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Satellite architecture – design of structures and mechanisms (visualization in praxis)

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Abstract

The new design methodology of recent years caused by the introduction of powerful computers i.e.:

- to assist and supplement the visualization process at the early stage of design
- to use solid model techniques to optimize the design configuration
- to establish kinematical movement models of the mechanisms
- to provide design interfaces for an FE model; is now an unavoidable tool in spacecraft engineering

It is normal systems procedure to divide a spacecraft system into two principal elements:

- the payload, and
- the bus

During the iterative process of design of the satellite bus structure by considering launch vehicle constraints and payload configuration drivers the initial design "grows" to the final design configuration synthesis phases. Computational geometry and 3D imaging provides an excellent opportunity for optimizing, modifying, adding and analyzing the structure using FE analysis.

The main task of this paper is to show through the representative examples, in terms of both structural and mechanical hardware, the satellite architecture as a new discipline and to highlight the use of visualization and intelligent design by aerospace applications.

Introduction

If one proceeds from the basic definition of architecture, design and engineering, the place the satellite occupies in any of these fields at the moment would be very difficult to define precisely. The satellite is certainly more of a place and a space where experiments and observations take place -- while it is changing position and taking up required trajectories -- than it is a means of transport such as a plane or a carrier rocket that has brought its payload -- satellite -- into a desired position. The development of technology brought us from the first Sputniks and Explorers to the present satellites, modern works of art in technology and the sojourn of the man aboard a space body (of a satellite type) gives a new quality to everything. This flying body becomes a **home** -- for the time being only for astronauts, but it is not hard to predict that in a short time, entire colonies, settlements will be evolving around the Earth. Perhaps only then will architecture become one of disciplines to be used when designing these objects or, to put it better, these objects will completely fit into architecture. Therefore, I think that today we can speak about a new discipline within architecture -- still in the cradle -- **architecture in outer space.**

The purpose of this article is to present its readers -- through examples from the practice -- one of the aspects of the application of modern designing methods: the visual representation of an object that is being created. As the design of the examples presented here begun in my firm two years ago and as we are still using the same system and program and present opportunities are greater, computers are more powerful and possess a larger capacity, and a virtual army of people deal with perfecting new programs, one must understand that some elements may already appear "old-fashioned" and outdated.

N. B. No programs will deliberately be mentioned here by their names, only by their capabilities.

Spacecraft Subsystems

The spacecraft system itself may be conveniently divided into two principal elements: the payload and the bus (support structure). The bus provides the payload with all the necessary resources for its functioning, it gives life to the payload and the mission target and provides certain shelter for the equipment. The breakdown into subsystems is shown on Figure 1.

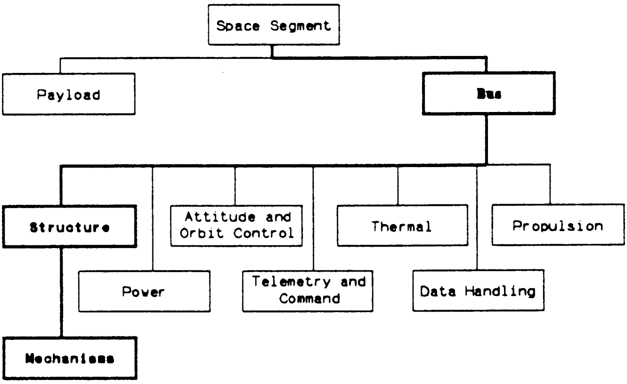


Figure 1: Spacecraft Subsystems

The subsystems interact strongly with each other and the design of any one of them affects and has resource implications on the other. The most significant characteristic of spacecraft system design is to identify the mission aspects and design elements that exert major influence on the type of satellite that may meet the specific mission requirements. The process is the identification of the "design drivers." In some cases, the drivers will affect major features of the spacecraft hardware. The varied mission requirements, combined with the need to minimize mass and therefore power, has thus led to a wide variety of individual design solutions.

The first step in structural design is to establish specification based on the mission requirements with as much detail as can be expected at the concept stage. A generalized list of requirements for structures is given as follows:

- Accommodation for the payload and spacecraft systems
- Withstand launch loads
- Stiffness
- Mounting/Interfaces
- Alignment
- Thermal and electrical paths
- Accessibility

Example 1 Design of the Gamma Ray Spacecraft

Figure 2 shows what the satellite consists of.

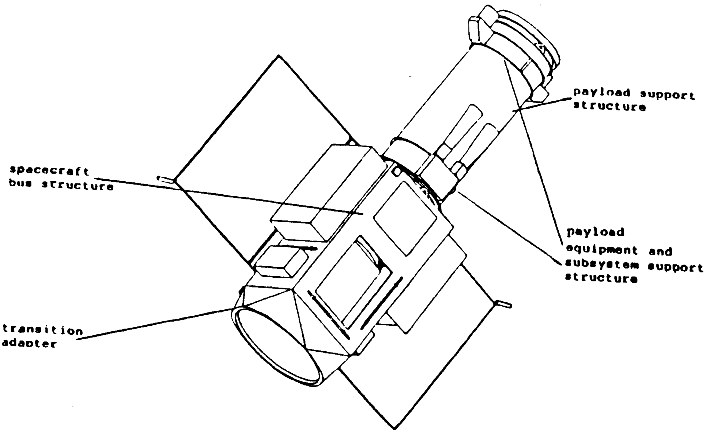


Figure 2: Gamma Ray Astronomy Satellite
Structure Definition & Description

Gamma Ray Astronomy with Spectroscopy and Positioning

Scientific objectives are as follows:

- imaging and accurate positioning (1 arc min) of celestial gamma ray sources
- fine spectroscopy of cosmic sources with high resolution
- study of active galaxies by
  - luminosity measurements
  - spectroscopy of line and continuum spectra
- investigation of point and extended sources within our galaxy
- observation of any transient events like gamma ray bursts or super novae

Payload Definition

The payload for the gamma ray astronomy with spectroscopy and positioning comprises:

- detector assembly
- coded aperture mask
- optical transient camera
- x-ray monitor
- data and power electronics

Brief description of step by step design:

Taking into consideration the basic requirements and defining design drivers, using the already existing types of the Ariane fairing, and permitted envelopes for double launch upper position (see Figure 3), sketches have become shapes of the outer permitted satellite contours. Of course, the entire geometry was done in cooperation with the firm that was responsible for designing the payload -- in the case of the gamma ray astronomy it is a telescope of very large dimensions that is isostastically fixed to the bus carrier. In order to economize when constructing the bus, the library of solids/buses was used to see which one of them meets the requirements best. The selected bus-structure (see Figure 4) was taken and the research directed towards coordinating the needs of inner space for mounting the other subsystems equipment. The finally created solid model started receiving inputs from various sides, from different firms which then -- based on the layout -- built and added their own elements. The thermal subsystem represented the greatest problem, but defining and calculating radiators was made easier by the possibility to manipulate with solid models in space and to simulate the positions of the satellite in relation to thermal sources.

The result of the entire analysis in this first stage of defining the spacecraft were 4 solutions that were proposed for further analyses. All these configurations could be very efficiently simulated with the help of solid models by very quickly changing the position of elements, mutual relations and subsystems. The fact that the mass budget and the center of gravity analysis were available to the designer engineer represented a particular advantage at any moment, so that entire trajectories of the C of G were made until the stage when the design was frozen and when it was established on the basis of trade-offs that the chosen configuration should be developed further.

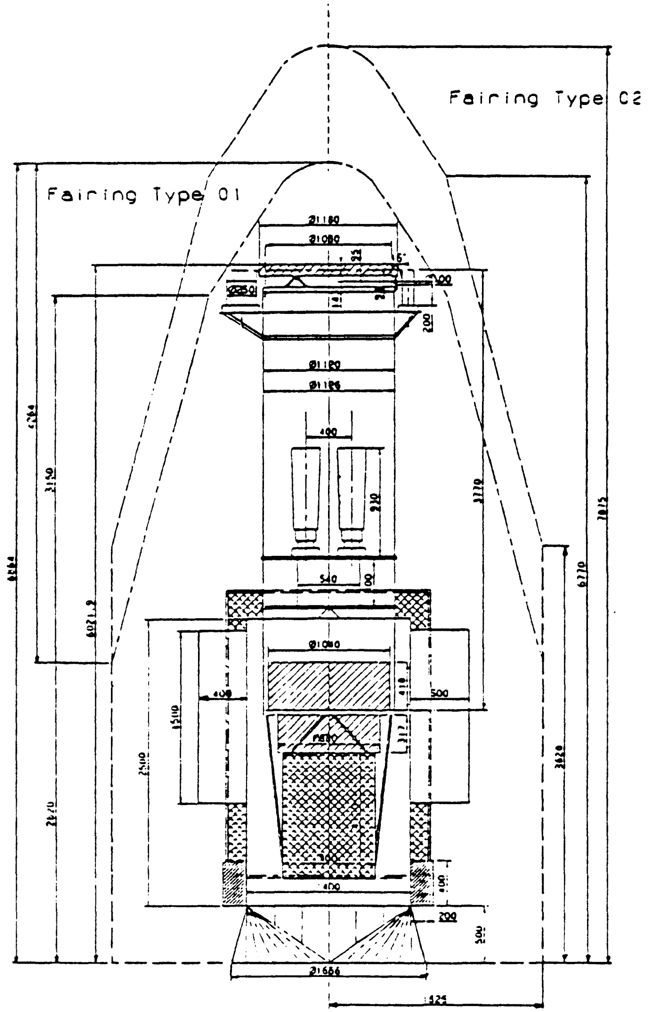


Figure 3: Satellite Structure in its Stowed Configuration within the Ariane Fairings

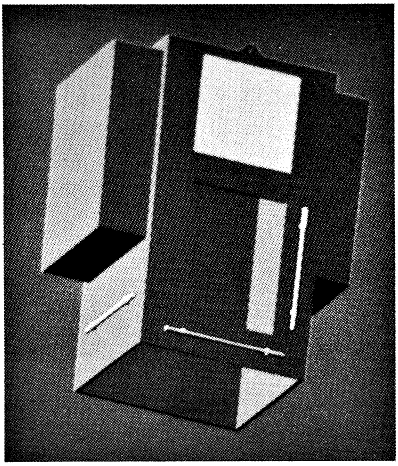
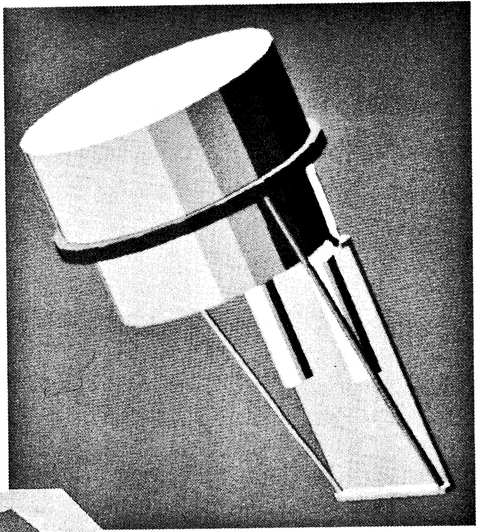


Figure 4:
Bus Structure; North and South Panel Compartments with Equipment and Instruments, Heat Shield Radiator, Magnetic Coils

Figure 5:
Stirling Cooler Assembly Concept



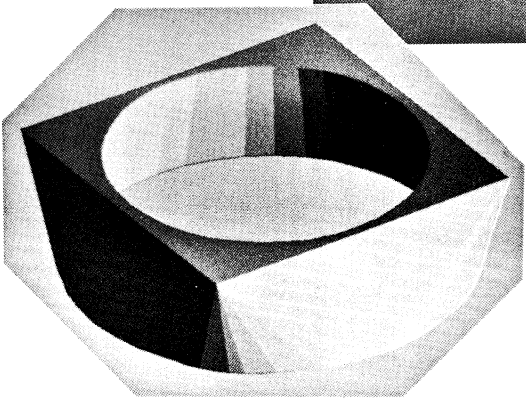


Figure 6:
Transition Adapter -- provides the Geometrical Adaptation from the Square Spacecraft Bus Structure to the Circular Ariane Interface

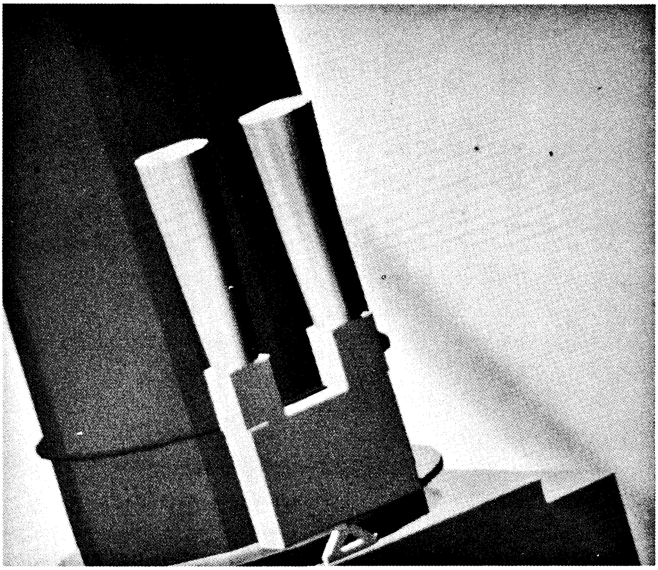


Figure 7: Star Trackers, Gyro Package, Payload Telescope Tube Connection to the Bus

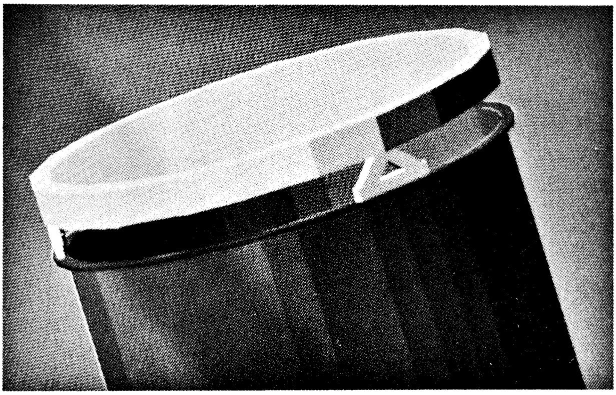


Figure 8: Mask of the Payload Isostatically Mounted to the Telescope Tube

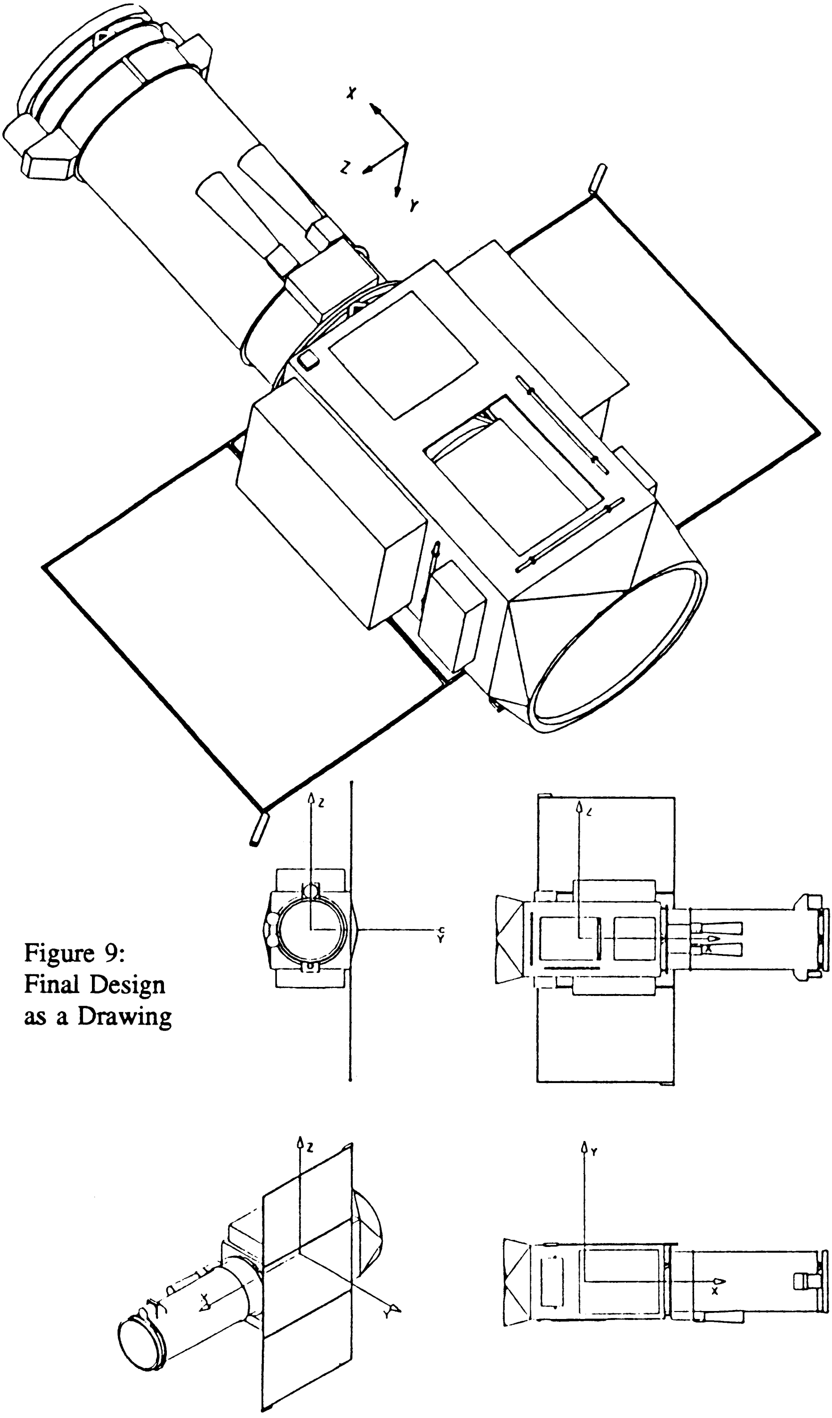


Figure 9:
Final Design
as a Drawing

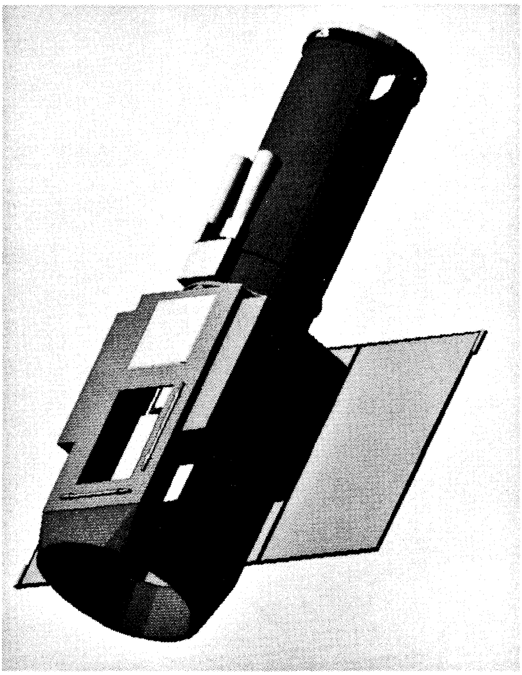
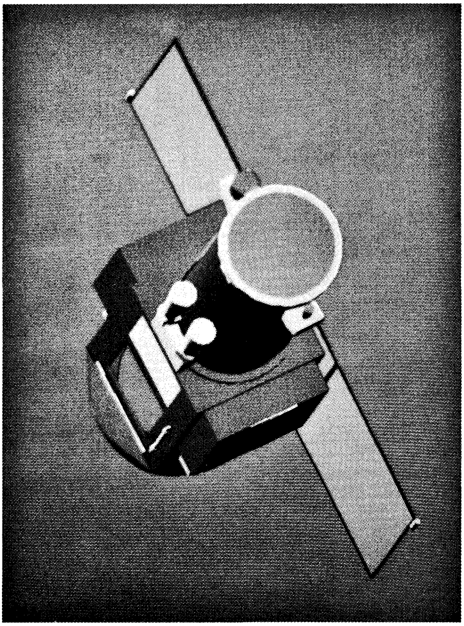


Figure 10: Final Design as a Solid Model



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In this way, the first design, ready for further analyses and further optimization has been made. The finite element analysis has been made from solid models by directly applying already existing geometry, and dynamic analysis has shown how the mass and stiffness conditions are to be coordinated (see Figure 11).

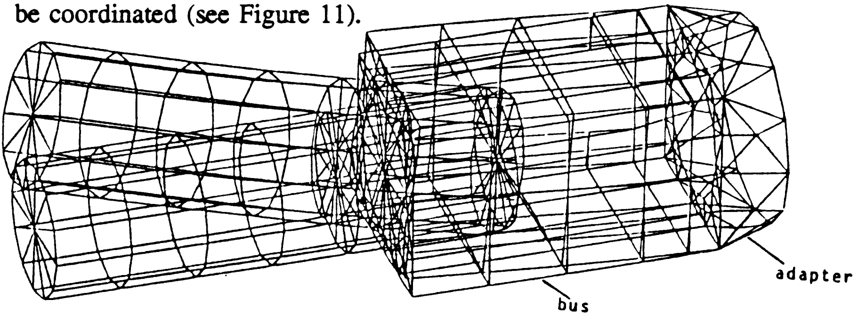


Figure 11: First Lateral Eigenfrequency = 15.9 Hz

Mechanisms meant for the deployment of the massive solar arrays have been taken in consideration and their basic kinematics has been performed by special programs that simulated boundary conditions and established movable joint-hinges. In such a way, the feasibility of design has been confirmed.

All these processes are iterative and inconceivable without computers in the cases of changes in geometry and positions of subsystems. The visual presentation in space -- using solid models technique and being able to see into the construction by "taking off" elements, even seeing and measuring movements of individual systems -- leads to an optimum in design and enables better cooperation within a project team and better organization of the design process.

The following figures show results of the above-mentioned process of designing the satellite structure.

Example 2 Design of Antenna Mechanism

Unlike the structure of the entire spacecraft, mechanisms -- in their nature and key assumptions of their application -- along with the solid model design require a kinematic approach to the problem. The most frequent cases of applying mechanisms in the satellite technology are deployment mechanisms that bring antennas, solar arrays, booms, masts ... from the stowed position during the launch stage into a deployed position when in orbit. As almost every square millimeter of the satellite surface is occupied and covered by various instruments, it is very important to define the deployment trajectory and avoid any collision possibility.

The example given in this paper describes the development of the design of the unfurlable mash antenna mast.

From its stowed position, in which the entire mash antenna is wrapped into a package of 790 mm diameter and 1,900 mm height, the antenna rotates to its final position and develops into more than 5-meter diameter. The entire process of different rotations has been analyzed for several different types of spacecraft buses and configurations and with different sequences of the antenna opening considering time and space (see Figures 12 ÷ 17).

The result of the final kinematic analysis was the obliquely positioned axis that made the movements from the start stowed position to the end position feasible.

The program that has solved kinematrical problems also gave inputs for the dynamic analysis of the entire movement.

Figure 12: Side Fixing Deployment of Mast Kinematics
Characteristic Angles
176.60437°, -245.4584°, 76.6831° (for Reflector)

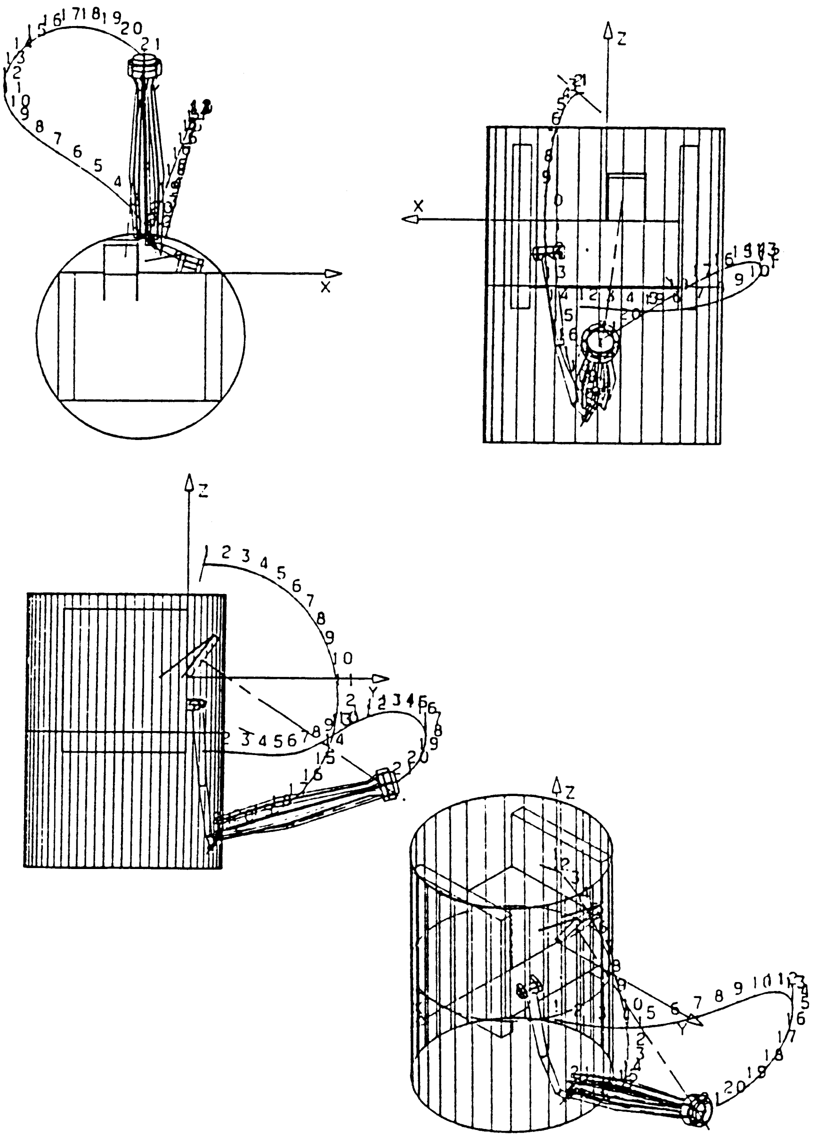


Figure 13: Satellite Bus, Mast and Deployed Antenna

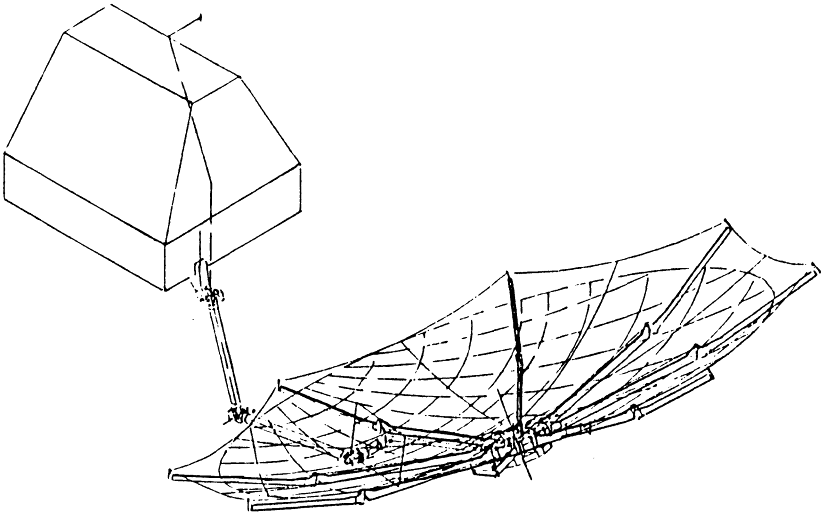
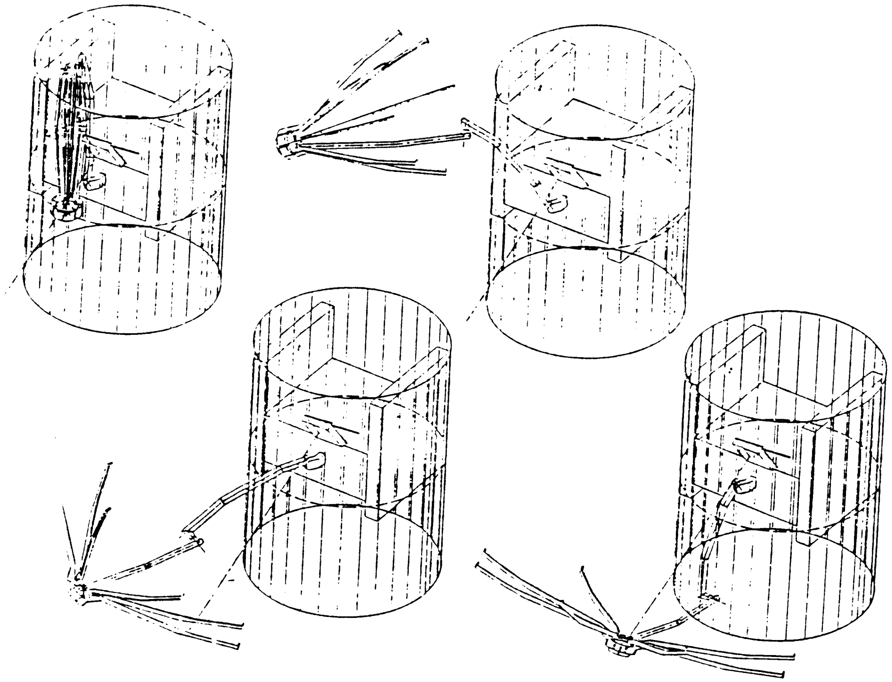


Figure 14: Sequences of Antenna Deployment



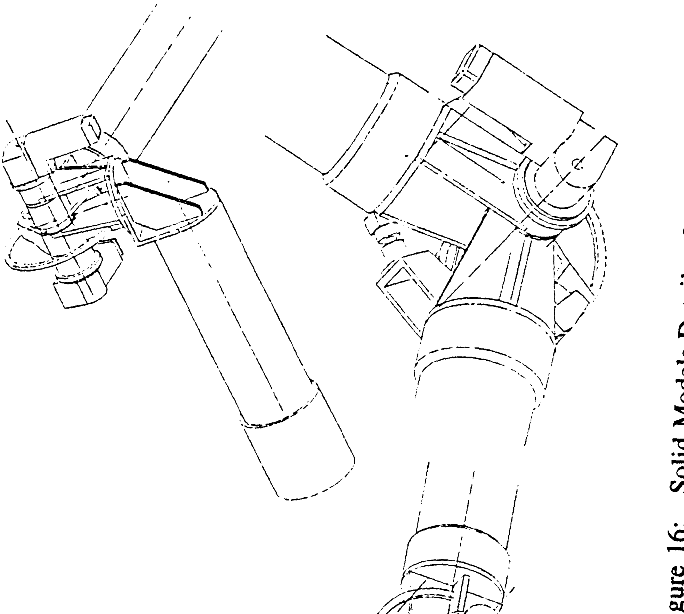


Figure 16: Solid Models Details of Antenna Hinges

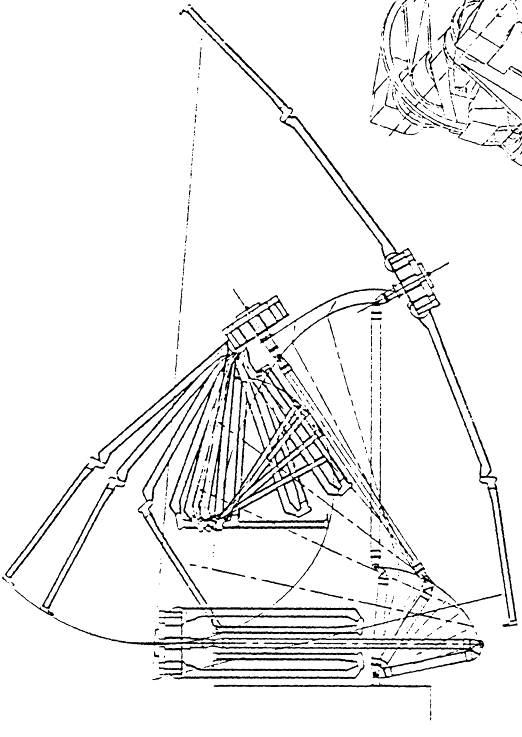


Figure 15: Sequences of Kinematics

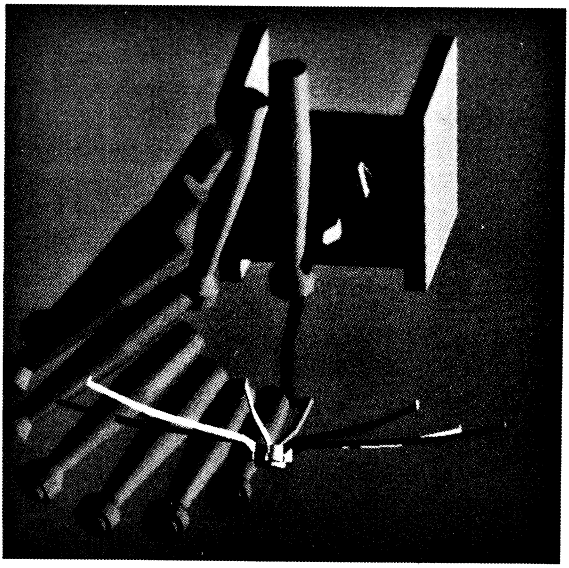
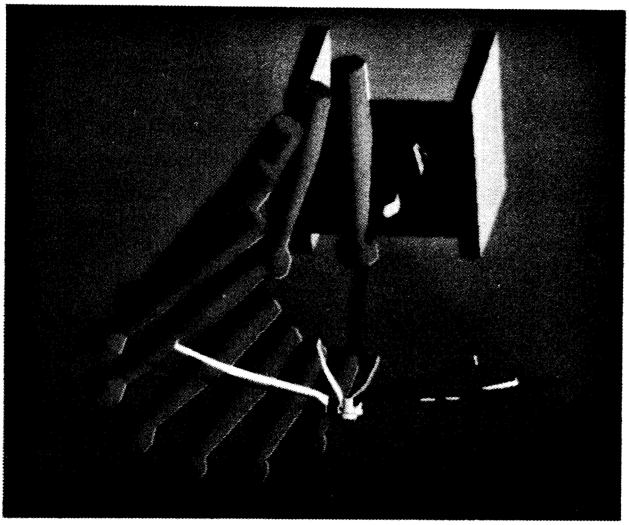


Figure 17: Antenna Deployment Visualization - Solid Model



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Conclusion

Both examples from the practice of designing satellites show that visualization is irreplaceable during the entire process of design. The processes of presenting the object of design and its development through 3D images contributes to better understanding of the problems, both in the architecture of satellites and engineering and designing of mechanisms.

Constant changes in design, the opportunity of directly analyzing structures on the basis of the 3D model and the kinematical presumptions of mechanism movements will continue to represent a challenge to new generations of engineers and scientists in the future as well. Both software and hardware programs are going to improve further and become more powerful and faster, albeit easier to use and uniformed so that they could be compatible throughout the world.

List of References

1. Fortescue, Stark: Spacecraft Systems Engineering, Wiley
2. Agrwal: Design of Geosynchronous Spacecraft, Prentice-Hall, N.Y.
3. Hallmann/Ley: Handbuch der Raumfahrttechnik, Hauser Verlag Vienna
4. Renner, Mauck, Balteas: Satellitentechnik, Springer Verlag
5. ESA/Dornier/MBB/ORS Projects: GRASP and UMA
6. Spacecraft Structures/ESA SP-321, 238, 289
7. W. v. Braun: Station im Weltraum (Across the Space Frontier), Fischer Verlag, Frankfurt
8. The Cambridge Encyclopedia of Space, Cambridge