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"SOLARIS"
ORBITAL STATION - AUTOMATIC LABORATORY FOR OUTER SPACE RENDEZVOUS AND OPERATIONS

J. J. Runavot

Translation of "Solaris: Station Orbitale - Laboratoire Automatique pour le Rendezvous et les Interventions Spatiales", Centre National D'Etudes Spatiales, Centre Spatiale de Toulouse, Toulouse, France, Report, September 10, 1980, pp. 1-27

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16. Abstract
The preliminary design for a modular orbital space station (unmanned) is outlined. The three main components are a support module, an experiment module, and an orbital transport vehicle. The major types of missions (assembly, materials processing, and earth observation) that could be performed are discussed.

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"SOLARIS"
ORBITAL STATION - AUTOMATIC LABORATORY
FOR OUTER SPACE RENDEZVOUS AND OPERATIONS

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I. Introduction /3*

Solaris is made up of three main components, either permanent or useable as the need arises:

- The orbital station, placed in a 780 km heliosynchronous orbit, 6 AM - 6 PM local time, will constitute a true support module during its fifteen years of operation. It will be useable in various applications: earth observation, synthesis of materials, and outer space construction. The services it will provide are either completely new for Europe, such as rendezvous and docking, or represent a change in scale, e.g., the power supplied to payloads or modules connected to the station (10 kw at the end of its life) and the communications capabilities provided (continuous transmission of hundreds of Mb/sec in real time through the use of geostationary relays).

- An operations module with advanced remote manipulation facilities. It thus will be able to carry out complicated tasks dealing either with materials synthesis experiments or assembly and construction.

  The module, carried up by a space vehicle, can be connected to the orbital station. When remaining locked onto the space vehicle, it prefigures a complete operations system that would eventually be able to operate in geostationary orbit, for example.

*Numbers in margin indicate pagination in the foreign text.

- <u>Orbital transport modules (automatic space vehicles)</u> will make possible the continued operation of the system thus put in place: Tens of rendezvous could be accomplished during the orbital station's lifespan. Through such rendezvous, the nature of missions and of the operations module will be altered. Aside from the maneuver and rendezvous function, the vehicle offers the possibility of making recoveries, either in separate pieces sent back over a period of time or by the return of a large reentry vehicle containing a two-ton payload.

Solaris makes it possible to develop these new capabilities, notably rendezvous, recovery, and control. They are indispensable if one hopes to be a power in the uses of outer space.

Until now the ability of a nation to maintain its independence in sapce technology revolved around one essential point -- the possesion of a launcher capable of placing objects in geostationary orbit.

In the next ten years, the key to independence will be skill in controlling complex processes in orbit, putting into operation (if not constructing) large paltforms, repairing space vehicles without interrupting service, etc.

Project Solaris will permit the unification of European efforts in the area of technical development with the objective of mastering such operational techniques.

This document presents a possible, albeit preliminary, design of the orbital operations system. It is based on using the Ariane IV launcher and results from reflection on the future of outer space, the new capabilities that must be developed, and the possibility Project Solaris offers Europe and France to take up the challenge through a major but reasonable effort. /4

Chapter II summarizes the new capabilities, presents the response embodied in Project Solaris, and compares it to the competing American and Russian systems.

Chapter III gives an account of possible missions and uses for Solaris.

Chapter IV presents the basic design and general characteristics of the system. From amongst the possible solutions, it identifies those involving existing technologies and those which demand a considerable R and D effort. This effort in itself constitutes one of the justifications for undertaking Solaris's development, which both unifies the work and demonstrates the acquired capabilities in orbit.

Lastly, the development of Solaris is sketched out in Chapter V. Particular attention is paid to the way it overlaps with the R and D program.

II. Future Needs and New Capabilities: The Response Embodied in Project Solaris /5

II.1. Future Needs and New Capabilities

The response to what is at stake in outer space during the next twenty years necessitates the use of the most effective technology to carry out space operations. To do this it is necessary:

- to dispose of lauch equipment which lowers the cost per kilogram in orbit;

- to be able to get around the limits in mass and dimensions inherent in this equipment, to alter or further develop the space system;

- to increase the operational life of space systems;

- to exchange material with the system in orbit (deposits and withdrawals);

- to dispose of larger on board electrical power supplies;

- to have reliable, practically permanent, high speed communications linkages with the systems in orbit or between systems.

II.2. The Response Embodied in Project Solaris

Project Solaris, using the Ariane IV launcher, attempts to respond to all the preceding considerations. It can be broken down into three parts:

An orbital station whose primary function is to be a power supply module furnishing on the order of 10 kw of useable power, and also featuring:

- a structure for receiving "payloads";
- the ability to rendezvous with automatic space vehicles and to grow through a succession of dockings;
- a long lifespan (15 years);
- an alterable, modular design for all the subsystems required by the preceding functions;
- a very rapid data transmission capability.

An operations module, an extension of the station for performing complicated mechanical tasks and including: /6

- advanced computer circuitry;
- remote manipulator arms;
- a surveillance system including television cameras.

Automatic vehicles, launched as needed and designed to offer, besides facilities for navigation and rendezvous, equipment to recover a ballistic reentry vehicle as well as maximum possible payload size and mass.

This strategy is based on using a low orbit instrument, as is consistant with the evolution of technology. It paves the way for other missions, notably those in geostationary orbit.

It is interesting to compare the overall characteristics of this instrument with those of other systems, whether existing (Salyut-Progress) or under development (Power Module).

Comparison with the Power Module /7

NASA's Power Module will complete the Space Shuttle system by supporting several Space Shuttle missions during its 5 year lifespan. It can function in two modes:

- connected to the Space Shuttle (in its Spacelab configuration, for example) to provide it with extra heat exchange capacity and 25 kw more power;

- in "free flight", but then the payload that becomes attached to it to obtain power, stabilization, and heat dissipation will have to carry its own communications system.

The comparison is limited to the orbital station and the Power Module:

	Power Module (9/77)	Orbital Station
Launch Date	1986	1990
Orbit	380 km, 55° or 28.5° (imposed by the Shuttle)	780 km heliosynchronous
Mass	14,000 kg	4,100 kg (1100 kg pyld)
<u>Power Supply</u>		
Solar Generator Area	533 m^2	160 m^2 (AsGa)
Orientation Mechanism	turning	fixed
Batteries	4928 kg	120 kg (NiH_2)
Continuous Power Furnished Payload	25 kw	10 kw aft 15 y 20 kw at start
<u>Heat Dissipation</u>		
Extendable Radiators	∿100 m^2 (350 kg)	no
Freon Loop	yes	no
Dissipation Capacity at Teq = 20°C	15 kw	8-10 kw
<u>Telecommunications</u>	dependent on the payload	up to 600 Mb/s

<u>Comparison with the Salyut-Progress System</u> /8

This system, presently operated by the Soviet Union, is designed for manned flights. Comparison with it is made only in capabilities other than life support:

	Progress	OTM
Mass at Liftoff	7000 kg	4900 kg
Useable Volume	6.6 m^3	49 m^3
Payload Mass	2300 kg	4000 kg
Autonomy	3 days	7 days
Attached to Station	30 days	several months

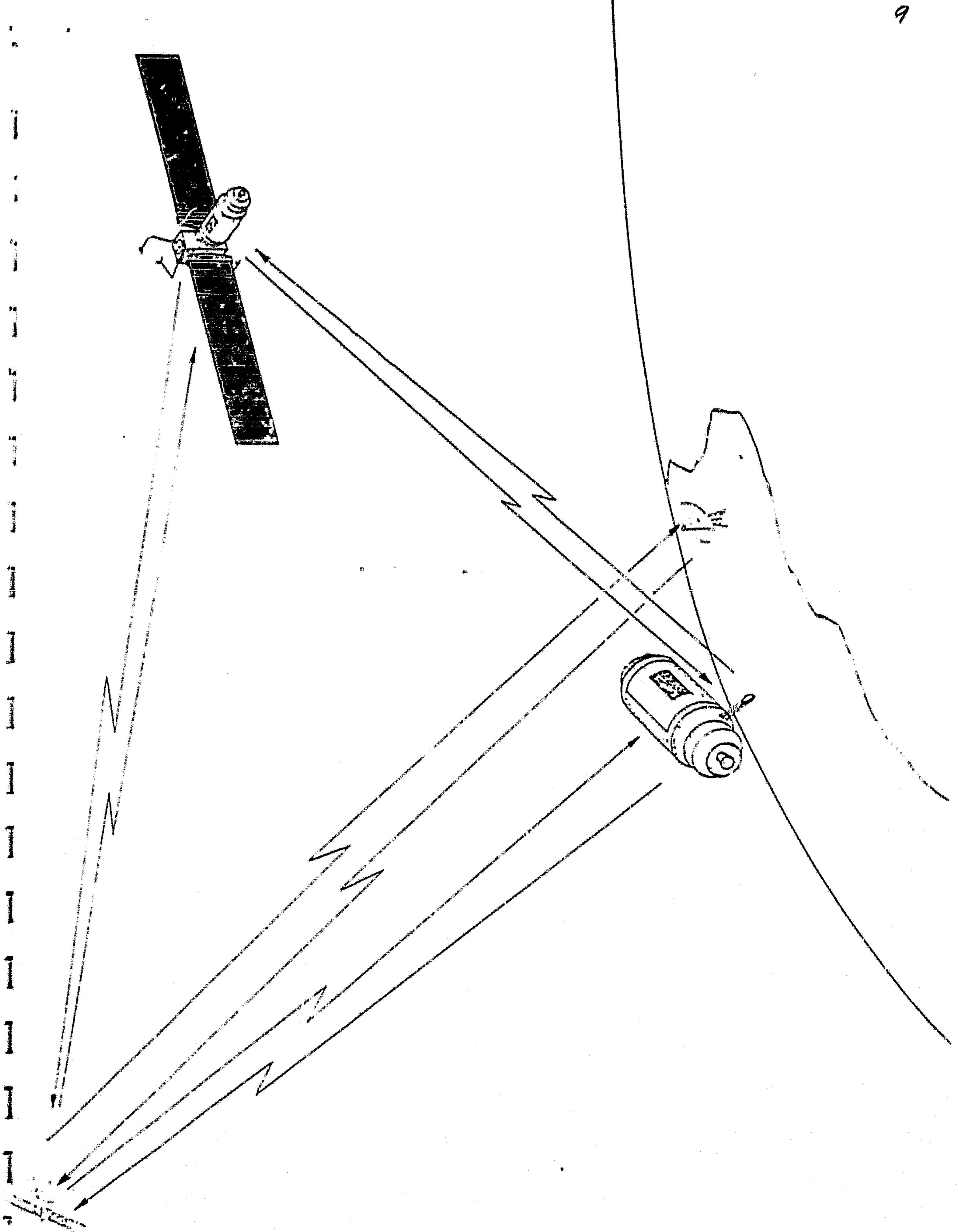
	Salyut	OS
Orbit	350 km, 51.6°	780 km heliosynchronous
Mass at Liftoff	18,900 kg	4100 kg
Useable Volume	100 m^3 (with crew)	8 m^3 (internal) possible extension up to 100 m^3 (external)
Power	4 kw for whole unit probably 1.5-2 kw for payload	10 kw for payload
Communications	a few Mb/s for limited periods	up to 600 Mb/s permanent

III. Principal Missions /10

Through its goals, its design, and the technology it puts to work, Solaris opens up a vast field of applications, as illustrated by its three principal missions:

- Experimentation with assembly and construction in orbit, which, beyond the services offered by the station, brings into play the operations module and its refined remote manipulation capabilities. It constitutes the first stage in developing a workshop for constructing and assembling large structures in space.

- Synthesis of materials in space. This is the last stage before actual production. The processes involved are ones whose promise and preliminary specification will have been established at the end of a program of study and experimentation in this area (theoretical studies, experiments on the ground, flights of short duration). For this mission, the high power supply, the capacity for orbital operations, and the recovery feature



will allow the processes to be perfected or a pilot production run to be carried out.

- An earth observation mission for which the high power and high speed transmission capabilities make the use of microwaves possible.

III.1. Construction in Space

If an immediate jump to very large space platforms is not made, the construction of large beams would appear to be an obligatory step. Associated with rendezvous and assembly, it paves the way for a whole series of new applications:

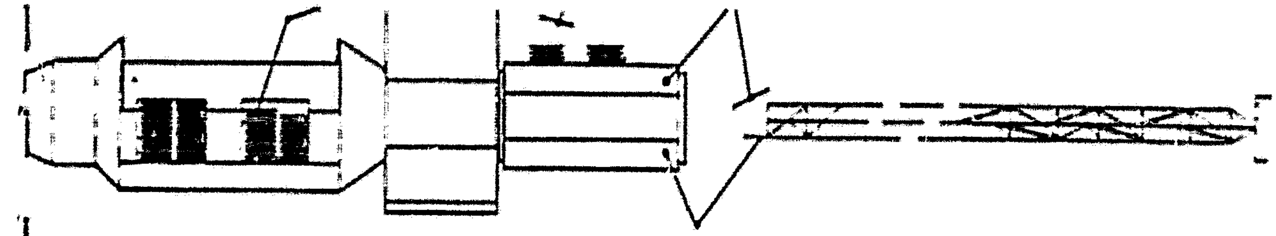
- in observation and location (passive radiometers, interferometers);

- in the creation of large scientific interferometers or telescopes;

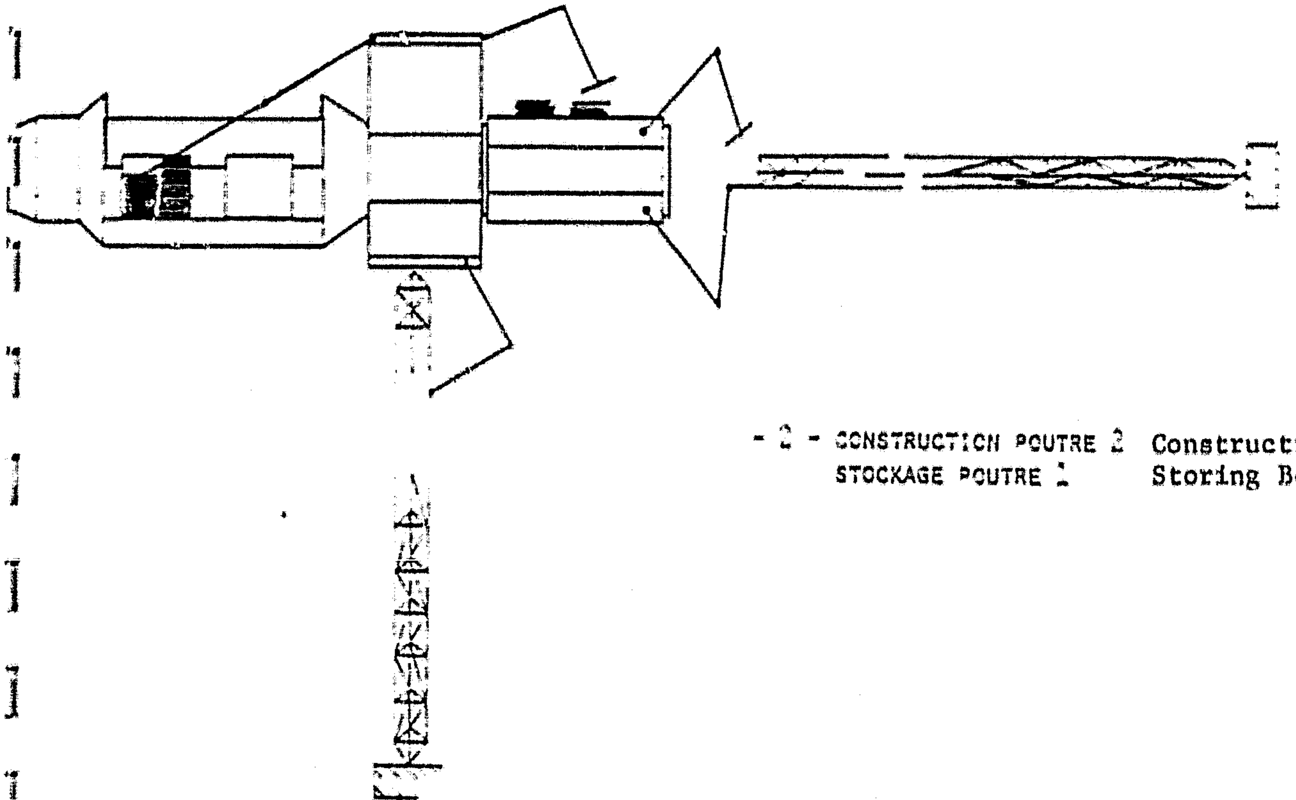
- etc.

Solaris represents a first step down this road, even if its dimensional objectives are modest. It is in effect a test bench for materials, procedures, and construction methods thanks to its remote manipulator arms. It also tests out the assembly and combining of deformable structures ("impactless" docking). It could, for example, put together beams tens of meters long for constructing an interferometric station. /13

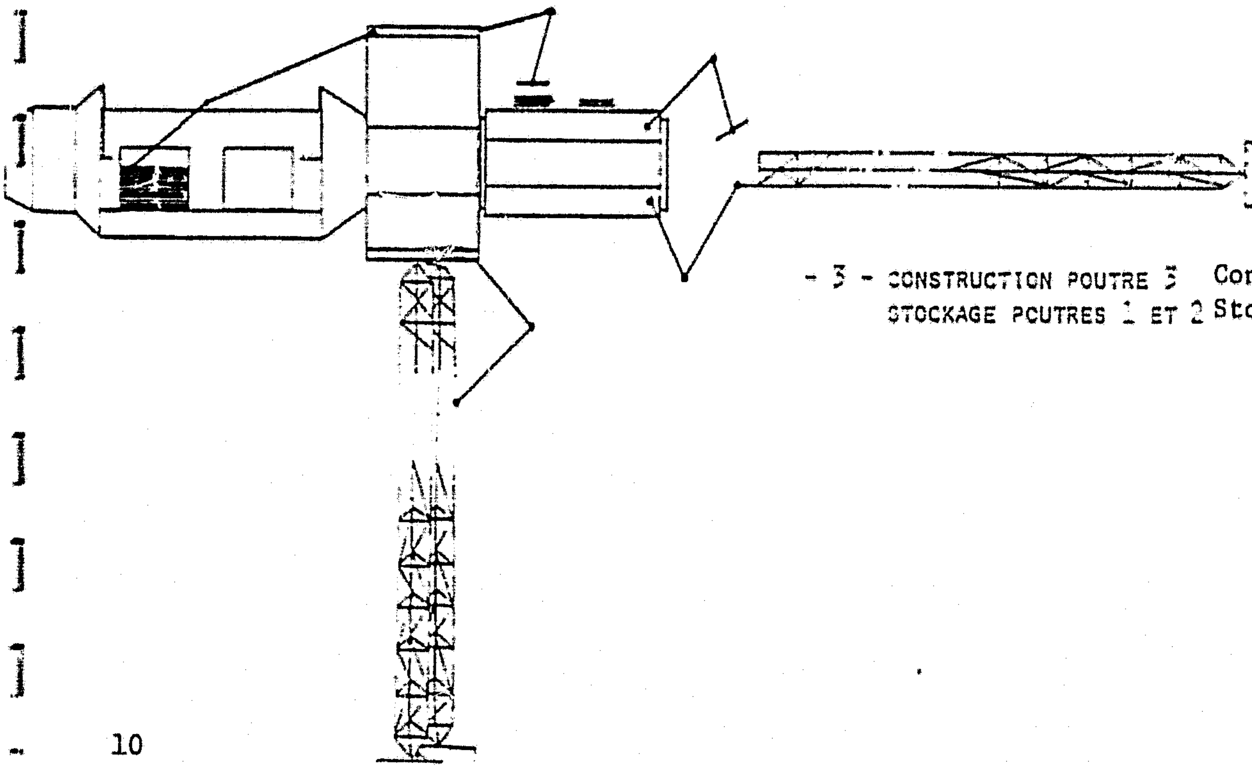
Creating such a station would require two flights of the automatic space vehicle: The first would carry three containers (with individual dimensions of 1.5 m x 1.5 m x 1.5 m). Each container would provide the material for constructing, through remote manipulation, a beam thirty meters long with a deployable antenna at its end. The second flight would carry the cental body on which the three branches of the star would be assembled.



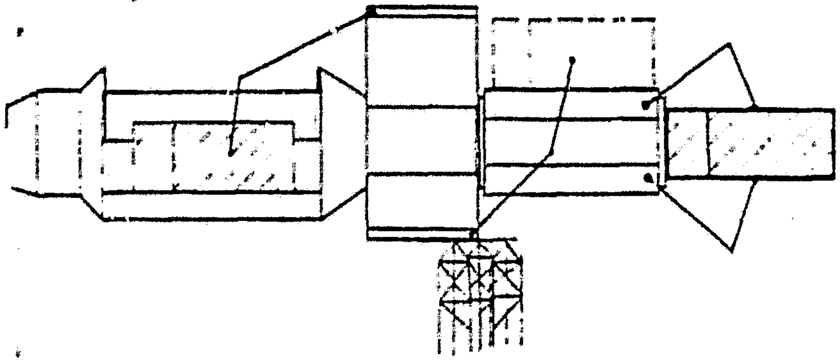
- 1 - CONSTRUCTION POUTRE 1 Constructing Beam 1



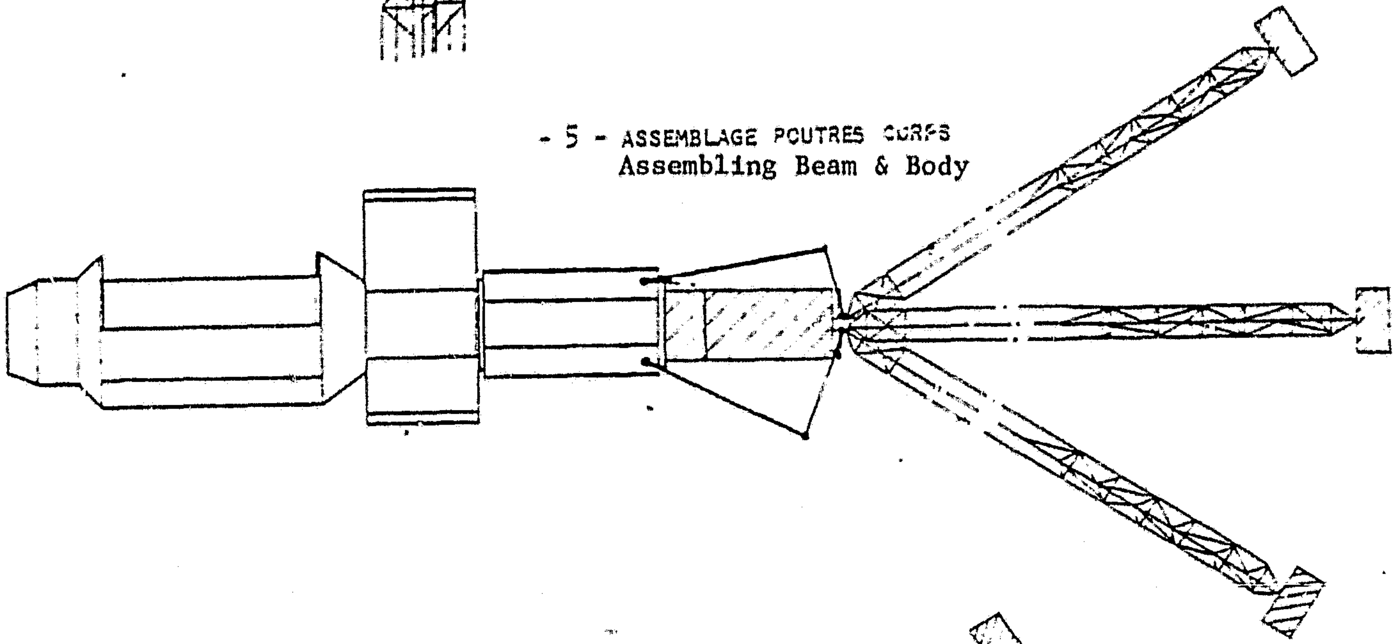
- 2 - CONSTRUCTION POUTRE 2 Constructing Beam 2
STOCKAGE POUTRE 1 Storing Beam 1

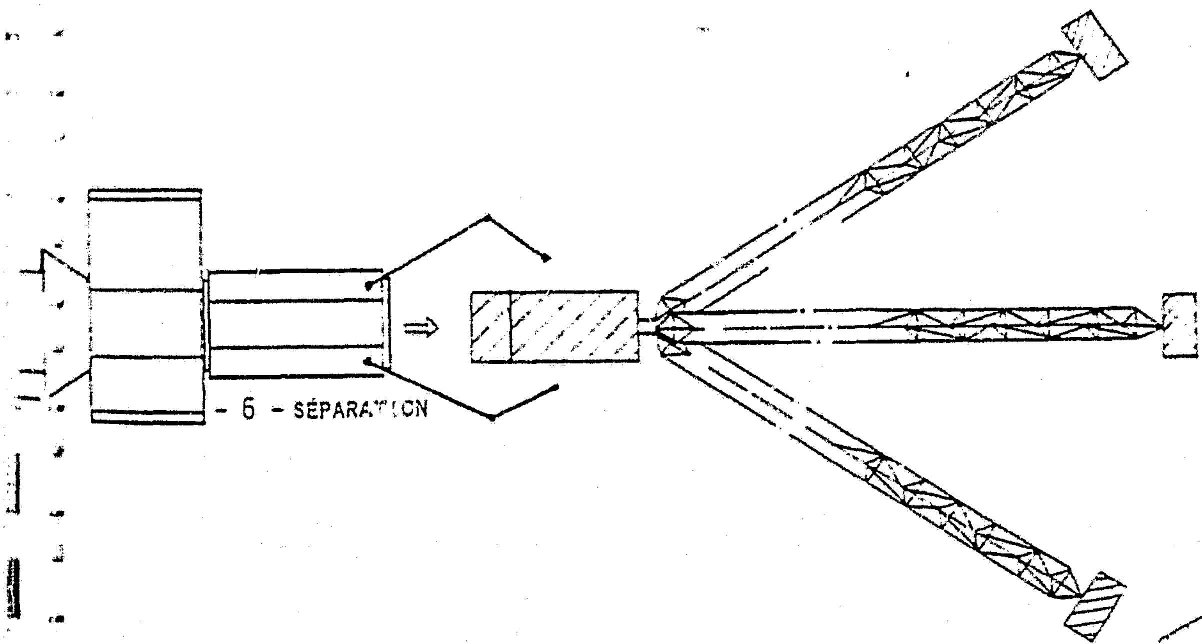


- 3 - CONSTRUCTION POUTRE 3 Constructing Beam 3
STOCKAGE POUTRES 1 ET 2 Storing Beams 1 & 2



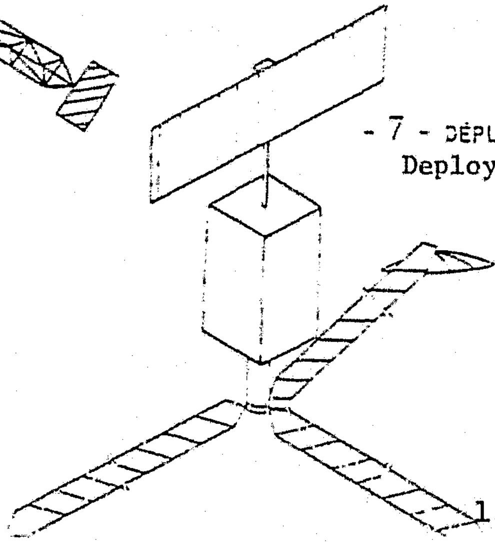
- 5 - ASSEMBLAGE POUTRES CORPS
Assembling Beam & Body





- 6 - SÉPARATION

- 7 - DÉPLOIEMENT
Deployment



III.2. Synthesis of Materials in Space

The greatly reduced gravity obtainable on board space vehicles makes it possible to put into operation processes of preparation or separation that work better than on the ground, or are even impossible there:

- contactless transformations for products which react with crucibles (glasses, ceramics, alloys);

- production of products of high crystalographic quality from liquids or gases (pure, massive crystals, new alloys);

- separation and purification of products with the aid of forces whose amplitude is much weaker than gravity on the ground (vaccines, pharmaceutical products).

The products and processes amenable to space operations will be identified in the years to come, at the end of a program of fundamental research and of experiments of limited duration or similarity.

The final perfection of selected processes or a pilot production run requires:

- a residual gravity of less than 10^{-5} g;

- several kw of electric power;

- the ability to dissipate the same amount of power in the form of heat;

- the possibility of recovering finished products, in moderate or large quantity, and possibly certain production materials as well;

- extensive capacity for automating processes and for more or less autonomous mechanical operations.

Solaris makes this group of features available. It supports rigorous and multiform experimentation and an annual production of several hundred kg for processes able to last several months: /14

- a residual gravity far lower than 10^{-5} g (fixed solar generator, weak primary structural member, relatively high altitude orbit);

- 10 kw of available electrical power at the end of lifespan (20 kw at the beginning);

- large cold surface for dissipating heat;

- recovery with the aid of reentry vehicles delivered by orbital transport vehicles, either of two tons in a single shipment or of several hundreds of kg divided up over time;

- Capacity for automation, either entirely within the payload itself or aided by the station's computer, and for mechanical operations aided either by the station's remote manipulator arms or by the operations module.

III.3. Earth Observation

Through the support services it offers, Project Solaris permits the execution of earth observation missions difficult to envisage with conventional space vehicles:

- large amount of available electric power in the station for instruments;

- large area for attaching instruments on the side of the station facing the earth, excellent heat dissipation facilities, and the availability of remote manipulation systems for assisting deployments or other tasks;

- Capacity for high speed, continuous data transmission in real time.

These earth observation missions are based on the use of passive microwave radiometers, and especially of synthetic aperature radar of either high resolution (metrical) or high informational quality (multifrequency or multipolarity).

As an example, the orbital station could receive and support one of the following two instruments: /15

<u>10 BHz High Resolution Synthetic Aperature Radar</u>

- Resolution	2 m
- Scanning Width	25 km
- Antenna	4 m x 1.25 m
- Electrical Power Transmitted	4 kw
- Electrical Power Absorbed	10 kw
- Thermal Power Dissipated	6 kw
- Telemetric Output	360 Mb/sec

<u>5 and 10 BHz Thematic Synthetic Aperature Radar</u>

- Resolution	10 m
- Scanning Width	100 km
- 2 Frequencies and 2 Polarities (2 Transmitters)	10 BHz VV and VH 5 BHz VV and VH
- 4 Antennae 10 m Long	.4 m wide (2) .8 m wide (2)
- Transmitted Power	600 w per transmitter
- Electrical Power Absorbed	3 kw + 2.5 kw (processing)
- Thermal Power Dissipated	∿3 kw
- Telemetric Output (after on board holographic processing)	300-400 Mb/sec

The station's lifespan, its range of possible activities, and the capacity to carry up new instruments in automatic space vehicles make continuous, evolving missions foreseeable.

IV. Description of Solaris /16

A preliminary, but indicative design for the system has been proposed. It is conservative in certain aspects, notably concerning the orbital station's general architecture, However, it has the advantage of showing that the system's assigned objectives can be met with the Ariane IV launcher, given technological developments that will in any case be necessary in the future. Also included are new, adapted designs for a certain number of subsystems.

IV.1. General Characteristics

The system is put in place in several steps. The first is the launching of the orbital station. The orbit decided on is a circular heliosynchronous one with an altitude of 780 km and an ascending node at 6:00 PM local time. This has the following advantages:

- best station configuration (energy generation and storage, heat dissipation, etc.);

- less acceleration and residual vibration (fixed solar generator parallel to the direction of motion);

- capacity for observation missions with global coverage;

- accessibilty of recovery site.

The price is a loss in mass of several hundred kilograms and a longer time required for rendezvous and recoveries. This is without great importance for an automatic system carrying only production materials.

Similarly, the atmospheric reentry under consideration is of a ballistic type, the easiest to master at first. At the cost of a greater rate of deceleration (but perfectly compatible with the materials to be recovered), it offers the maximum payload volume and an excellent targeting precision (about 10 x 20 km).

Lastly, the docking method chosen is of minimum impact. A system of this kind must include high performance optical terminal guidance equipment. It is compatible with the minimum thrust deliverable by the means of propulsion on the automatic vehicle. Such a system guarantees that the station's solar generator will not jar loose during docking and is obligatory for future docking operations involving large structures.

IV.2. The Orbital Station /17

The orbital station receives and supports the functioning of payloads for the missions indicatied above.

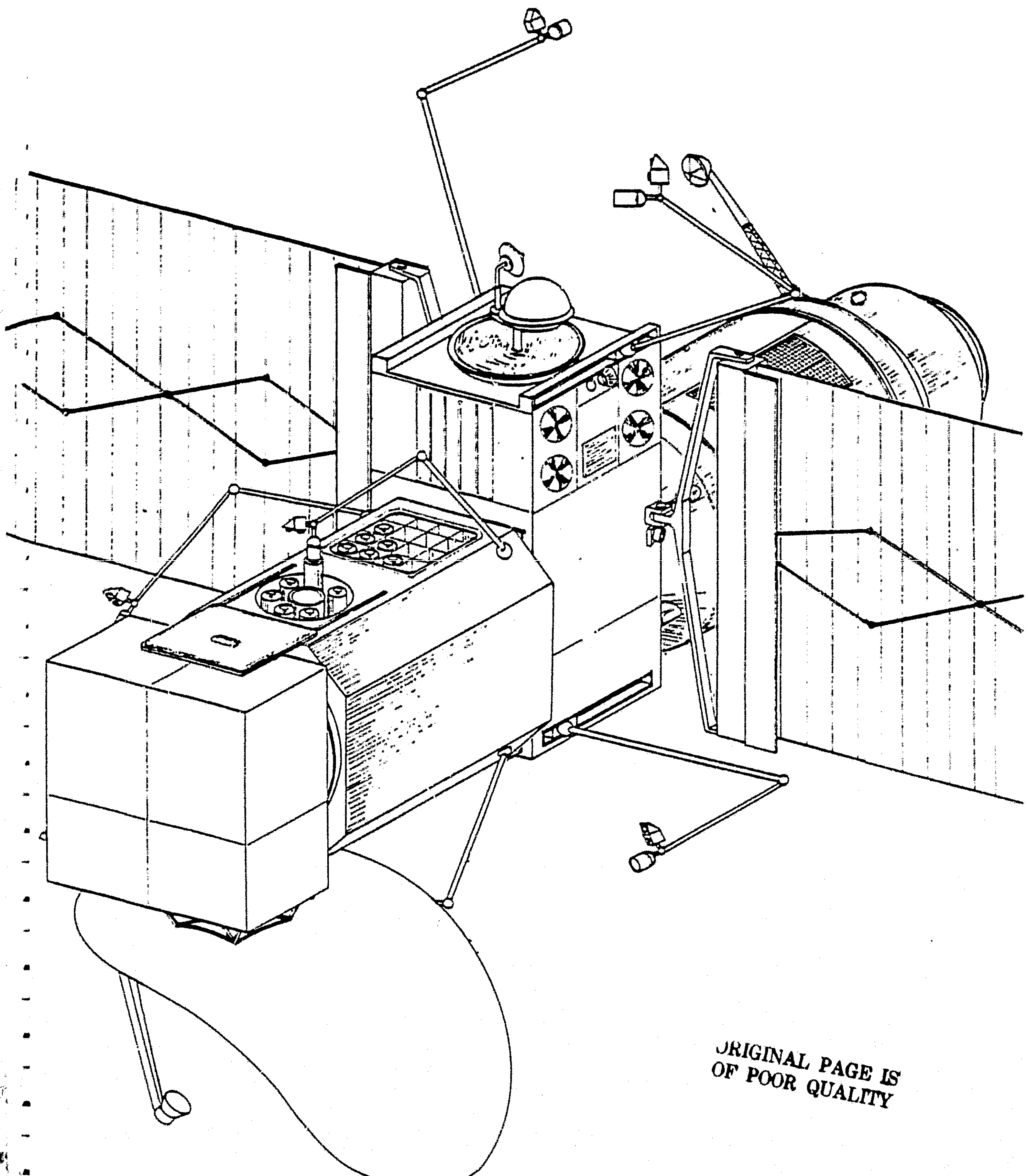
It consequently performs the following main functions:

- Generation and storage of energy: It is able to continuously furnish payloads with 10 kw of power.

- Maintenance and modification of orbit: It maintains the specified heliosynchronous orbit and is capable in the course of its life of making ten excursions to neighboring heliosynchronous orbits (variation in semi-major axis on the order of 25 km).

- Control of attitude: It provides attitude control compatible with the various missions. In particular, it should permit angular velocities of less than a few 10^{-4} degrees/sec and linear accelerations of less than 10^{-5} g.

- Data transmission: Through the intermediary of geostationary relays, the station can continuously transmit data in real time at very high rates (200-600 Mb/sec, according to the



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option chosen).

It in addition performs less conventional functions representing a real advance in European space know-how:

- docking of automatic spce vehicles;
- reception of variable payloads which can be added to by successive dockings.

A preliminary calculation of mass indicates that the station could be put into the specified orbit by the Ariane IV launcher with a comfortable margin, even at the present stage of design.

In contrast, the desired performance and lifespan, and the ability to grow and change configuration, necessitates new designs (for example, compromises between super-redundance and repair by interchangeability) for the majority of subsystems. New equipment and techniques have to be developed.

- On Board Energy Subsystem

To obtain the desired power capacity and lifespan, highly efficient cells (AsGa, for example) must be used so as to reduce the size of the solar generator, which nevertheless will require the development of a new design.

As far as energy storage and distribution in the station are concerned, a new architecture will have to looked into and developed (even if continuous distribution is retained). It will have to be adapted to modularity, variable loads, serviceability, and a high level of power. /19

As a corollary, high voltage distribution channels, various associated components, regulating limiters (by cutting out, for example), and batteries of high power per unit mass (NiH, etc.) have to be developed. Finally the advantages of kinetic storage and distribution by alternating current should be the object of studies to determine alternative solutions to the basic problem.

- Thermal Subsystem

As a result of the long lifespan, the variability in operating conditions, and changes in configuration, it has to be modular and entirely active. All its components should be developed in conformity with the principle of control by on board computer.

- Attitude and Orbital Control Subsystem

Besides a new architecture adapted to changes in configuration, the station's relative flexibility, and numerous functional modes, certain innovations will probably be necessary in the equipment (gyrolaser, ionic propulsion with greater thrust).

- On Board Command and Data Transmission Subsystem

The necessary developments concern:

- High speed communication with the relays (transmitter, automatic tracking antenna) and with the interior of the station (optical fibers or diffused infa-red linkages);

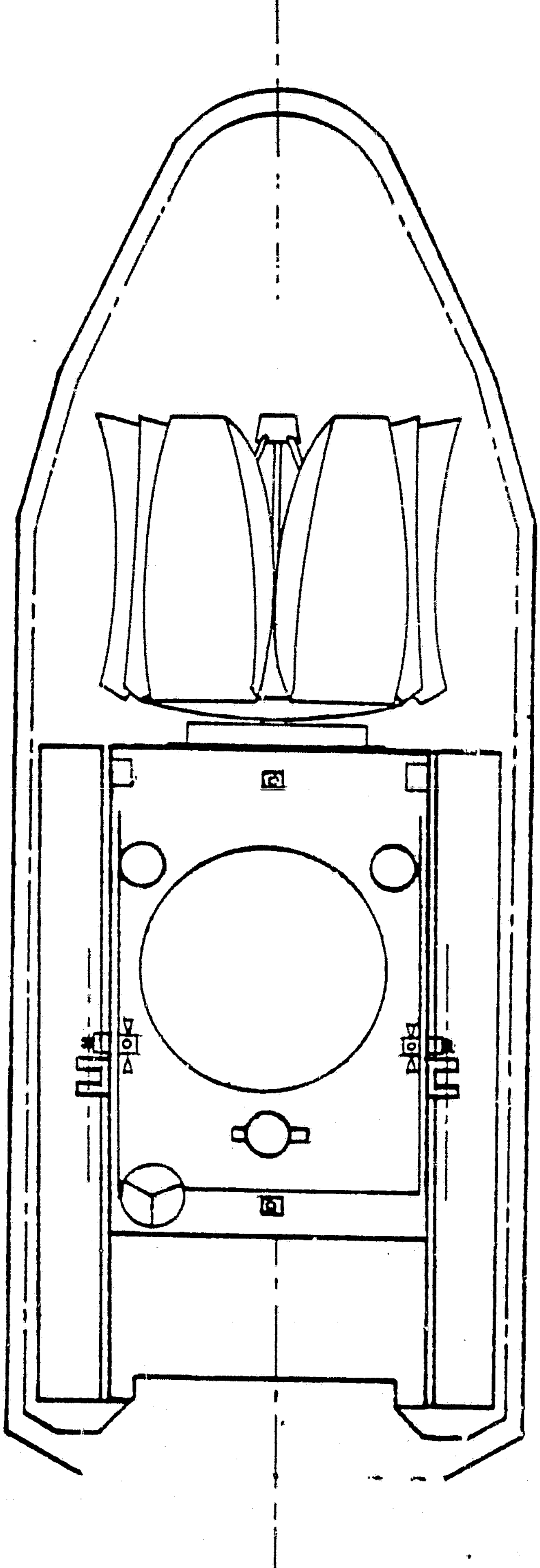
- Architecture and standard data channels adapted to changing station configuration, reversible connections, and rapid two-way exchanges;

- Reliable reversible connection technology;

- High performance hybrid components;

- Rendezvous, Docking

Besides two-way connection technology, it is necessary to



Orbital Station at Liftoff
STATION ORBITALE AU LANCEMENT

develop a relatively long-range trajectory calculation system for two objects in orbit, and especially on the basic elements for terminal guidance (based, for example, on lidars) and docking mechanisms.

IV.3. The Operations Module /21

The module will represent the concrete result of an ambitious R and D program in the fields of automation and remote manipulation. The basis of the program will be existing French expertise, as brought together in a research association (with the participation of CEA, Renault, etc.).

The OM's job is two-fold: Within the narrow framework of Solaris, i.e., docked to the orbital station, it will perform the complicated mechanical operations needed for certain experiments (ovens, deployment of appendages, assemblies, etc.). Elsewhere, carried by the transport module in autonomous orbit, it will constitute a prototype system for servicing satellites or large structures in space.

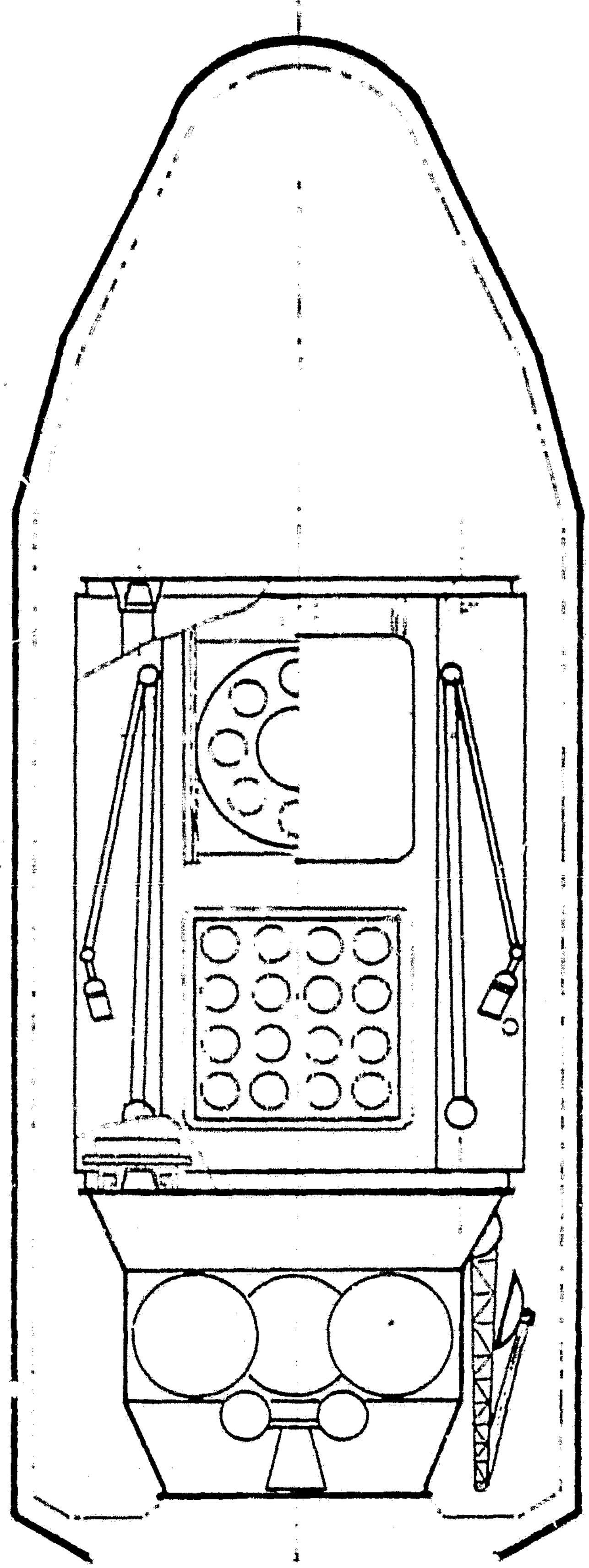
In the second case, all that is required is an extension of the transport module's energy generation and communications capabilities.

In the first case, it will use the maximum capacity of the transport module and permit successive dockings, which will extend and enlarge the orbital station.

- Architecture

The module is basically made up of:

- two docking interfaces, male and female;
- a central compartment which can contain complicated materials processing experiments, among other things;
- a group of remote manipulator arms, ten meters in length, to which grasping mechanisms, specialized tools, and sensors can



MODULE D'INTERVENTION

AU LANCEMENT

Operations Module at Liftoff

be fitted. The arms can range over fairly great distances outside the module or perform work inside the cental compartment.

- computer circuitry with advanced software able to control the maipulator system in either sequential or closed loop modes.

- Subsystems and Technical Developments

The needed technical developments essentially concern the manipulator arms and the computer circuitry.

Firstly, all the manipulator arm components, articulations, motors, and sensory and grasping gear, must be developed and checked out.

Secondly, besides perfecting the computer software, a high-performance computer interfaced with the one in the orbital station has to be created.

A certain number of the other required innovations are the same as for the orbital station, particularly concerning two-way connection technology.

Lastly, system-wide studies should take place parallel with the rest of the program on the subjects of repairability and assembly and construction methods in space.

IV.4. The Automatic Space Vehicle /23

The automatic space vehicle has the following functions:

- transporting modules toward the station (for maintaining and altering it), including in particular the reentry vehicle and operating module;

- injecting the reentry venicle or material destined for destruction into the atmosphere with the proper speed and attitude.

It must therefore be capable of making all the corrections necessary for rendezvous and reentry, of approaching and docking with the station and of remaining mechanically and eletrically linked to it for a few days.

As an extra function, the space vehicle's propulsion and navigation module can also be used to place objects in geostationary orbit after minor adjustments have been made to it.

- Architecture

Two factors have been decisive in the automatic space vehicle's design. They are the need for the maneuverability and autonomy inherent in an automatic system, and the desire to obtain the maximum possible payload mass and volume.

It is therefore basically characterized by:

- its modularity;

- its adaptibility for various missions;

- the search for lightness.

At the same time it will use proven technology as much as possible on all elements that do not concern the new services or the foreseeable applications of new techniques.

The preceding functions are grouped into two functional subunits, one performing the funcitons of attitude control, navigation and propulsion, the other the functions of approach, docking and linear transfer. The two subunits are linked by a tubular structure surrounding the compartment belonging to the payload.

Starting at the launcher adapter, one finds:

- the propulsion-navigation module which, besides transmitting force during liftoff, controls all the attitude and trajectory changes made after the vehicle is placed in parking orbit and before docking takes place, as well as high frequency communications and energy generation;

- the payload compartment, approximately 3.3 m in diameter and 5 m high; /24

- the docking subunit, which includes components for guidance, capture, locking, and connection.

- The Reentry Vehicle

Its development will profit to the highest degree from the national efforts made in this field.

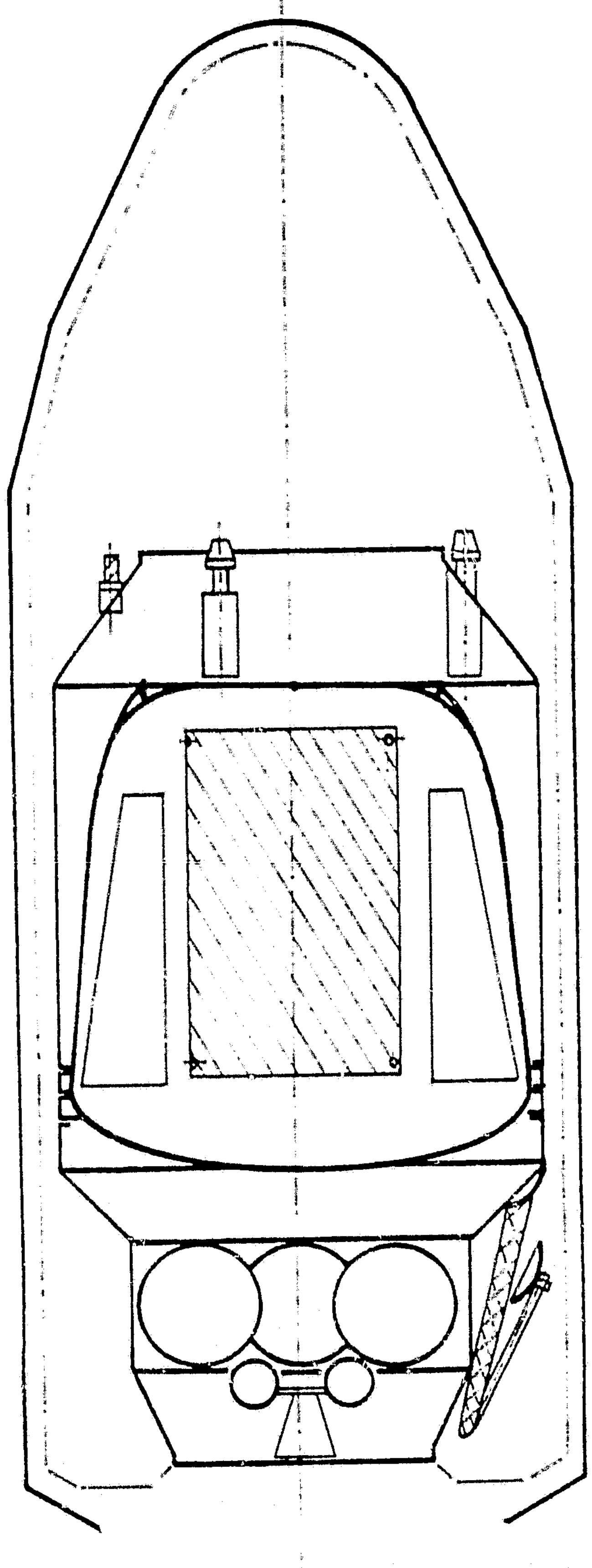
Reentry is of a ballistic type; the propulsion-navigation unit will produce the desired initial conditions before being separated and destroyed.

The reentry vehicle will have either a zero lift coefficient (sphere) or a low one (ovoid) held at zero incidence. The latter has some advantages in terms of interior arrangement.

The thermal loop may be ablative, which would only require an adaptation of designs and material already developed. However, the development of protective silica shielding, for example, would contribute to the eventual creation of reentry gliders.

- Strategy, Performance

For rendezvous, the space vehicle is placed in an elliptical parking orbit 200-780 meters in altitude and in the same plane as the station's orbit. When the relative position of the station and space vehicle is favorable (maximum delay: 3 days), it maneuvers so as to enter an orbit allowing it to drift towards the station. Then, when 100 km away, it is taken in charge by the station's detection system and executes a succession of corrections until contact occurs.



CORPS DE RENTREE AU LANCEMENT

Reentry Vehicle at Liftoff

For the return flight, the maneuvers are programmed from the ground. Meanwhile, the stations's detection system calculates the trajectory and transmits it to the ground via relays so that the point of impact can be predicted.

Taking account of the space vehicle's initial orbit, the launcher will support a maximum mass of 4900 kg (10% margin deducted), which permits:

- for a one-way mission, a payload of 3900 kg;
- for a two-way mission with reentry vehicle, the recovery of about 2000 kg of payload;
- for a split up two-way mission, the recovery of approximately 4 times 300 kg of payload.

- Subsystems and Technical Developments /26

Except for the developments previously mentioned concerning calculating relative trajectory, docking, and thermal protection, the essential part of the technical effort concerns the propulsion-navigation module.

It is necessary to develop an attitude and navigation unit. Designed in a modular and alterable manner, it must be adaptable to less complex functions than the space station performs or to placing satellites in geostationary orbit. Also, a relightable, biliquid engine developing a thrust of 2000-10,000 n (depending on the technique for leaving orbit) has to be developed. Such a propulsion module would be will adapted to the geostationary payloads to be carried by Ariane after 1985 or 1986.

V. Development /27

Organizing Solaris's development presents certain peculiarities due to the advanced technical character of the vehicles that have to be studied and bulit, the complexity of the system, and the breadth of the program.

As a result, the transition to the developmental phase could not occur before 1985, after a very long preliminary phase.

This phase, after the elaboration of objectives and technical activities, is basically devoted to the execution of a major, ambitious R and D program.

At the same time systems analyses will permit the gradual specification of the unit's design as the results of the R and D program are compared with the initial objectives.

At the end of such a phase, detailed design work for Solaris could get under way. By this time, the effect of the possible surprises inherent in any ambitious technical program would have been minimized.