  - distribution
    - commercial
    - entertainment
    - education
  - direct broadcast
- navigation satellites
- Earth observation satellites
- ground segment (all categories above)
  - operational stations
  - telemetry, tracking and command stations
  - supporting hardware
  - supporting software
- manned space stations
  - recoverable
    - Eureca
    - Spacelab
  - fixed stations
- finance sector

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

major categories in which the business can be grouped and a variety of subdivisions, particularly in the field of communication satellites, and a widening range of activity within the ground segment of all user categories with a massive potential for expansion of business levels in the future.

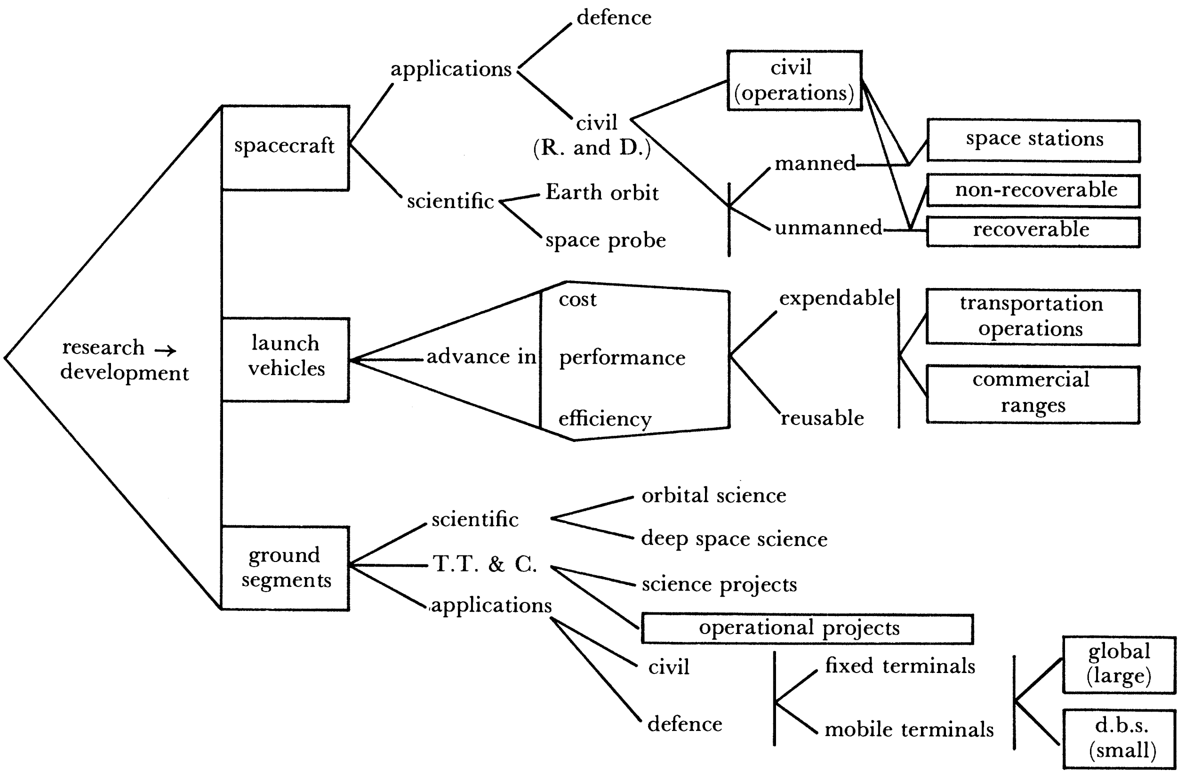

Figure 1. Evolution of space activities. Activities in rectangular boxes earn revenue.

Against the simple listing in table 1 it is appropriate to consider, in figure 1 the stages that we have already passed through in reaching the present situation. Table 2 highlights a few of the firsts in terms of technology applications and then operational systems and we come to the present when we have in place various types of global, regional and national communication satellite systems covering both terrestrial as well as maritime mobile facilities; these, of course, will be discussed in much greater depth in other papers. One or two aspects of communications satellites need, however, to be mentioned at this stage, and figure 2 shows the growth in this field; one specific point to note is that there is the curious situation of the missing *aeronautical* communication satellite systems. Starting in the early 1960s, various systems have been conceived whereby satellites would provide air-to-air and air-to-ground communication facilities, particularly over long-haul flights in difficult ocean areas, and even several calls for tender from organizations have taken place with a commensurate amount of wasted industrial effort deployed in submitting bids. So far all such attempts to launch a system have proved abortive and although at this time a modest level of effort continues in monitoring appropriate requirements and planning possible developments, it is a curious fact that as yet no such operational system exists for civil aviation activities. Of course one is aware of the arguments of the airlines

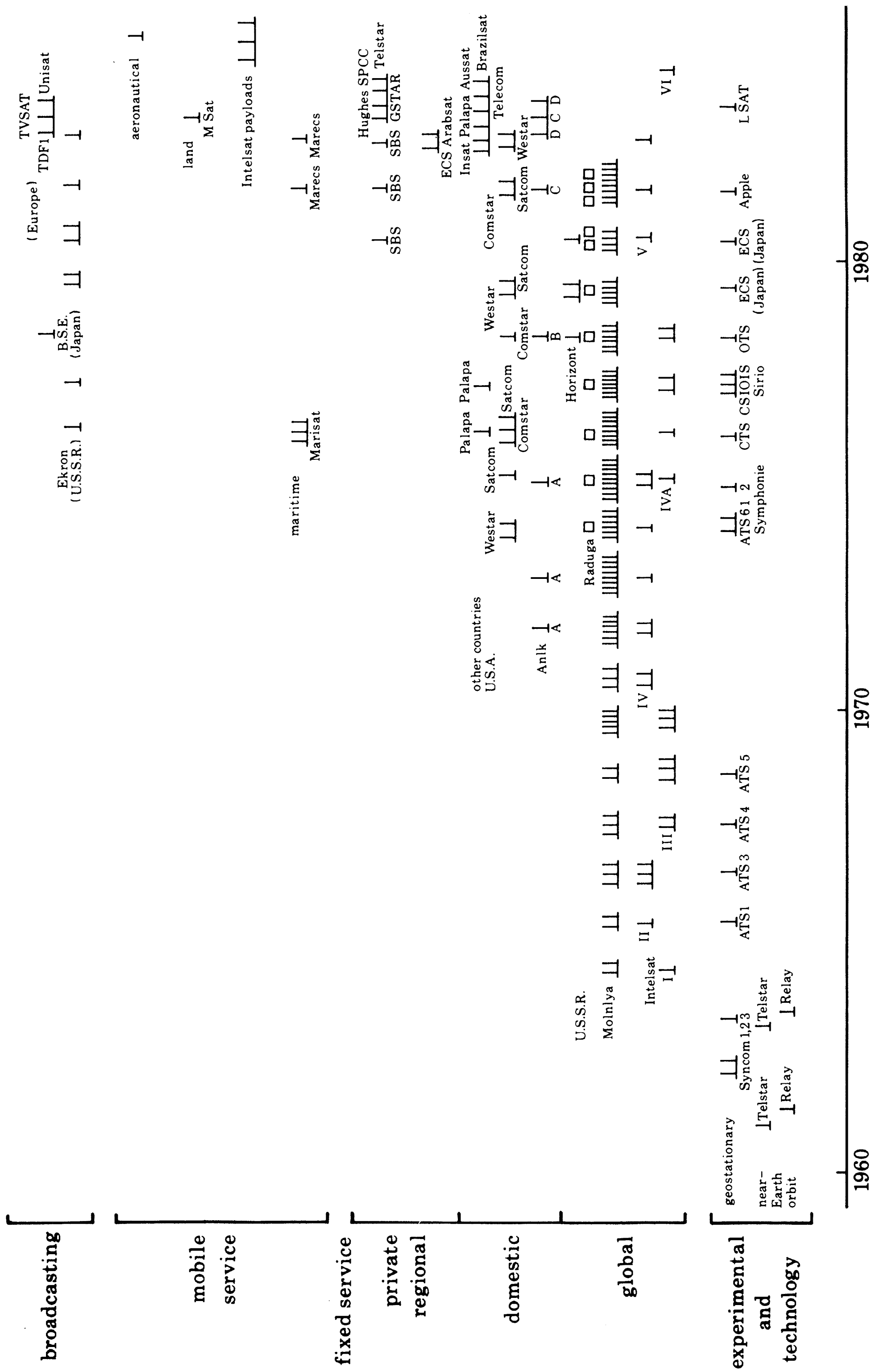

FIGURE 2. Evolution of communication satellites.

TABLE 2. THE STAGES OF INDUSTRIALIZATION

event	*year*	*project*
international operations		Space station
	1990	
commercial materials processing		materials processing factory
	1983	tracking & data relay
inter-satellite communications		Spacelab modular pallets
commercial transportation		manned laboratory
multi-role transportation (scientific, industrial and military)	1980	STS-2 second use of Shuttle STS-1 reusable orbital Shuttle
multi-purpose systems		Marisat maritime communications Skylab materials processing
consolidation		ERTS-1 Landsat images and data
space stations		MARS-2 Mars landing Salyut prototype space station
	1970	
development and exploitation of advanced technologies		Apollo II manned lunar landing
		Venera-4 Venus descent and impact
revenues and commercial operations international commercial collaboration (Intelsat formed)		Earlybird and Intelsat I
global operations		Telstar commercial sponsored communications satellite
practical applications		Discoverer-13 military reconnaissance Transit navigation satellite
technology demonstration	1960	Tiros weather satellite Courier Experimental
scientific exploration		Echo communications
	1957	Sputnik artificial satellite

and those who have been against such systems in past years, namely that the economics must be seen to be supportable and the systems really required before they are deployed. But it does seem that it can only be a matter of time before these criteria are met. It may be not too controversial to suggest that before the end of this decade, a serious and successful attempt will be made to deploy a system of satellites to provide what appears to be an interesting and useful operational service, while bearing in mind the added facility of position surveillance, which is associated with the value of such systems. The aeronautical scene is certainly one that will be watched with interest in this industrialization process.

Education through satellites

Another aspect of satellite communication not dealt with in depth by a separate paper is that concerning its educational services. The world community watched with interest the successful conduct of the SITE experiment in India with the ATS 6 satellite (and indeed the use of that satellite in other parts of the world) to explore the potential use of satellites as a system for the provision of educational services, particularly to developing countries, although with interesting applications and implications for remote areas of developed societies. The success of the SITE experiments is apparent when one now observes that 15000 to 20000 villages in India are being

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

equipped with operational read-out terminals, and plans are well in hand for many thousands more to be so equipped to bring the communities within that subcontinent into closer communication with educational services provided by the Nation.

There is a point I would like to make arising out of a paper I prepared some years ago on the subject of operational educational systems in such countries; one of the interesting conclusions from that work was the importance, and indeed the difficulty, of maintaining and servicing a widely distributed system of ground stations in such circumstances. The problem, which is already significant and difficult with several *tens* of thousands of stations in a developing country, becomes quite acute when a system may incorporate a *hundred thousand* or more terminals. Bearing in mind that the eligible number of villages in India that *could* well use such educational facilities is some 520000, then the subject is worthy of careful consideration. The problem arises not only in the careful specification and design of the ground equipment to operate for as long a period as possible between *regular* maintenance and servicing, but also in the very large numbers of qualified engineers and the associated logistic problems and costs involved not only with this routine maintenance but by the taskforce availability to service the stations that fail at some intermediate time *between* routine visits. This is a separate subject in its own right, but I mention it here because of two aspects. The first is the interesting implications between such dedicated system ground elements and the presence or absence of the domestic service infrastructure, which is firmly in place in developed countries because of the domestic requirements for entertainment or household activities involving electrical or electronic equipment. The second point is the very substantial marketplace for ground equipment, much of which can, and should, be met by local industry; the ground equipment in a typical fully operational system for a country accounts for some 80 to 85 % of the total system value.

Mobile systems

The mobile communication operations on land, such as the Canadian initiative with M-Sat (or Mobile Satellite), are worthy of note. They form an activity that, it would seem, is attracting increasing commercial interest at this time and provides yet another diversity of equipment and revenue-earning opportunity, which must be seen in a healthy context in relation to this whole industrial sector. The other aspects of communication satellites will be dealt with in separate papers.

Navigation satellites

The navigation satellite system is one that has seen considerable success so far and a widening marketplace for both terrestrial and ship based equipment; again to be dealt with comprehensively in other pages.

Earth observation

Earth observation activity is something that I would certainly wish to emphasize in this paper; we shall of course be hearing later of the important work that has opened the way to so much industrial opportunity in both the Earth and space segments and the fascination that emerges from the realization that many users in the world of the information derived from remote-sensing platforms in space, do not as yet realize they are potential users, particularly in developing countries. Table 3 shows simply the main categories of uses. Users divide into two main categories, namely commercial and non-commercial with defence. The situation of users is a problem that faces the world community at present, since the fragmentation and

TABLE 3. USE SECTORS

use sector	state: natural	state: man made
atmosphere	meteorological	pollution
land	resource	land use
	cartography	
	disaster	
water (inland)	resource	pollution
	disaster	irrigation
water (ocean)	resource	pollution
	disaster	(coastal)

remoteness of this marketplace is certainly one of the factors that has led to the slowness so far in the expansion of the commercial uses of this important application of space technology. While in no way wishing to pre-empt the material in other, more detailed papers, I would just mention (to keep the subject in balance) that one observes with interest, certain countries in Europe on the other side of the Iron Curtain (such as Hungary, the scene of the International Astronautical Federation Congress this year), where excellent work is also being done in the use of satellite remotely sensed imagery in relation to aspects of the country's developments.

The other feature to be mentioned is that developing countries are showing a degree of attention to the organizational problems as typified by the creation of the African Remote Sensing Council. We clearly have a long way to go in the expansion of the operational use of Earth observation systems. We must recognize, however, the large humanitarian sector of users, together with the more direct sector of commercial operation: the latter, however, must, by the end of the century, be one of the major areas to be affected by the industrialization of space.

Meteorology

There is no specific paper on meteorological satellite activities elsewhere in this meeting, not in any way owing to its lack of importance, but owing more to the fact that the services have been, and must inevitably continue, to be mainly provided by international or national official organizations. The World Meteorological Organizations, The United Nations, and the various National Meteorological Services (of which that of the United Kingdom has been one of the most active and successful) have created a network of Earth observation communication, interrogation read-out and dissemination systems for meteorological purposes, which have advanced, to a very significant degree, the knowledge of the world's weather and its ability to be forecasted. While the instrinsic value of the information obtained by meteorological satellites is immense in *equivalent* financial terms, it is difficult to see how other than a small amount may emerge (at least in the near future) in terms of directly saleable commercial revenue. It is, however, appropriate to underline the immense importance of this field of application and its close relation to the whole-Earth observation activities that we deal with elsewhere in the meeting.

Space transportation and space stations

The process of injecting our satellites into orbit and, more recently, the process of recovering them, emphasizes that *commercial* transportation in space is indeed with us. It is interesting to note that the U.S. Government has recently named that U.S. Transportation Department as the leading licensing agency for expendable launch vehicles; 'America's newest transportation industry' as Secretary Dole referred to it. Other Government Departments will be involved with labour, safety, marketing and export controls. It is also interesting to note the reference to the development of commercial launch ranges in this respect.

We shall be hearing more in this meeting about the use of reuseable vehicles as well as non-reuseable ones, but it is to be noted that there are groups in the United States and in Europe actively pursuing novel and (they claim) inexpensive methods of providing launch services for satellites by new expendable vehicles. In more orthodox ways, other countries, such as India and China, are developing their own launch vehicles with varying degrees of assistance in the early days from other countries: Japan of course has its family of vehicles that were initially built under license from the United States, but encompassing more home-based technology as time progresses. We must note the reports of reuseable vehicles now being developed in the U.S.S.R. and reports of countries in the Western World taking an interest in the later provision of reuseable or recoverable services in this respect. The subject of space transportation is indeed one of considerable commercial opportunity.

Other papers will discuss developments in space stations; these will highlight the important opportunities of *using* the environment of a space station, and its microgravity field in particular, to great advantage in material processing. It would be hoped that a meeting such as this, held in a few years time, would be able to include separate papers of actual commercial experience, such as the electrophoretic separation work, which appears to be so well ahead as a result of commercial initiatives being taken in the United States already. This work should be watched with great care, and surely any country with industrial interests that may be assisted by the use of a space station environment should be addressing diligently and urgently the question of how to ensure the accessibility of its industries to those facilities in the next few years as we move from feasibility and early development through to prototype operations and finally to actual operational processing capabilities. The commercial use of space stations is a subject little addressed in certain countries so far and yet one that shows signs of immense importance in the future.

Other industrial opportunities, such as the proposals for the LEASECRAFT concept, Spacelab, SPAS, and so on, wherein a satellite platform would be available for leasing to customers to plan their own experiments, alerts the community to the wide scope for commercial initiatives in the space environment.

Long-term developments

Now to consider further into the future. It does not seem appropriate to discuss solar power stations in orbit at this meeting, but this will certainly be covered within the more general large space platforms discussed in Mr Franklin's paper. The momentum that has been built up, modest as it has been in recent years towards this concept, has been steadied by the confusion emerging from the contemporary variations with a downward trend in fossil fuel prices; it would seem that some time has yet to elapse before the world may see whether or not there will continue to be a foreseeable trend regarding the cost and availability of hydrocarbon and nuclear energy sources. Clearly, from work done, the concept of space station energy production on a large scale in the next century is there to be considered more carefully.

These and other aspects of the future will ensure that the space community is never lacking for medium and long-term projects of interest, which move towards commercialization as time elapses.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

3. Examples of a few projects not covered elsewhere in this symposium

Spacelab

As explained already, one or two projects would seem to be worthy of particular note although not the subject of main papers. The first of these is Spacelab, which represents a highly successful European project within the responsibility of E.S.A. led substantially by German industry with varied levels of support from other countries within the European space arena. There was some difficulty in scheduling this meeting, to know whether Spacelab would or would not have flown by the time it was held and I am pleased to say that we now know that it has done so, and done so very well.

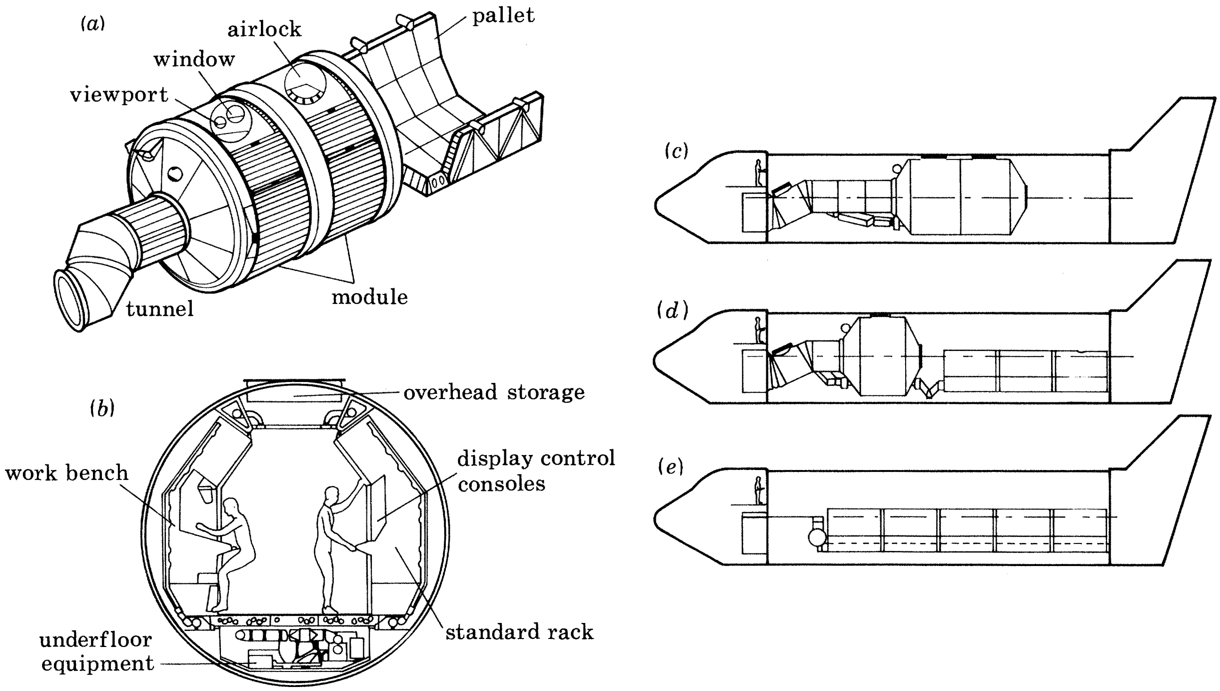

Figure 3. Spacelab: (*a*) overall configuration; (*b*) cross section; (*c*)–(*e*) typical Spacelab flight configurations in Orbiter cargo bay, (*c*) large module, (*d*) small module with pallet, (*e*) pallet only.

Figure 3 shows the Spacelab configuration with its flexibility to accommodate variable lengths of pressurized sections to house astronauts for various purposes in exchange for commensurate lengths of the unpressurized pallet to support various other experiments. Figure 4 shows the configuration used in the recent Shuttle flight and figure 5 shows Spacelab ready for installation within the payload bay of the Shuttle vehicle before launch. Figure 6 shows Spacelab's overall configuration. Figure 7 is a view inside the Spacelab with technician specialists at work on their equipment and consoles.

Spacelab represents an exciting and important contribution by Europe to the space inventory of equipment; it provides up to nine days of space station activity in its tethered role within the Shuttle payload bay before its return to Earth. Spacelab represents an important commercial opportunity for experimenters to sponsor a wide range of work that can be accommodated on a

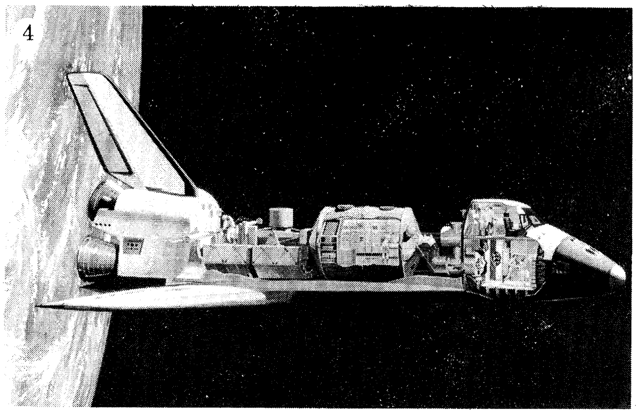

FIGURE 4. Spacelab configuration in Shuttle STS-9.

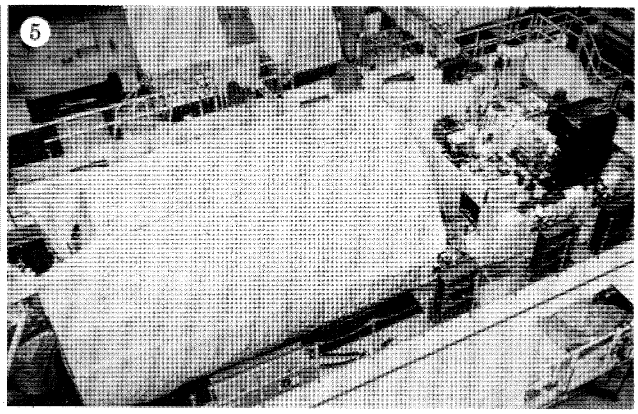

FIGURE 5. Spacelab ready for installation.

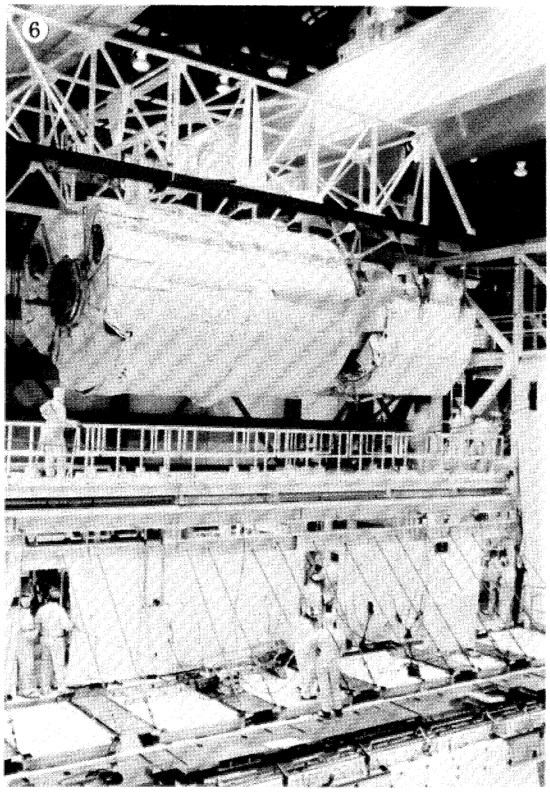

FIGURE 6. Spacelab overall configuration.

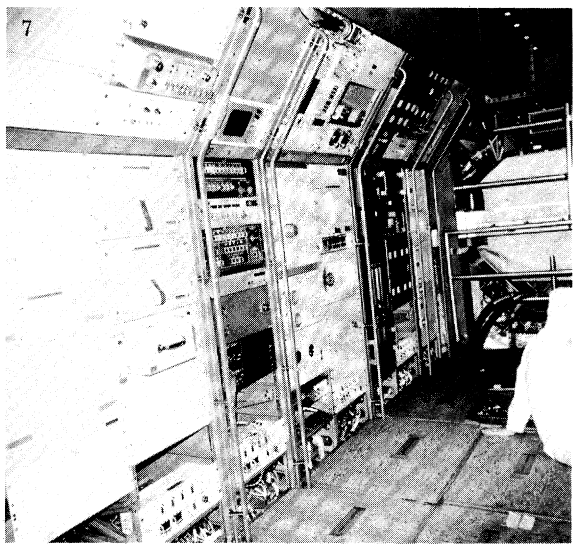

FIGURE 7. Internal view of pressurized section of Spacelab.

commercial basis and flown accordingly. A second Spacelab has been ordered by N.A.S.A. in addition to the European one that has just flown, and as such Europe is clearly making a major contribution to manned space work. This experience is most important in providing Europe with first hand awareness of the opportunities and implications of becoming involved in the N.A.S.A.-led space station planning currently underway for the next decade.

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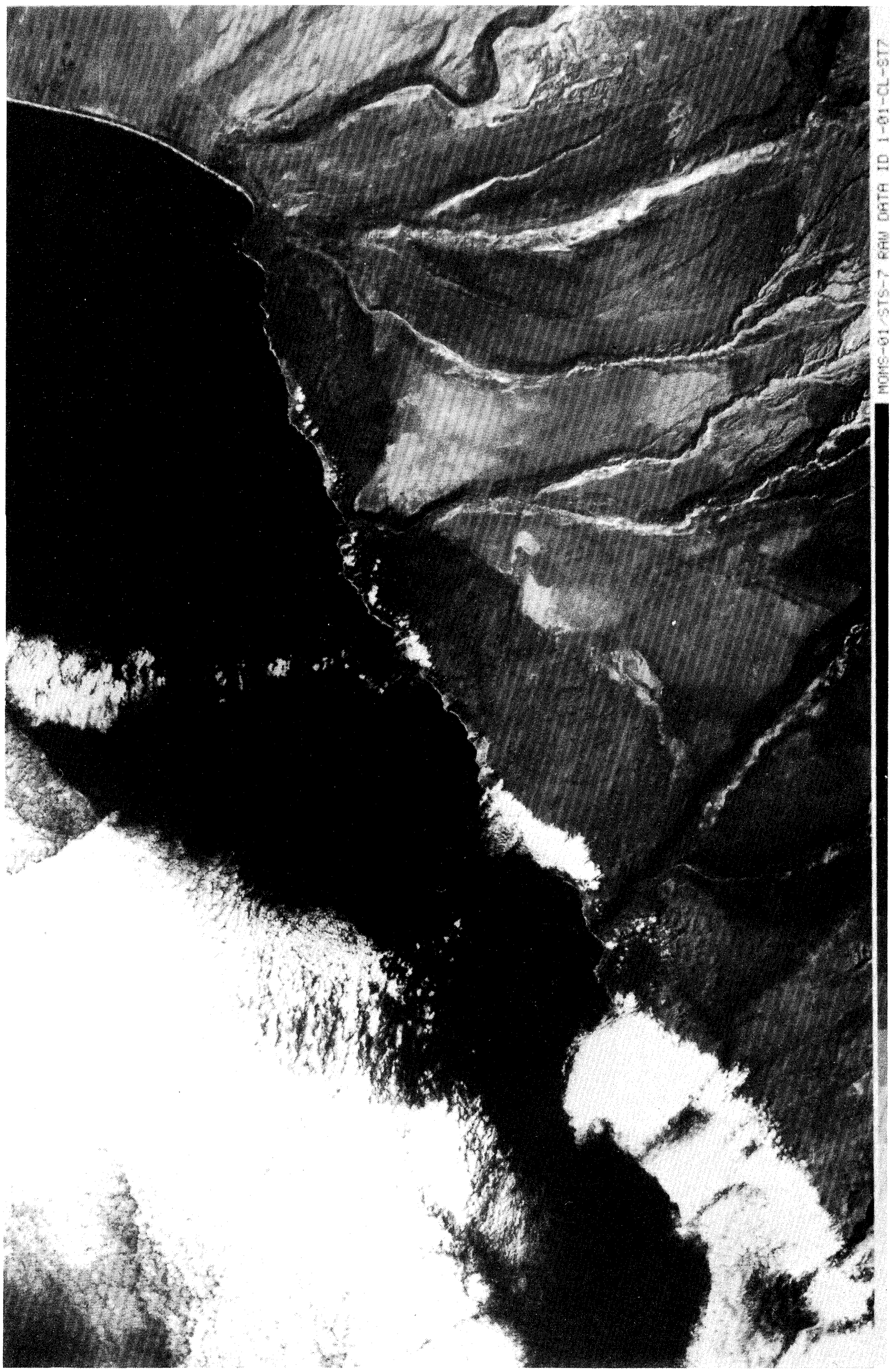

FIGURE 12. SPAS–MOMS imagery. This is the very first MOMS-1 picture (raw data). It shows the coast of Chile near Africa with the Andes. It is a full-scale picture (138 km × 94 km) with approximately 4720 scan lines with 6912 pixels each. It was imaged during the STS-7 mission on 20 June 1983; the Sun elevation angle was 40.5°. (Data pre-processing and image processing by M.B.B. and R. Haydn (University of Munich).)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A MATHEMATICAL, PHYSICAL & ENGINEERING SCIENCES

Eureca

A further European initiative of importance is the Eureca project and figure 8 shows the general system as planned. Eureca is of course an unmanned spacecraft that will be taken up either in the Shuttle or in a recoverable launch vehicle and injected into orbit, where it will operate untended for long periods. At that time it is capable of being recovered by a

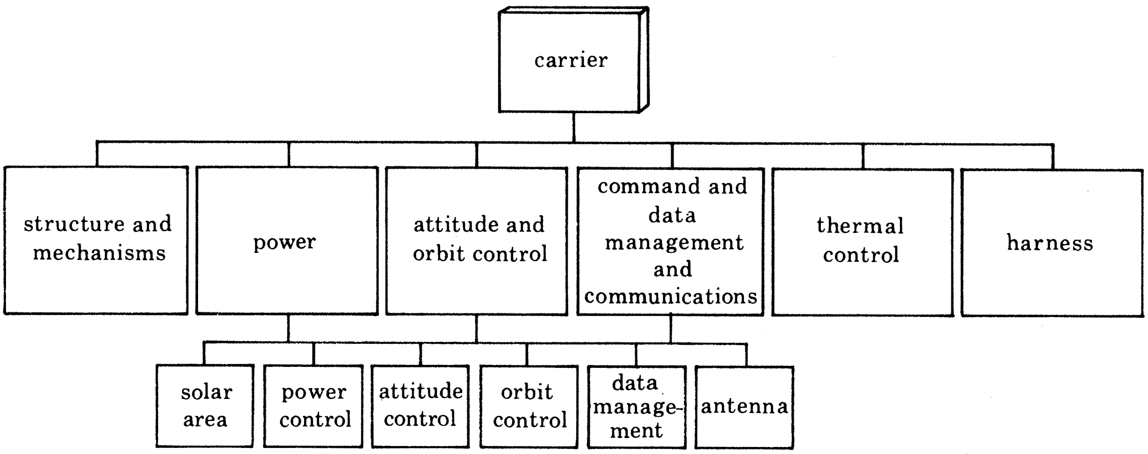

Figure 8. Eureca project. Necessary subsystems (middle row) and facilities (bottom row) to operate the retrievable platform and the experiments are shown.

Shuttle and either serviced in orbit or modified with new elements, or brought back to Earth for processing and modification before re-use in a similar mission subsequently. Eureca therefore represents a further important initiative by the European space community. As an E.S.A. programme supported by various E.S.A. countries, again it will be providing immensely important operational opportunity to experimenters from all over the world. It is important that these projects be widely publicized and understood since, although they have been borne of early experimental need, the operational capabilities are significant and it is never too early to move into pre-operational activity.

SPAS

The next project of considerable interest is the initiative taken by M.B.B. in Germany with the development of the SPAS system. SPAS was flown successfully in the STS-7 Shuttle flight of September 1983, and figure 9 shows SPAS within the laypoad bay of the Shuttle in orbit. Figure 10 shows SPAS after it had been taken out of the payload bay by the remote manoeuvring system of the Shuttle, and deployed in orbit. It was moved away from the Shuttle some distance by the self-contained propulsion unit on-board, and in fact took the first photograph of the Shuttle taken from a separate spacecraft close by in orbit, before the SPAS rendezvous and docking with the Shuttle and being recovered by the RMS and relocated in the payload bay before being brought back to Earth.

SPAS contains a variety of interesting equipment as indicated by (figure 11). I would like to point out the MOMS system in particular, which is a self-contained Earth observation package that was used with great success during the STS-7 mission to provide imagery of specific places on Earth, scheduled beneath its flight path, of which figure 12, plate 1, is an example. This

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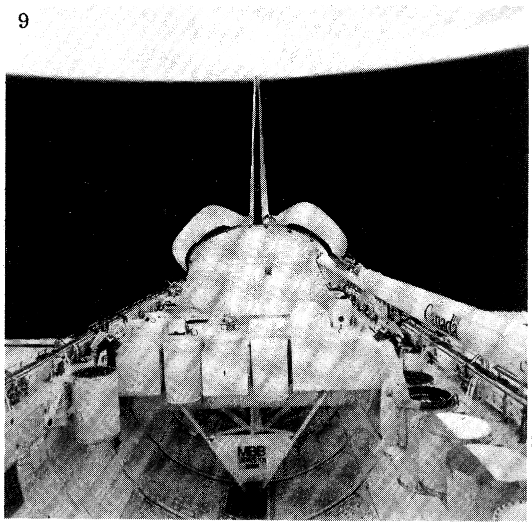

FIGURE 9. SPAS in shuttle bay.

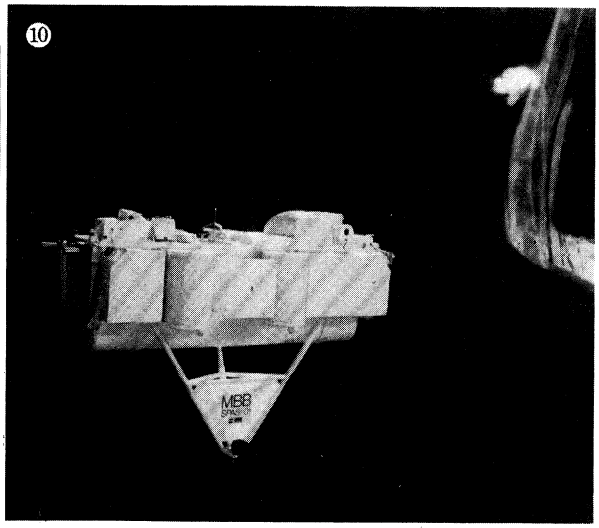

FIGURE 10. SPAS free flying in orbit near Shuttle.

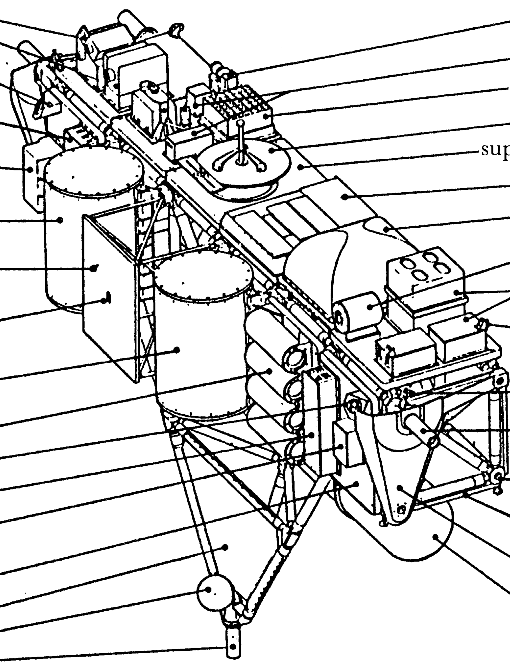

FIGURE 11. SPAS configuration. (By courtesy of Messerschmitt–Bölkow–Blohm G.m.b.H.)

has been provided by totally electronic means and is imagery to a spatial resolution of 20 m, which is a significant advance on Landsat imagery obtained to date. SPAS–MOMS represents an important operational facility for the future, bearing in mind that an area of observation can be scheduled by commercial contract with the owners of the MOMS system, for a Shuttle flight that may be scheduled with minimum notice because so little (1 m length) of the payload bay of the Shuttle is taken up by the SPAS package, as demonstrated by figure 13. It clearly has the flexibility to be fitted into small sections of the payload bay and is a good indicator and hint for all spacecraft designers of the future who might be interested in having their equipment carried in the Shuttle; namely that a narrow, easily accommodated package is likely to get an earlier flight date than a large cumbersome package taking up more of the payload bay, and will certainly cost less (table 4).

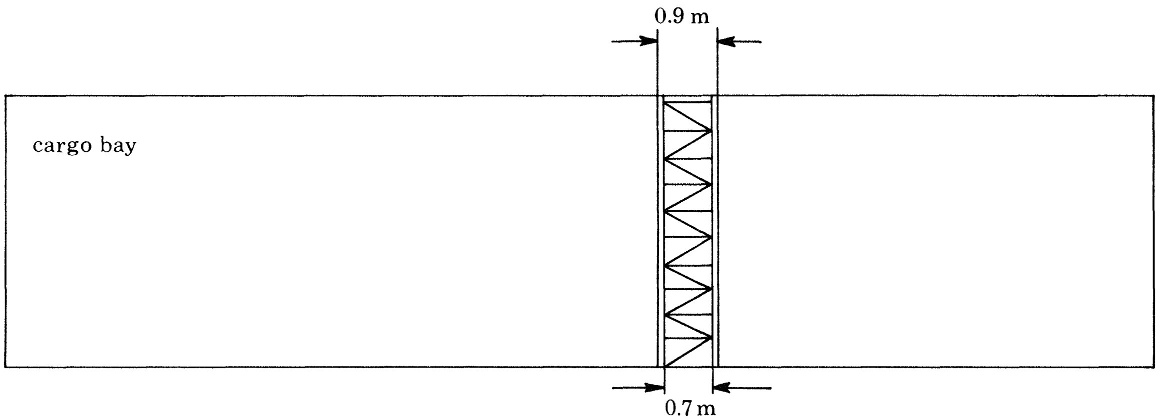

FIGURE 13. To show size of SPAS relative to Shuttle payload bay.

TABLE 4. SPAS LAUNCH COST

	cost: millions of U.S. dollars
N.A.S.A. nominal shuttle launch cost (1982 value for launches in 1986 and 1987)	70.6
launch cost by N.A.S.A. volumetric charging scheme (for one SPAS element)	$\frac{70.6 \times 0.9}{0.75 \times 18} = 4.7$
	mass/kg
mass share covered	$\frac{4.7}{70.6} \times 29.7 \times 0.75 = 1480$ (max.)
deduction for structure and payload and subsystems support panels	250
remainder for payload and subsystems and support equipment	1285

The SPAS–MOMS initiative is to be commended and clearly opens the way for initiatives in commercial terms that do not necessarily require levels of expenditure hitherto associated with dedicated flights.

These are a few examples that are indicative of commercial opportunities at present.

4. THE ORGANIZATION OF SPACE

A word now on the important question of how we organize space activity in relation to the industrialization process. Events so far have led to organizations such as N.A.S.A. in the United States, E.S.A. in Europe, and others, as shown in table 5, which also shows some of the procurement agencies in the countries concerned. These Agencies have, with the use of public funds, initiated research and technological applications leading to the design and development of first generations of application satellites. It would seem eminently sensible, and indeed difficult to imagine any other way that such processes could have emerged, bearing in mind the

Table 5. Organizations

region or country	*space agency*	*relevant procurement organizations*
international and regional	E.S.A.	N.A.T.O. N.I.C.S. Intelsat Intersputnik Inmarsat Eutelsat A.S.C.O. (Arabsat)
Argentine		A.D.C.S.S
Australia		Aussat
Austria	A.S.A.	
Brazil	I.N.P.E.	S.B.T.S.–Embratel
Canada		Dept of Commun. Telesat Canada
China (P.R.)		
France	C.N.E.S.	C.N.E.T.–C.N.R.S.
Germany	D.F.V.L.R.	Bundespost
India	I.S.R.O.	
Indonesia	L.A.P.A.N.	Perumtel
Italy		C.R.A.–C.N.R.
Japan	N.A.S.D.A. I.S.A.S.	
Netherlands	N.I.V.R.	
Sweden		S.S.C.
United Kingdom		D.T.I. M.O.D. S.E.R.C. United Satellites
United States	N.A.S.A. D.O.D.–D.C.A.	N.O.A.A. Comsat General A.T.&T. Hughes Galaxy R.C.A.-Satcom S.B.S. U.S. Sat. Systems Western Union and others

high capital cost of R. and D. in this particular field. The pattern that is now emerging, however, is that with Government having supported the early R. and D., the industrial sector is then able to identify the commercial opportunities of different elements and assess both investment levels and associated commercial risk involved in picking up such work and deploying it in a normal commercial environment. This is clearly happening successfully in the United States and in Europe with communication satellites of different sorts, and we have had the emergence of Intelsat in the 1960s followed by Inmarsat, in the late 1970s, helping the maritime users. There is now a proliferation in the United States of commercial companies that are privately owned, with different interests in the space communication services field. Such interests have ranged from the provision of total services and the procurement and launch of dedicated satellites for data transmission for entertainment purposes, right through to a large number of companies dealing with specific sectors such as software elements within the total spectrum of industrial opportunity. Naturally the United States, with its predominantly commercial approach to communications, has had a major start on the rest of the world in industrial experience of the problems and opportunities created by such a free market.

The European scene has moved far more slowly I regret, but in recent years the P.T.Ts of Europe have brought the Interim Eutelsat into being, which is now successfully operating its first generation European communications satellite systems for the provision of various services within the Continent of Europe and to surrounding areas. Other regional systems have emerged such as the Arabsat system currently under development, but there are interesting and important examples of national initiatives already, such as that in Indonesia, where for some years. now the national Palapa domestic communications satellite has been in successful operation To date, 132 ground stations have been deployed in the many provinces in Indonesia within the 3200 mile wide archipelago of 13677 islands, and there clearly exists a massive opportunity in that country for further development of such systems. It is the most creditable demonstration of a developing country using advanced technology to assist in its economic evolution and indeed Indonesia is one example of a country with a strong and professional grasp on the appropriate uses of advanced technology for national development purposes. Similar initiatives are evident within India, which has been mentioned before in relation to education satellites and again a national organization, I.S.R.O., has been set up to look after much of the space work.

It is not appropriate or necessary to catalogue all the various organizations that exist at this time in various countries, but the ones mentioned so far have been so referred to in order to make the point that the process of industrialization is fundamentally aided by governments looking ahead and taking initiatives with public funding in the *early* stimulation and application of scientific and technical endeavour, and then a carefully phased hand-over (or at least joint involvement) to industry as appropriate events dictate. What *is* essential is to provide an adequate opportunity for industry – if it so wishes to invest in space – *to gain access to revenue*, because unless a fair and reasonable coupling is provided, clearly industry cannot be expected to invest without methods becoming available to service its investment in the interest of its shareholders. This lack of willingness of earlier U.K. Government Administrations to allow access to operational revenue within the U.K. has certainly been one of the major inhibiting features of industrial investments in the early 1960s when private initiatives were being sought for this commercial use of space communications facilities.

It must be said, however, that the counterpart is also important to note, namely, that countries where high levels of Government expenditure have been evident in the first few years of the technology development process run the risk that industry becomes used to any easy, captive marketplace and instead of the public funds being used to seed and stimulate a normal independent industrial development, it can be looked at by industry to be a market *in its own right* and consequently weak and ineffectual international marketing and planning takes place in industry; such attitudes do not well equip such industries with experience to address the open competitive markets of the world. It is essential that industry moves in its own right at an early date, otherwise it may enjoy for a limited period the easy government generated levels of business, but these *must* be at risk in the finite length of time that these subsidized projects can be allowed to continue. Unless a lean, hungry and competitive industry has emerged from the early years, it will not penetrate the world markets, compared with those countries that have experienced a tougher and rougher entry into the world marketplace. A quick examination of the non-aligned and third world contracts placed for the systems for communication satellites, for example, which are in place or under development at this time, reveals that the main success has come from companies in the United States, Canada and France.

The final point I wish to make on this question of the organization of space industry is the need for careful planning to identify both the opportunities as well as the problems. Such planning must be made effectively by both governments and by the industries concerned, as well as that available from independent consultants, because unless the most imaginative and well founded programmes are initiated, the projects eminating from them will be more at risk than others that have not been well thought through.

5. International cooperation

Of course the nature of space, both in its size and scope, lends itself to international cooperation and much has taken place already. This has often been between companies and between collaborating agencies of different countries; perhaps the most visible and formal cooperation arrangements have been made within Europe. Of necessity, international European consortia have emerged to bring the technical expertise into a common team and also to assist in the allocation, with some reasonable logic, of contributed public funds of each country back into the industries of those countries. This led to the three main spacecraft consortia in Europe emerging in the 1960s and operating throughout the 1970s, although in recent years some of the national mergers and changes in industry have, of necessity, blurred the shape of the membership of the consortia and so at this time perhaps more *ad hoc* groupings have become apparent in addressing European and world markets.

Space station

Looking to the future, the question of international industrial collaboration is very essential when considering projects such as the space station. Looking back to the post-Apollo era and the extensive studies, discussions and negotiations, on what part Europe might play in that programme, I remember well how frustrating and difficult it was to get agreement on what part Europe would play in that work. Spacelab emerged from those considerations – but not without a considerable amount of wasted effort – going through the possibility that the Tug might be the European contribution and indeed looking into possible collaboration in the Shuttle itself. So looking ahead now to the space station, a degree of realism is essential as to what parts *might* sensibly be eligible for international participation; in looking at this it should not (I suggest) be assumed that access to a space station facility will necessarily be related precisely to whatever funds other countries or continents may make available for space station *equipment* that may be *supplied* from those sources. Several countries have a possible interest in collaboration with the United States and the space station and these so far include Canada, Japan, and Europe. It can be seen that careful thought is necessary to explore just how all of these interests might come together amicably and effectively to lead to good operational facilities in the 1990s.

The nature of the space station is such that it would seem eminently sensible that international cooperation *does* take place and it would appear to be the intention of the United States at this time to encourage it. It behoves the other countries therefore, to look carefully to the opportunities and implications of such cooperation and to move firmly and in a timely manner to secure an appropriate position in this respect. The ultimate factor of course, is the level of user interest. and who will wish to pay for time in these various space station facilities. It is important that potential collaborating countries, companies, and indeed *all* possible users, address this matter as carefully as possible at this time. We are talking, of course, of operational use many years away in the future and much further development and thought about the best way to use the space environment can, and will, emerge in that time.

I would not wish to limit these few words on cooperation simply to space stations, so I note also the benefits in the world marketplace of appropriate industrial teaming to bid for various markets, and note that it would seem that an important criteria will be getting the balance right between long-term commitments with various partners while having flexibility to change teaming arrangements as further needs emerge in other parts of the world.

Developing countries

A particular comment needs to be addressed to the question of developing countries, which represent a very important marketplace in the future for the technologies and equipment, software and expertise in general supplied by the *developed* countries. I would suggest, however, it is essential not to think of this as one-way traffic where developing countries are buying and remaining completely dependent on developed countries, but rather a two-way business where, of course, initial critical parts of systems, particularly in the space segment, will be provided by developed countries. But increasingly the *developing* country's industries will take part in the ground segment and thus permeate steadily but surely into responsibility for the provision of, and operation of, major parts of the system. Bearing in mind the remarks earlier concerning the high percentage of total system values associated with the ground segment, there is scope for all in meeting the operational requirements of the future in the developing countries. The work with which I am involved in Africa and elsewhere at this time, underlines fully the importance of good collaborative arrangements with local experts and local industries as well as the governments, to secure sensible and successful programmes for the future.

6. Financial implications

The 'bottom line' of any development programme of course is the question of funding. As I have just discussed, the nature of space as it has evolved has led to a very significant deployment of public funds in the early years, but with a progressive transient take-up by the private sector. Major opportunity therefore exists for the finance houses at all stages of the work, which ranges now through the space transportation processes, the deployment of satellites themselves, and certainly the provision of the ground segment; and this is why we should study carefully the paper by Mr MacArthur on this finance sector.

A point of great importance is the relation between technology and finance in space projects; without the right approach to funding sources by industry, no commercial project will succeed. Without an ability by the finance sector to appreciate the nature of technical opportunity, and risk, associated with the advanced technology of space, projects will not be successful. The interface is vital and operational procurement organizations, such as Eutelsat and Inmarsat, clearly have a great need to recognize this interaction: for example, in the preparation of appropriate cost models showing the parametric variation to be expected due to technical change, the degree of sensitivity of costs to specification or performance alterations, etc. Without wishing to over emphasize the point, these complex relations demonstrate the breadth of disciplines necessary in the industrialization process.

I also wish to emphasize the importance and opportunity in the insurance aspects of equipment particularly related to the space sector. Large projects are involved and correspondingly large sums of money and insurance cover of several hundreds of millions of dollars attracts serious and professional thinking and planning in the determination of premium levels as well as the payment of the insurance cover in the event of any regrettable failure! We have seen evidence of all of these aspects in recent years, and as a consultant concerned with assisting banks and insurance companies in both the planning, as well as the subsequent failure mode assessment of such systems, I am certainly in a position to underline the importance of recognizing the role of finance and its relation with technology in this whole space field. We are, of course, now acquiring an increasing amount of statistical data with regard to launches and satellite performance functions, but the complexity is also increasing, and so the question of insurance is a small but vital expanding sector of the whole process of commercialization and industrialization.

7. Concluding remarks

We are already well into the process of the industrialization of space and serious and extensive commercial activities are widely underway in all parts of the world. Space is big business and will continue to be so. Levels of space business are currently measured in several billions of pounds per annum and when one combines the opportunities of *supply* of the equipment as well as the *sale* of services, then we are looking at many tens of billions of pounds of business available to the industries of the world even within the rest of this decade. It is therefore not only exciting and dramatic, but a most serious business sector; and yet it is still considered by many of the non-aerospace or electronics fields of activity as something apart, not to be taken too seriously. I refer, among other things to the implications within the wider use of Earth observation data and also to the users of space stations. Experience has shown that not only is an intense and active campaign necessary to ensure awareness of the opportunities in different sectors of industry outside of aerospace, but there is a great necessity to *follow through* very extensively to consolidate such early interests that may have been seeded, and to assist and advise many companies of how best to take up an undoubtedly interesting and opportune role in this field. We must get the market pull lined up properly as well as the technology push, which is generally very apparent!

This is extremely important in the non-aerospace industries where potentially beneficial developments exist; an example is the pharmaceutical sector, in relation to which I have a list itemizing over 20 selected pharmaceuticals *each* of which sells for over $1 billion per kilogram (the highest is $20 billion per kilogram) and these are being actively considered as candidates for space environment processing, with all the benefits of higher purity and higher yield than can be achieved in Earthbound facilities. When such benefits are seriously in prospect, no one can afford to be superficial in assessing the possible industrial implications.

I hope that these few remarks have therefore set the scene for the rest of the meeting, which will cover key areas in more detail. For my part, I am delighted that so many people have come together at this time to take stock of the current situation and to address the exciting opportunities of the industrialization of space in the future.

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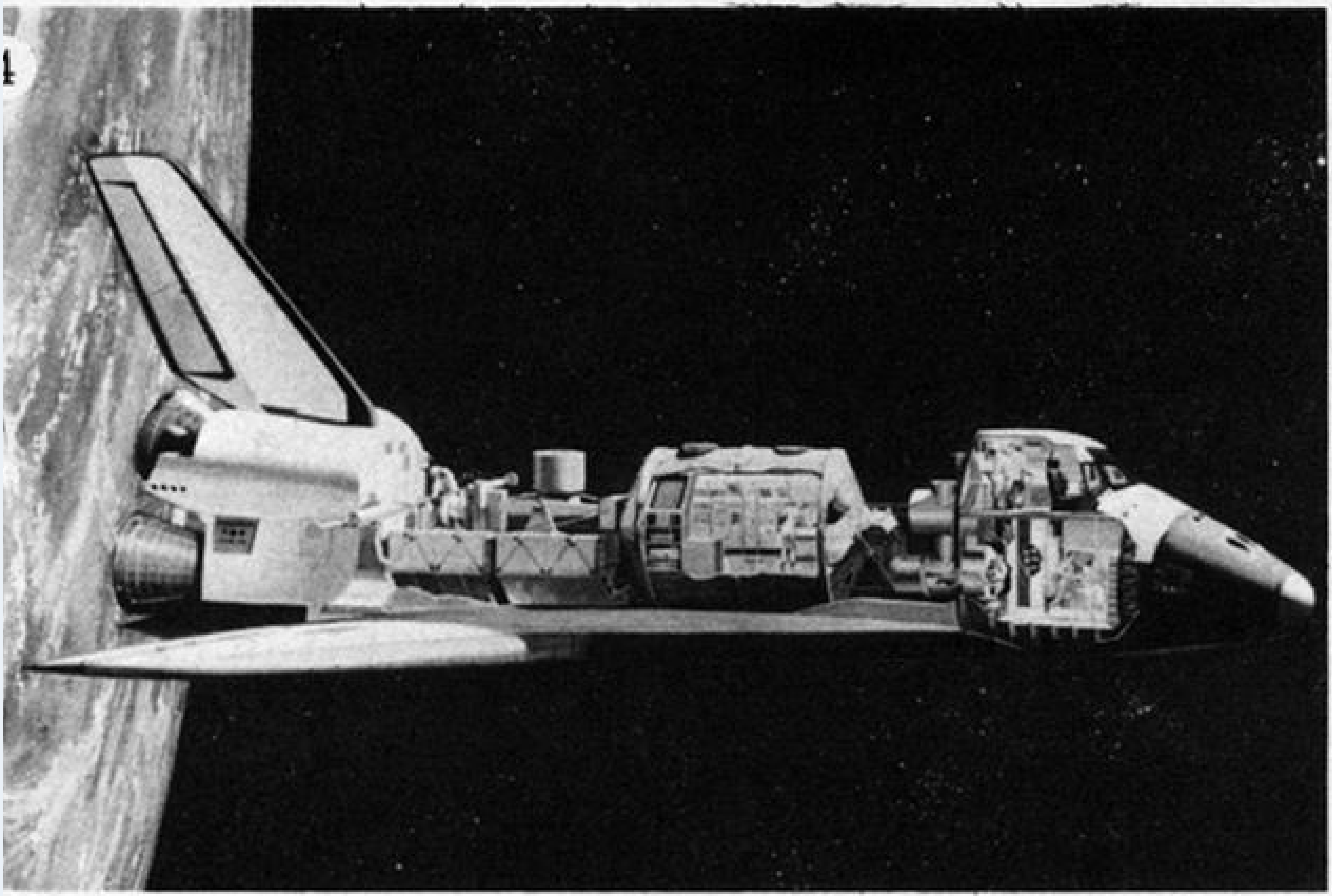

FIGURE 4. Spacelab configuration in Shuttle STS-9.

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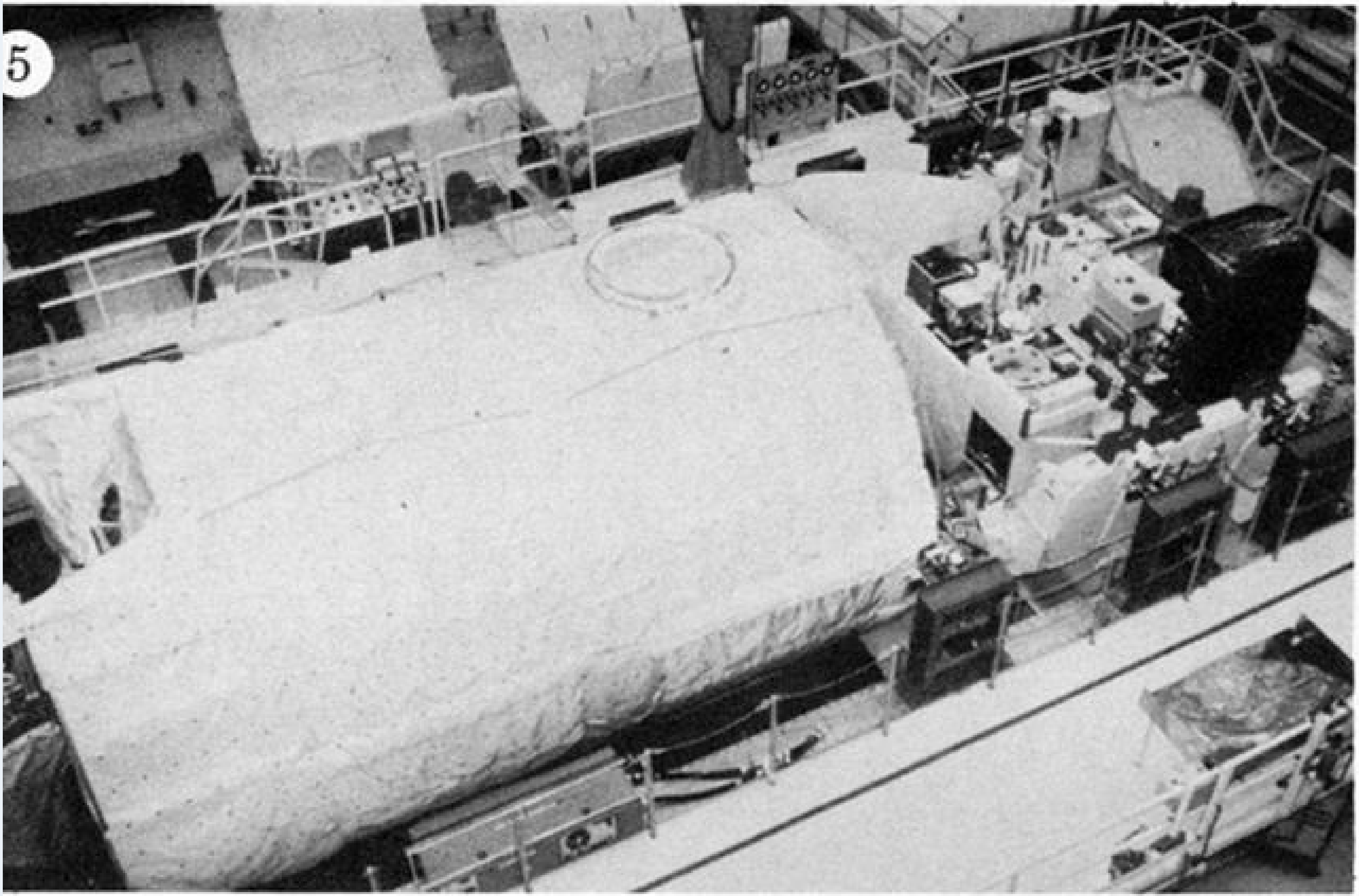

FIGURE 5. Spacelab ready for installation.

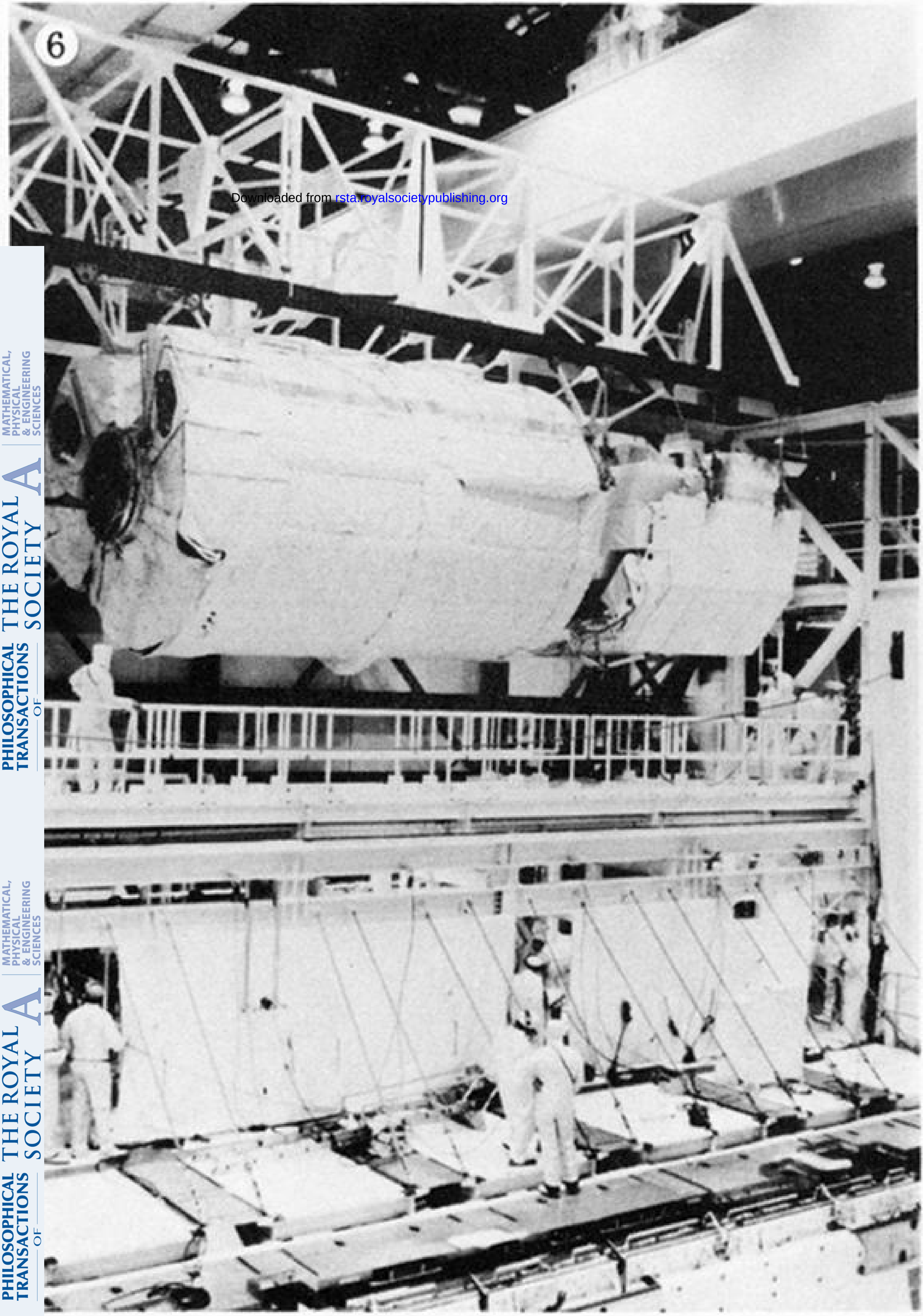

FIGURE 6. Spacelab overall configuration.

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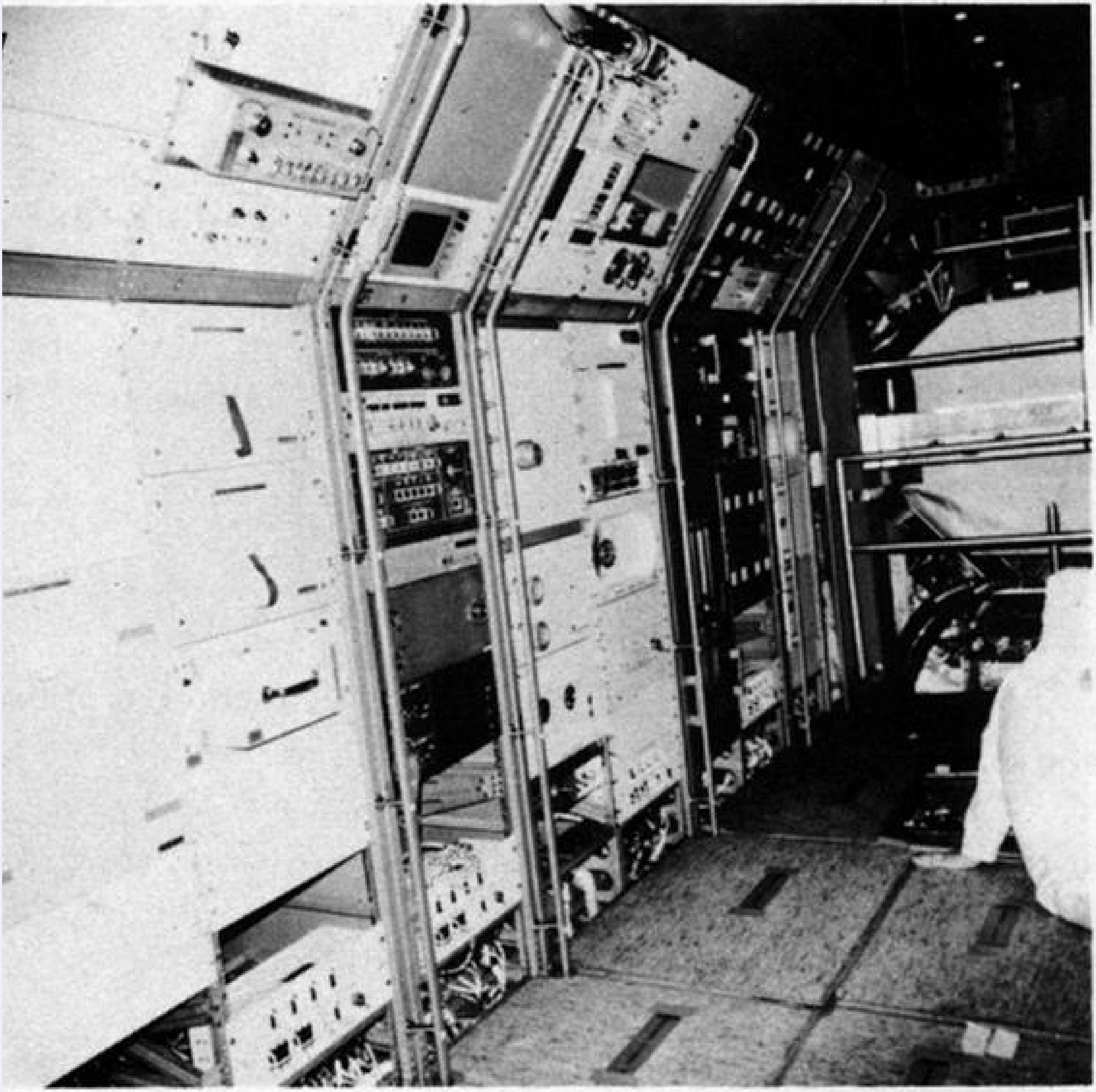

Figure 7. Internal view of pressurized section of Spacelab.

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THE ROYAL SOCIETY A
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FIGURE 12. SPAS–MOMS imagery. This is the very first MOMS-1 picture (raw data). It shows the coast of Chile near Africa with the Andes. It is a full-scale picture (138 km × 94 km) with approximately 4720 scan lines with 6912 pixels each. It was imaged during the STS-7 mission on 20 June 1983; the Sun elevation angle was 40.5°. (Data pre-processing and image processing by M.B.B. and R. Haydn (University of Munich).)

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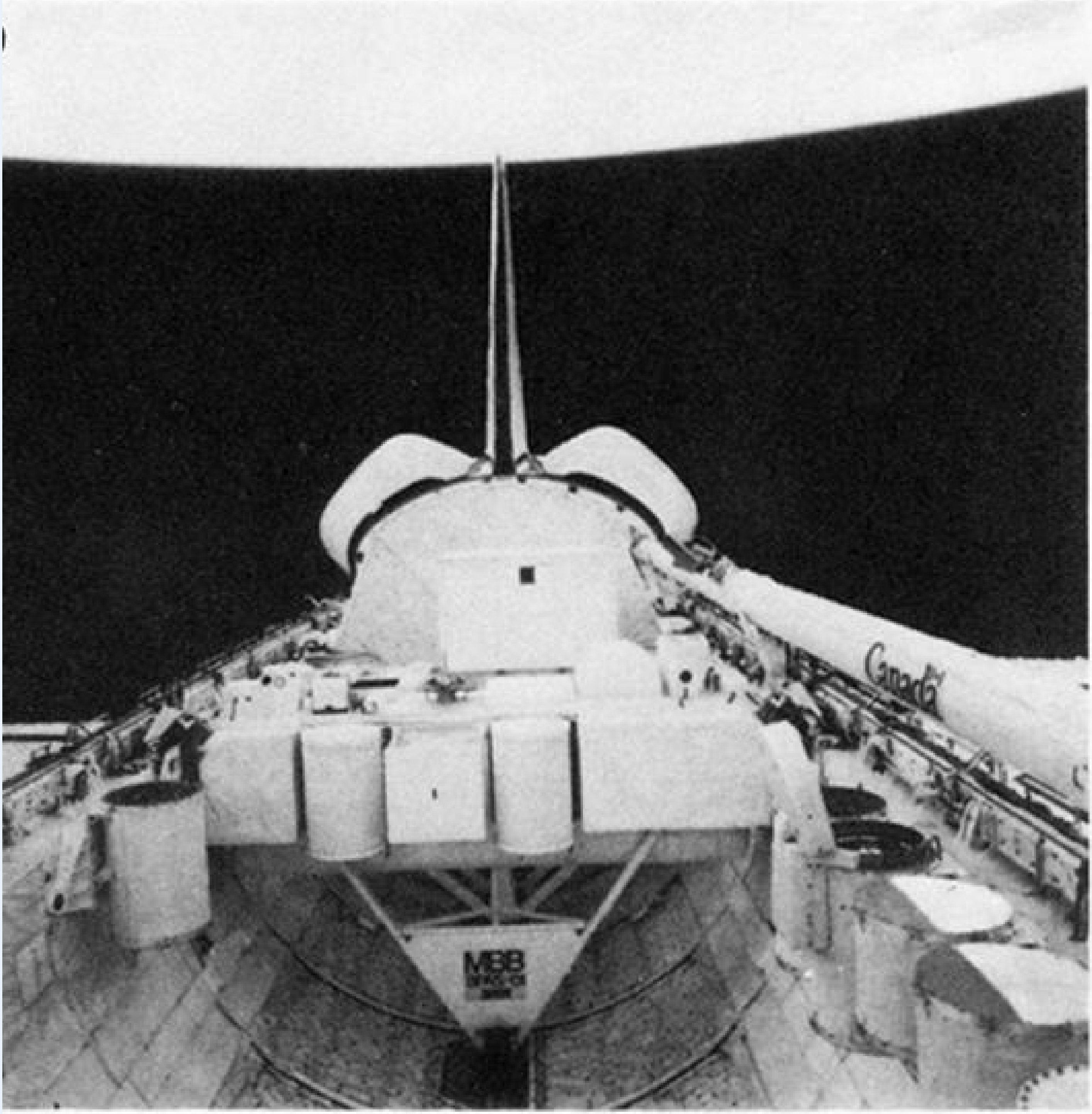

FIGURE 9. SPAS in shuttle bay.

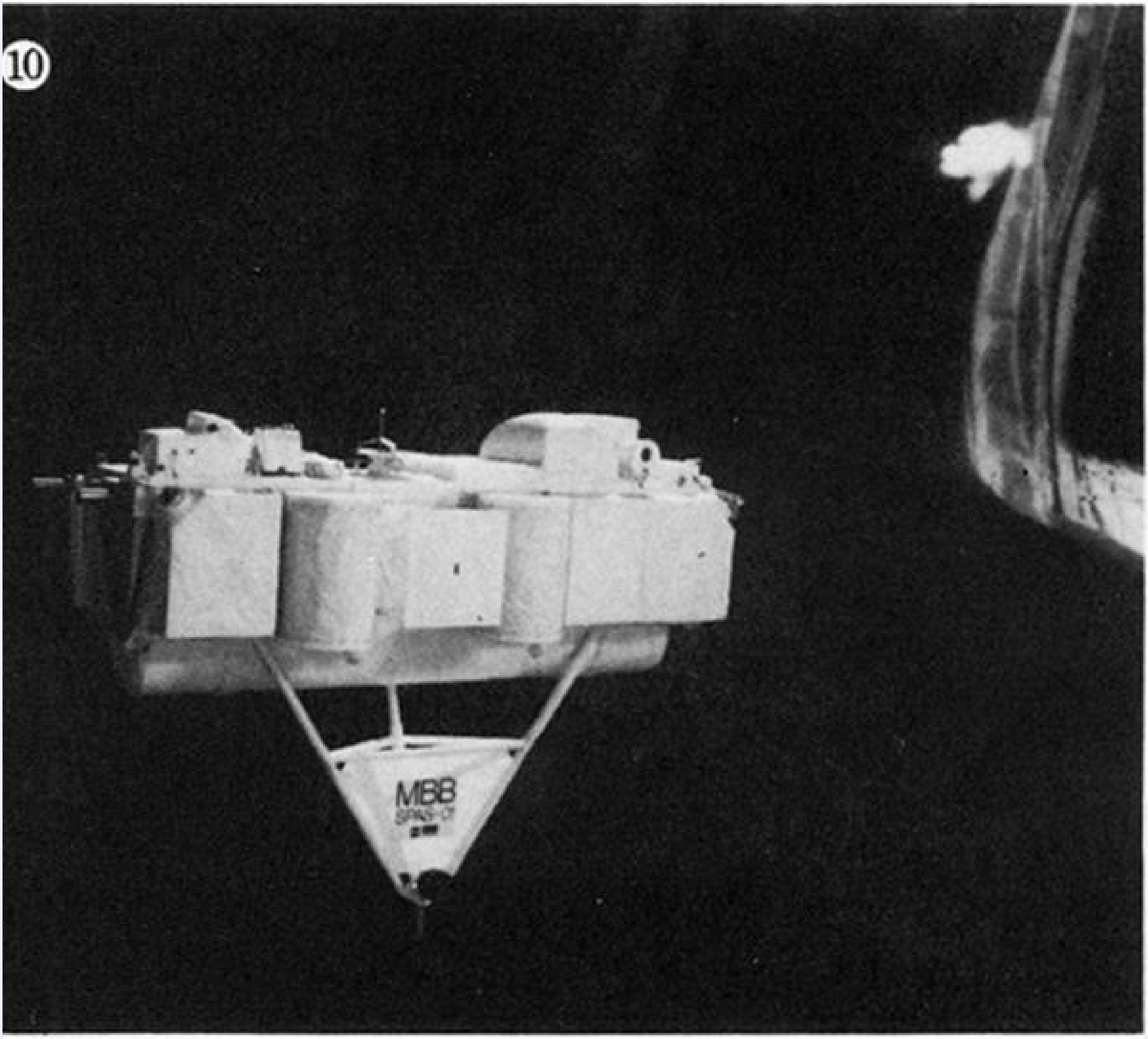

FIGURE 10. SPAS free flying in orbit near Shuttle.