SELF ERECTING MANNED SPACE LABORATORY

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The Langley Research Center of the National Aeronautics and Space Administration is currently involved in several research programs on manned orbital space stations. This research effort is focused on seeking out and solving the problems which lie in the way of the eventual development of such a vehicle for use as a space laboratory. In conducting this research activity, it has been necessary to consider many vehicle configuration designs and operational concepts in some detail. The Langley Research Center space station study program has been in progress for several years, and it was consisted of both in-house activities and contracted efforts with industry. In the early Langley Research Center studies, only zero-gravity configurations were considered; however, the requirement for artificial gravity simulation for experimental purposes was soon added. Human factors considerations indicated that large diameter vehicles with slow rotational velocities generally permit the most comfortable living conditions for the crew. The configurations which were studied were required to be compatible with the planned launch vehicles such as Saturn, and manned spacecraft such as Mercury.

The most familiar space station configuration is one which is composed of a tubular rim or torus and a central hub which is joined to the rim by a series of tubular spokes. However, it is obvious that a vehicle with sufficiently large diameter to permit a moderate level of artificial gravity to be simulated with a low rotational velocity is not capable of being boosted into orbit in one piece because of geometric factors. It has often been suggested that such a vehicle be disassembled, launched into orbit, and then reassembled by the crew members. With this concept, all equipment can be installed in its proper place in the various sections before launch, and, since the vehicle can be constructed of any material, adequate protection from the space environment can be provided. To obtain an early operational vehicle, it was apparent that emphasis must be placed on a means of obtaining a large volume, large diameter station without the necessity of having the crew assemble a number of smaller units which are launched into orbit either individually or collectively.

Inflatable or expandable spacecraft designs are distinctly advantageous from the standpoint of being able to be packaged as a small-volume booster payload. The Langley Research Center has done a great amount of work on the design and construction of inflatable space stations. Recently, a 24 foot diameter inflatable station was constructed for test purposes. This station plus a Mercury reentry vehicle, could be launched into orbit by a single booster, and after orbit is established, the station could be automatically inflated. There are two primary disadvantages of inflatable space stations. The first is that equipment cannot be installed prior to launch; it must be stored in a hub area and moved into position by the crew. The second is that the inflatable structure is not sufficiently resistant to penetration by meteorite particles for long duration missions.

The Langley Research Center recently developed a concept of self-erecting manned space station which combines the best features of both the rigid and inflatable space station concepts; i.e., the compactness of inflatable/expandable designs and the pre-launch equipment installation features of the rigid configurations.

The concept is a large, multi-manned space station composed of six rigid cylindrical sections joined by inflatable sections and arranged in a toroidal configurations. Three radial elements of inflatable structure join the torus to a central, non-rotating section. It is sized to be folded into a compact payload which can be launched by a single Saturn C-5 booster (S-IB and S-II stages). The Apollo vehicle, launched with the space station, serves only as a personnel transport and resupply vehicle. After the orbit is successfully established, the station can be automatically deployed without the necessity of having men assemble a number of smaller units in orbit. When fully extended, the station can be rotated to simulate gravity in the torus. The crew, launched with the station in an Apollo vehicle, will enter the station after it has been deployed, to set up and check out equipment and begin orbital operations.

Some of the characteristics of the basic NASA design are shown by the photographs of the model in Figure 1. This arrangement was used as a "basepoint" configuration for the North American Aviation, Inc. studies which were performed under NASA contract NAS1-1630. During the study period, a close working relationship was maintained between North American Aviation and the National Aeronautics and Space Administration to insure the evolution of the configuration could incorporate the best ideas of both organizations.

The general arrangement of the space station is shown in Figure 2. Struts, connecting the hub with each of the six rigid cylindrical sections, are used to assure uniform deployment from the launch configuration to the orbital configuration. The orbital configuration, with the non-rigid sections inflated, results in a space station with a 100-foot diameter, although the diameter could be treated as a variable. The hub provides non-rotating docking facilities for the two Apollo vehicles which serve as the crew escape vehicles as well as the personnel transport and resupply vehicles. One end of the hub has been enlarged to house a small zero-gravity laboratory.

This space station launch configuration is shown in Figure 3. The modules are clustered, as indicated by the cross-section A-A, and the enlarged section of the hub serves as the interstage between the space station and the one Apollo vehicle which is launched with the station. This payload can be launched by a single Saturn C-5 booster (S-IB and S-II stages), while the crew transfer and resupply mission can be accomplished by means of Saturn C-1 or Titan III launch vehicles.

While the diameter of the initial configuration was sized by the limited payload capability of the Saturn C-2 booster, it became apparent early in the investigation that the rotational effects on the crew members might be intolerable. In Figure 4, a number of the parameters affecting the man's tolerance to the conditions aboard a rotating space station have been plotted in a manner such that a "comfort zone" is defined. The bounds of this comfort zone are determined by four parameters - the percent change in gravity between the man's head and feet; the space station angular velocity; the radial velocity; and the radial acceleration. It is believed that the change in gravity or acceleration between the man's head and feet should not exceed 15% in order to prevent impairment of blood circulation and to reduce the discomfort felt when the man changes the relative position of his head and feet by bending over or lying down. The recommended upper limit on the space station angular velocity is approximately 3 rpm to minimize the effects of Coriolis acceleration. Experiments with a rotating room have indicated that 3 rpm, with the human subject at a radius of 40 feet is a tolerable condition. The radial velocity of the space station should be no less than 20 fps in order to minimize the change in gravity the man will experience when he walks along the rim of the station. The upper limit on radial acceleration, or gravity, was set at 0.5 g to reduce fatigue; the lower limit is somewhat arbitrary, it being the minimum acceleration under which normal body processes can continue to function.

It can be seen from Figure 4 that a space station radius of 50 feet does not fall within the comfort zone. Consequently, a radius of 75 feet was selected for subsequent space station designs. With the increased payload capability of the Saturn C-5 booster, this larger diameter station can readily be launched into a low altitude orbit.

An additional factor in the design of the self-erecting space station is the optimum shape of the module. A module can be either a right cylinder or curved, i.e., a section of a torus which has a circular cross-section, as illustrated in Figure 5. A man, walking through a cylindrical module, will experience a change in gravity because his distance from the center of rotation is changing. Also, toward the end of the module, he will feel as if he were on an inclined floor because his body aligns itself with the radius vector. A curved module overcomes these problems, but it is more difficult to manufacture and it creates an undesirable launch configuration. Most of the difficulties in the cylindrical module can be overcome by use of a stepped floor as shown in Figure 5 to approximate the floor in the curved module. This has been exaggerated in the figure to illustrate how this might be accomplished.

A 150-foot diameter space station, using curved modules, was designed. It is shown in Figure 6. It has six modules, connected by inflatable material, and there are three inflatable spokes connecting the hub to the modules. This space station is deployed by means of controlled pneumatic pressure in the spokes, rather than by mechanical actuators which were discussed previously. It was subsequently concluded that this was not a suitable deployment mechanism because the motions of the modules could not be closely controlled. Each module of the configuration has a section of inflatable material at its midsection which is used to reduce the module curvature in the launch configuration as shown on the right-hand side of the figure. If the curvature were not reduced, the payload cross-section would extend as far as the dashed line and it would tend to create aerodynamic buffet during launch.

The space station will be continuously subjected to meteoroid bombardment during its lifetime in orbit. Since the inflatable material which is used in the design has very poor penetration resistance, it has been minimized on all designs. Wherever inflatable material is used, it would be lined with penetration-resistant panels by the crew members after the station has been deployed. The meteoroid environment which was assumed for this study is based on Whipples 1957 estimate as illustrated in Figure 7. The majority of particles are very small, and cause only a gradual erosion of the exterior surface. Of particular concern are those which are sufficiently large to cause a penetration of the structure. Through the use of emperical data on hypervelocity particle impact, a multiwall structure was designed to reduce the number of penetrations of the space station structure as much as possible. This structure is shown in Figure 8. The outer two layers of aluminum skin and glass wood (or polyurethane foam) are used only for the meteoroid bumber. They do not carry any structural loads. All of the structural loads in the modules are carried by the aluminum honeycomb. Sections of the inner wall are welded together to form a pressure tight vessel; consequently, penetrations of the outer three layers of aluminum will not result in a loss in pressure within the space station. If this structure were used throughout the space station, it is estimated that there would be only about 10 to 20 penetrations per year of the inner pressure wall of the entire station.

After an intensive design effort, it was concluded that a self-erecting space station could be designed with a completely rigid rim if the modules were properly hinged. This configuration, Figure 9, is deployed by mechanical actuators located at each hinge position. Since the motion of the modules is critical, the deployment must be carefully phased to prevent binding of the hinges. Several crude models of this configuration have been made in an attempt to demonstrate the feasibility of the concept.

The spokes, leading from the hub to the rim, are of inflatable material and must be lined with panels of rigid structure to prevent meteoroid penetration. The hub of this space station configuration is very large because it is designed to carry all the loads encountered during launch. The lower portion of the hub is utilized as a zero gravity laboratory compartment. Zero gravity is created in the compartment by mounting it on bearings and driving it in a direction opposite to the space station rotation.

Certain requirements, established early in the North American Aviation study had a particular influence on the evolution of the space station configuration. One of these stipulations was that the space station laboratory should be available as early as possible in order to provide information on a variety of subjects which could greatly affect future operations in space. Another was that the station must have a one year operational lifetime. To accomplish this with such a large vehicle meant that a very conservative design approach should be taken. The equipment which is used must be within today's state-of-the-art. Since the space station will be the first long-duration manned vehicle to be placed in space, reliability of operation is exceedingly important. Consequently, one of the major characteristics which was developed was that of a completely self-sufficient life support system in each module. Each module will have its own environmental control system and power supply. With this approach, a failure in one module would not jeoparidize either the mission or the lives of the crew members.

The concept of a "shirtsleeve" environment has been utilized throughout the space station because of the necessity to provide a comfortable working environment for the crew members. Since the tour of duty for the crew members of the space station will be a minimum of six weeks, they cannot tolerate living in a pressure suit as do the crew of Mercury, Gemini, or Apollo. Pressure suits would be worn only in emergency situations. The crew members will have free access to all parts of the space station. There will be pressure tight doors and airlocks between each of the adjoining sections of the station; however, so that if there is a major failure in any one section it can be sealed off from the remainder of the station until it can be repaired.

The dimensions of this station are such that an internal volume of approximately 60,000 cubic feet is available. With such a large volume, it is now reasonable to consider a much larger crew than was originally planned for the 100-foot diameter station. With an increase in crew size, all systems must be resized and docking facilities must be provided for additional Apollo vehicles, since there must be one Apollo vehicle at the station for every three men aboard. Studies have shown that a crew of 27 men can readily be accommodated by the space station; however, a nominal size of 21 was selected on the basis of anticipated duties and work load on the space laboratory mission.

The multiple vehicle docking facility and the zero gravity laboratory compartment have a great influence on the design of the hub of the space station. The Apollo vehicle should have a non-rotating (with respect to the space station) docking attachment. Also, the Apollo vehicles should be stored in a position near the plane of the modules so that the moments of inertia of the space station more nearly resemble those of a disk than those of a sphere. These two requirements lead to the conclusion that the hub should be as short as possible. At the same time, the zero gravity laboratory must be isolated from the normal movements of crew members between the rim and the hub. In Figure 10, the recommended space station configuration is shown. It incorporates all the refinements which have been discussed herein.

A docking facility to accommodate maximum of seven Apollo vehicles is illustrated in Figure 11. When the Apollo approaches the space station, the docking attachment is driven opposite to the space station rotation. The Apollo which was launched with the station is moved to one side. The second Apollo docks, and is moved to a position diametrically opposite the first. The docking attachment then is permitted to approach the station rotational velocity and the crew members exit to the hub by means of tubes which are extended to the Apollo airlock.

Figure 12, a cross-section of the hub, shows how the zero gravity laboratory compartment of the hub can be isolated from the normal flow of traffic between the rim and the hub. It occupies the lower portion of the hub. As in the previous hub design, the compartment is suspended by bearings and mechanically driven opposite to the direction of the space station rotation. The exact method for the suspension and drive has not yet been worked out, but it is apparent that the system must provide some means of isolating the compartment from low magnitude distrubances in the motion of the space station.

Although NAA placed primary emphasis on the configuration analysis in this study, the many systems which would compose the operational space station were also designed. In all these technical areas, particular effort was devoted to developing an approach which would provide the utmost reliability in a very early time period. Only systems which are well within the state-of-the-art were considered.

A typical example of this approach is found in the design of the environmental control system. Each module has a complete system, independent of the other modules, so that a failure in any one module will not result in the loss of the crew members aboard the station. The environmental control system is semi-closed, i.e., it must be resupplied on a periodic basis with oxygen, nitrogen, and a small amount of water. Consideration was given to the use of a completely closed system, which has two primary advantages - lighter weight and no resupply requirement - for long-duration missions. It was found that for a six-week mission on the space station, the weight of the semi-closed system was equal to the weight of a closed system, including the additional weight in the power system required for the electrolysis of water. Despite the obviously desirable characteristics of the closed system, it was concluded that the semi-closed system was more desirable for use in an early time period. Oxygen regeneration equipment, just now in the early stages of development, will not have had sufficient operational experience by the 1966 time period to completely establish its reliability.

Each module has its own power system to provide the necessary electrical energy for all the equipment within the module. Several power sources - fuel cells, solar cells, nuclear reactors, and solar dynamic units - were studied for possible application to the space station. Only the solar cell system was able to meet the requirements for availability and reliability as well as the many other factors associated with the selection of a system. A solar cell power system is very expensive and requires a very large array area in order to provide the 17 kw peak power load for the space station; consequently, it is not recommended for use in a later time period when the reliability of the other systems would be established. The designs of the other systems were similarly established; however, these were not particularly unique and will not be discussed further here.

It has been found that the space station design which was presented herein has a gross weight of about 121,000 pounds, including all the equipment which would initially be placed in the station. The Apollo vehicle - command module, service module, and launch abort tower - which is launched with the space station plus the required interstage structure bring the total launch weight to approximately 150,000 pounds. Thus, the Saturn C-5 (S-IB + S-II stages) can readily launch the space station into a low altitude orbit, and a Saturn C-1 or a Titan III booster can be used to resupply the station and to transfer crews at scheduled intervals. For short crew mission duration, large numbers of C-1 boosters are required for crew transfer on the 21-man station, as shown in Figure 13. In order to mimimize the number of boosters required, the crew mission duration must be increased or the crew size must be decreased. The other means of overcoming this problem is to develop a multi-man logistics vehicle which could be used to transport all crew members to the station in one launching.

NAA has taken a very conservative design approach in this study. The use of more advanced systems or techniques would result in a decrease in the space station weight, but only at the expense of a decrease in the level of confidence associated with its operation.

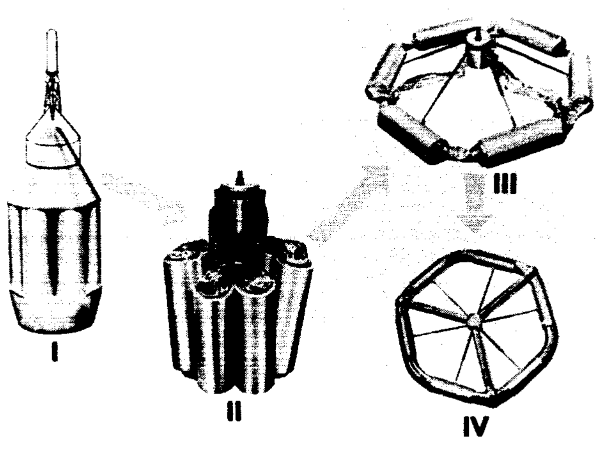

FIGURE 1. ERECTION SEQUENCE

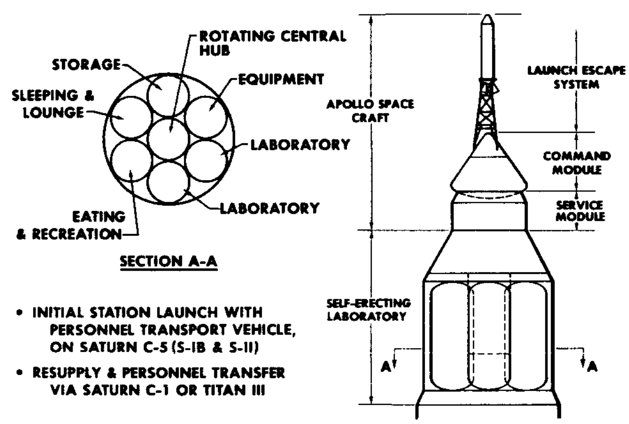

FIGURE 3. LAUNCH CONFIGURATION

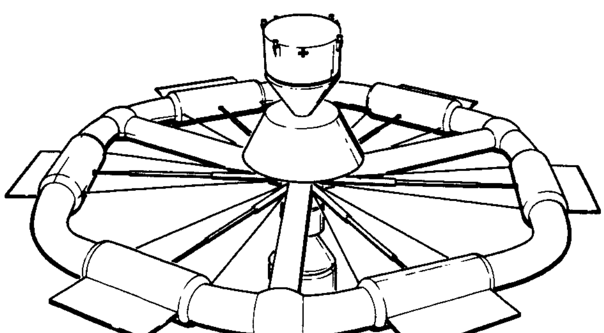

FIGURE 2. INITIAL CONCEPT

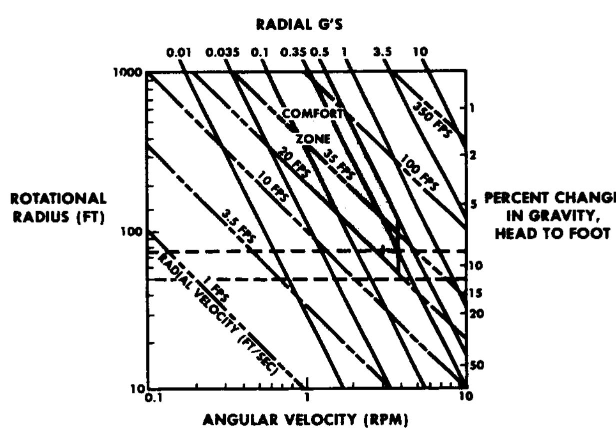

FIGURE 4. ROTATIONAL EFFECTS

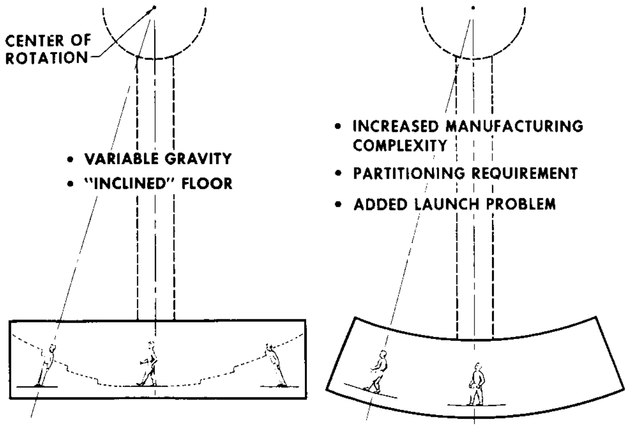

FIGURE 5. MODULE DESIGN CONSIDERATIONS

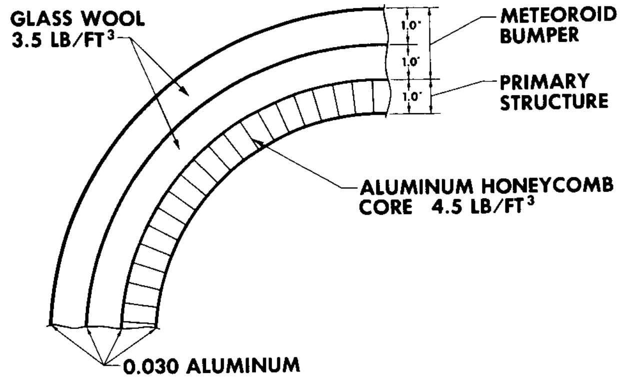

FIGURE 8. TYPICAL WALL STRUCTURE

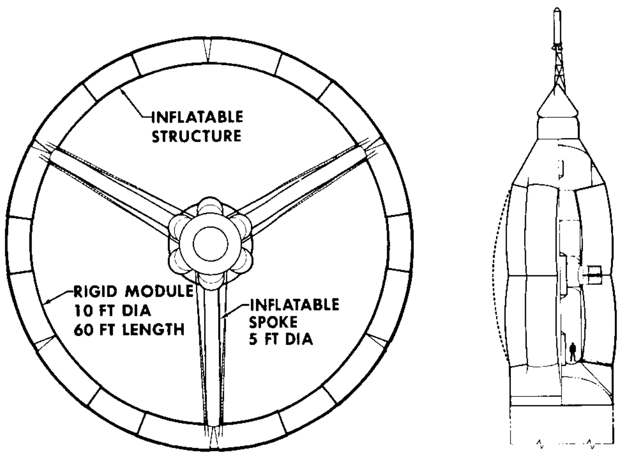

FIGURE 6. SPACE STATION CONFIGURATION
(150 FT DIA)

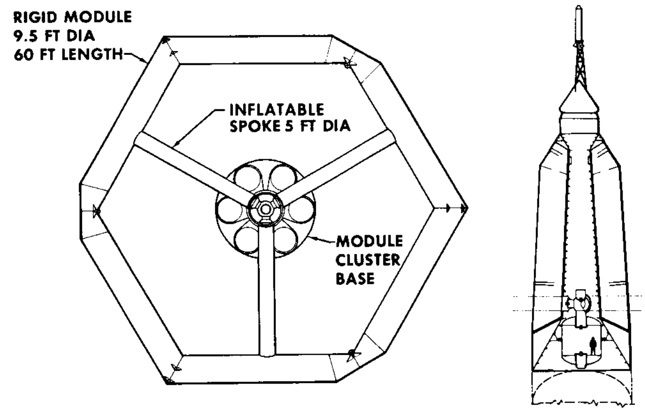

FIGURE 9. SPACE STATION CONFIGURATION
(150 FT DIA)

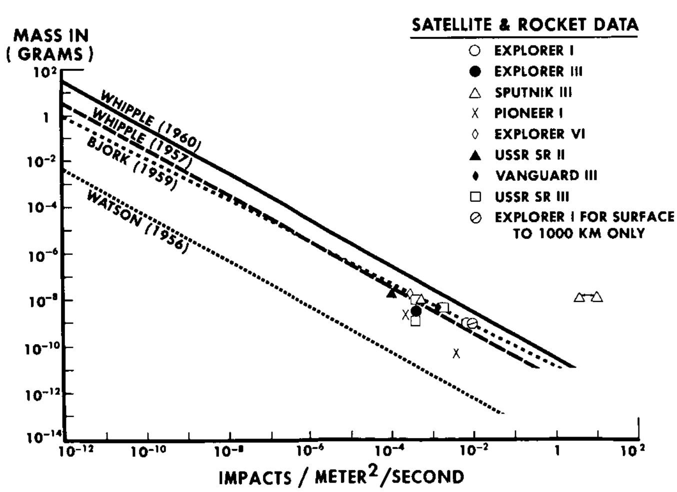

FIGURE 7. METEOROID ENVIRONMENT

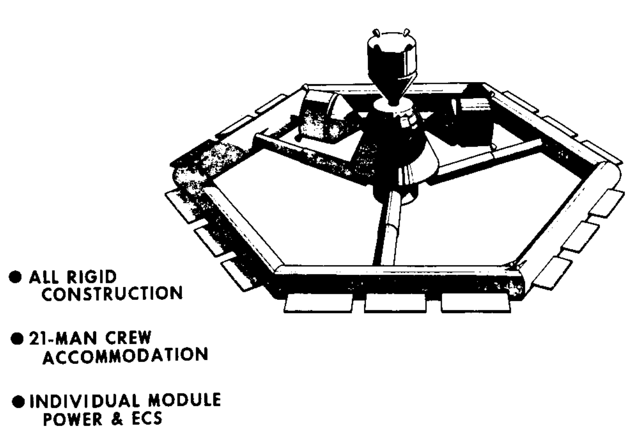

FIGURE 10. SELECTED CONFIGURATION

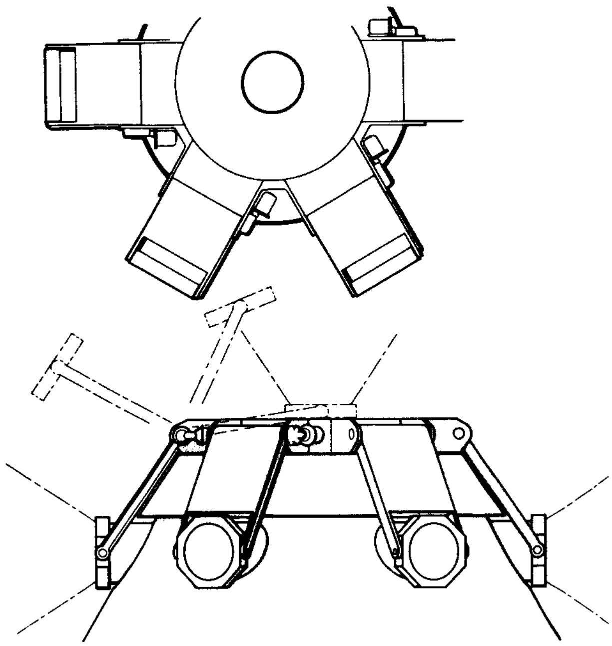

FIGURE 11. MULTIPLE VEHICLE DOCKING

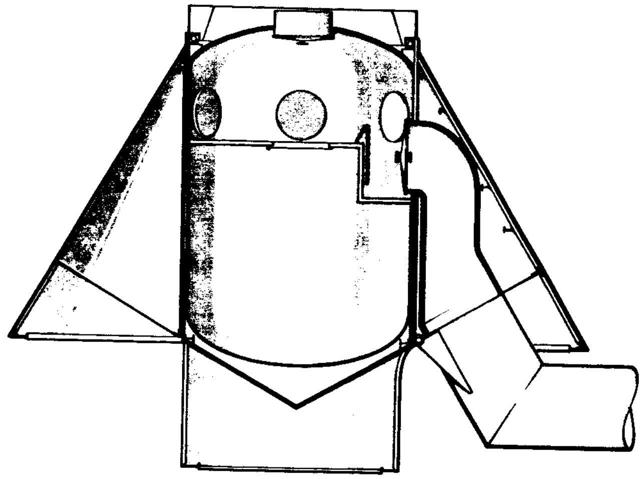

FIGURE 12. HUB SECTION

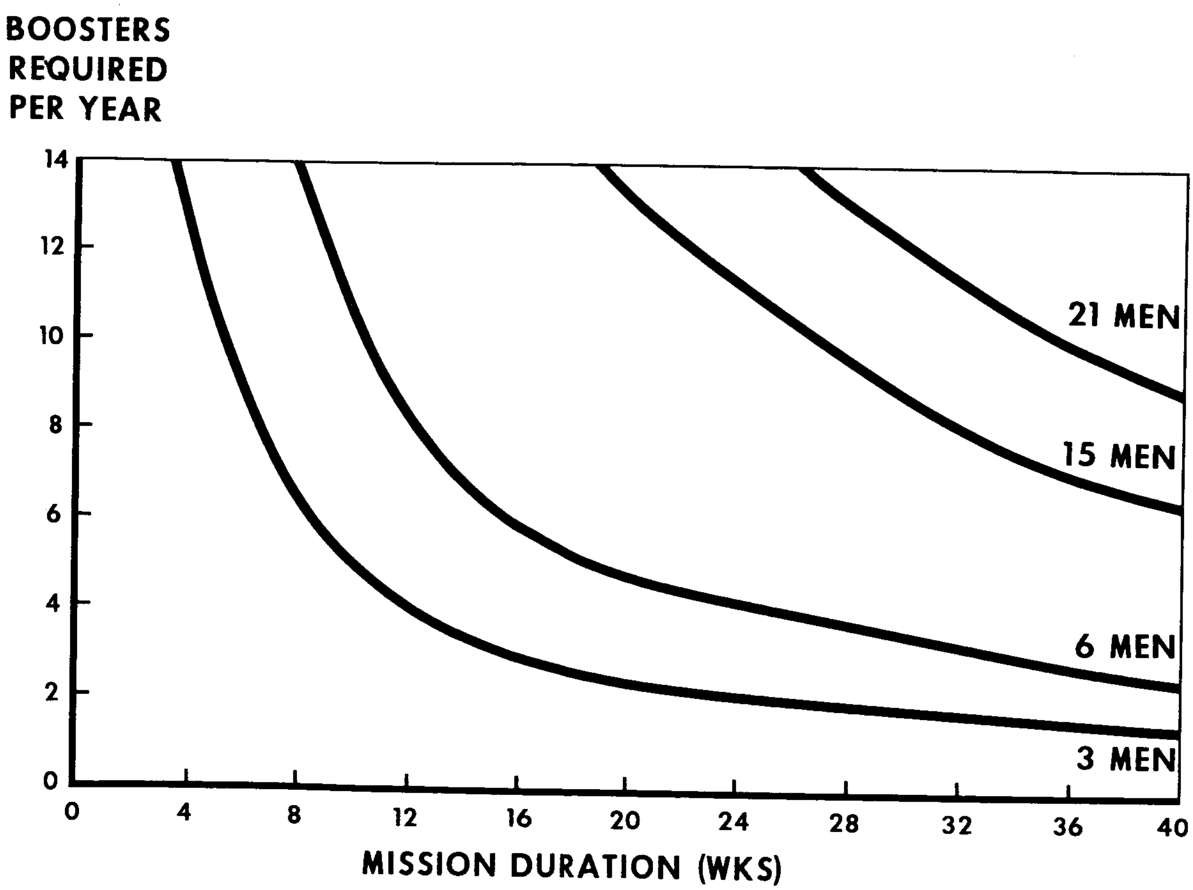

FIGURE 13. SATURN C-I BOOSTER REQUIREMENT