SATELLITE APPLICATIONS FOR EXPANDABLE SPACE STRUCTURES

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Wherever a large pressurized volume is required in space, the advantages of a compact payload during launch and injection should be considered. Whenever repeated expansion and contraction as well as the protection afforded by a rigid, load-bearing structure is required, the particular type of space structure discussed in this paper is a prime candidate. A companion paper, "Semirigid Structures for Space Applications," by P. M. Knox, Jr., and R. O. Moses, Jr., describes the development and construction of this structure in detail.

Very frequently, the principal applications of this structure are for manned systems. This would include such applications as the variable extension arms of an artificial gravity space station, the expandable hangar for maintenance of vehicles in space or a combined docking and airlock system. On the other hand, unmanned applications may be of more immediate value. These include an adaptation for use as a radiator for a nuclear reactor in space or the use of this available structure as a test bed for certain space experiments. An investigation of this latter application was conducted.

Test Vehicle Features

The adaptability of the structure investigated to several experiments which would provide data for space station design appears quite feasible. The features which provide this capability are listed in Table 1. The details of construction are summarized to identify their advantages for use in a test vehicle.

(1) The structure has been designed and tested for the environment to be encountered in a low altitude orbit launched on the ETR.

(2) The internal expanded volume approximates the size and shape of a small manned space station. Realistic simulation without large scaling factors is possible.

(3) The retracted dimensions of the structure fall within existing launch vehicle payload envelopes. This is critical both dimensionally (to satisfy aerodynamic criteria) and inertially (to satisfy mass distribution criteria).

(4) Design for internal pressurization up to 11 psig permits simulation of space station environments over a wide range of pressures as well as by use of different gas mixtures.

(5) The base bulkhead and forward dome attachment frame provide ideal locations for the attachment of equipment necessary for the vehicle

operation. The base bulkhead will withstand launch accelerations with a full load of equipment. A much lighter weight base structure can be constructed and installed if weight becomes critical.

(6) Access to internal equipment is available through a manhole in the forward dome during checkout operations. This hatch seal has been tested with the structure.

(7) The telescoping sections and forward dome are removable. This provides access for installation of large equipment and for any modifications necessary to conduct the tests.

(8) The external skin panels are easily removed for reworking or for replacement by test panels. Internal panels carry the structural loads.

(9) The structure seals and coatings have been tested for a 1-yr life. The design was established based upon this life criteria. A structure of this size and shape suitable for a 1-yr test period has not been previously available.

(10) The passive thermal control is designed to provide an environment that will give maximum internal equipment reliability. This can be easily revised to suit test conditions by modifying the external coating and the detachable insulation between the walls of the structure.

(11) The internal compartment may be modified to provide segments or smaller compartments if desired for test purposes. The design permits this modification to be readily accomplished.

(12) The telescoping sections inherently provide several identical large diameter joints for test of varying seal designs. This capability would require some modification for tests requiring more than merely varying the sealant materials.

(13) The side panels of each section protect the inner sections during launch. The outer panels of the forward section will withstand launch airloads and heating if necessary.

(14) A mechanical lock has been designed which will permit locking the structure in the expanded position if this is deemed necessary for test or operation.

Expandable Structure Experiments

Several experiments which may be conducted through the application of this structure have been conceived. These include the following:

(1) Tests of the expandable structure operation in space for development of actual applications.

(2) Simulation of space station shielding for radiation environment experiments on a tissue equivalent manikin.

(3) Micrometeoroid effects on thermal control of space stations and penetrations of a typical space station structure.

(4) Effects of the complete environment on passive thermal control of large discontinuous structures.

(5) Seals and sealant life tests.

TABLE 1

Test Vehicle Features

Design for Orbital Mission
Approximation of Manned Space Station Volume
Retraction to Within Payload Envelopes
High Allowable Internal Pressures
Accessible Equipment Mounting Structure
Internal Access for Checkout
Removable Sections and Dome for Installation
Removable External Skin Panels
Design for 1-yr Orbital Life
Variable Passive Thermal Control
Internal Segmentation Feasible
Multiple Joints for Test
Side Panels Protected for Launch
Mechanically Locked Extended Sections

In addition to these tests many variations may make use of the expanded volume after orbital injection to provide operating room or a controlled, shielded exposure. Many materials tests including tests of seals and sealants may fall in this category.

Expandable Structure Operation

Operation of the Expandable Space Structure in space cannot be completely verified by ground tests. Ground tests are limited in their ability to demonstrate expansion safely, completely and without damage in the zero-gravity environment.

At first glance, this does not appear to be a significant problem. However, the weight of the telescoping sections dampens fluctuations in pressure during expansion on earth. In orbit, this mass has the opposite effect, and the inertial effects may tend to aggravate any pressure fluctuations. The relatively large pressure needed on earth (a maximum of 0.25 psig) to lift this weight and expand the structure is reduced to a very low value in orbit.

In orbit, excess pressure may have to be used to overcome any tendency of the sections to bind (Fig. 1). These pressures may establish velocities of one section with respect to another that could damage the structure or seals when the motion is stopped by the mating flanges of adjacent sections. The control of expansion pressures is expected to be more critical in orbit than on the ground, since it is anticipated that less pressure is required to expand than on earth. The only opposing forces in orbit would be the friction of the guide rails and shoes, the bladder friction on the wall and the tendency of the bungee bladder folding system to act as a retracting spring. These have been insignificant compared to gravity forces in expansion tests.

In order to verify that the expansion of the structure can be adequately controlled in orbit and that the possible uneven deployment of the telescoping sections is an insignificant factor, it is recommended that the structure be placed in orbit and expanded in an operational test. Data collected would determine any unusual problems that cannot be anticipated from ground testing.

The test would be conducted by evacuating the structure during the initial ascent and coasting period. After the payload is separated from the launch vehicle, the holddown bolts attaching the upper section to the adapter plate would be released and the structure expanded.

The expansion would be controlled by limiting the maximum pressure to a value which could not accelerate the sections to a damaging velocity. At the onset of any slight binding tendency, the pressure buildup to this value should release the structure. Flow rates would also be controlled to a safe level. Any of several gases could be used, including dry air, O_2, N_2 or a mixture of O_2 and N_2. Gas selection would be dependent upon other tests being carried.

After complete expansion, the pressure would be automatically increased to design pressure. The high pressure source or a vibrator could be commanded to operate intermittently if complete expansion did not occur.

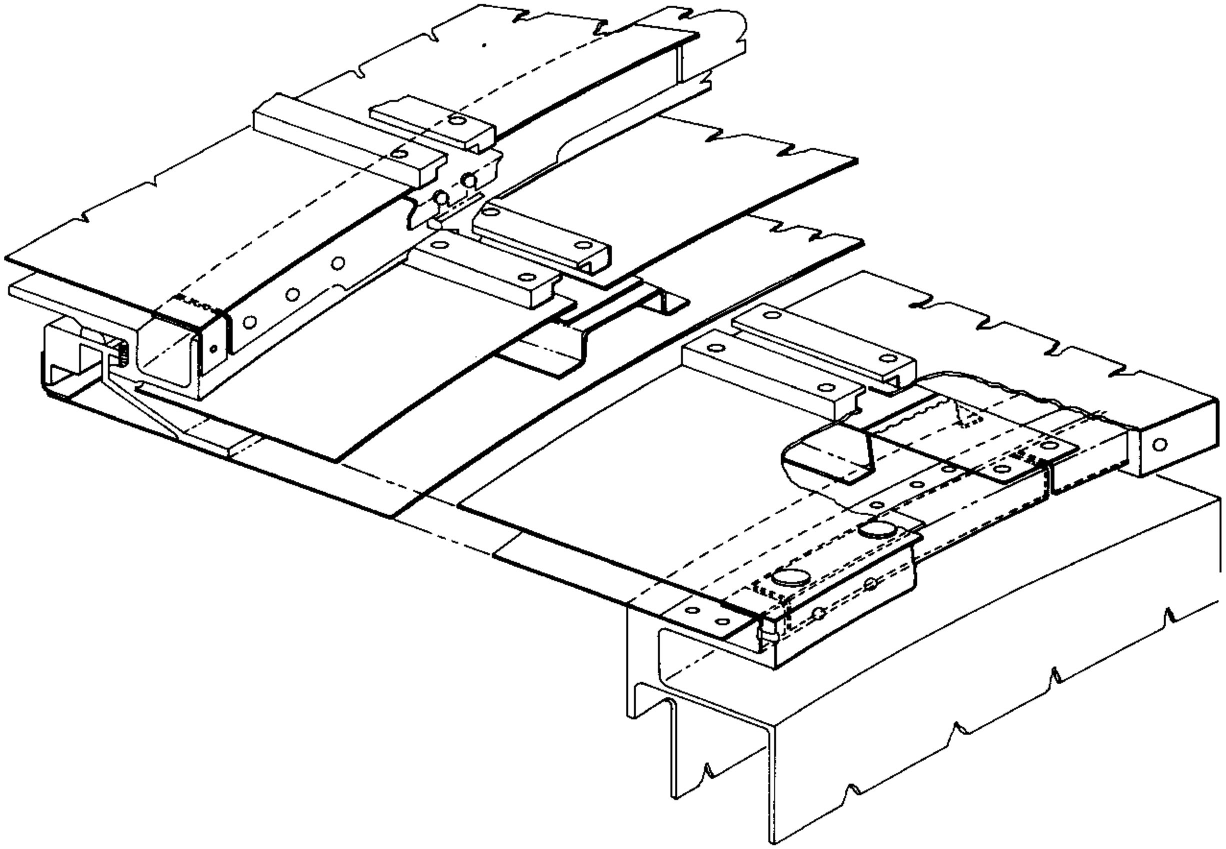

Fig. 1a. Structural Configuration, Expandable Space Structure Vehicle

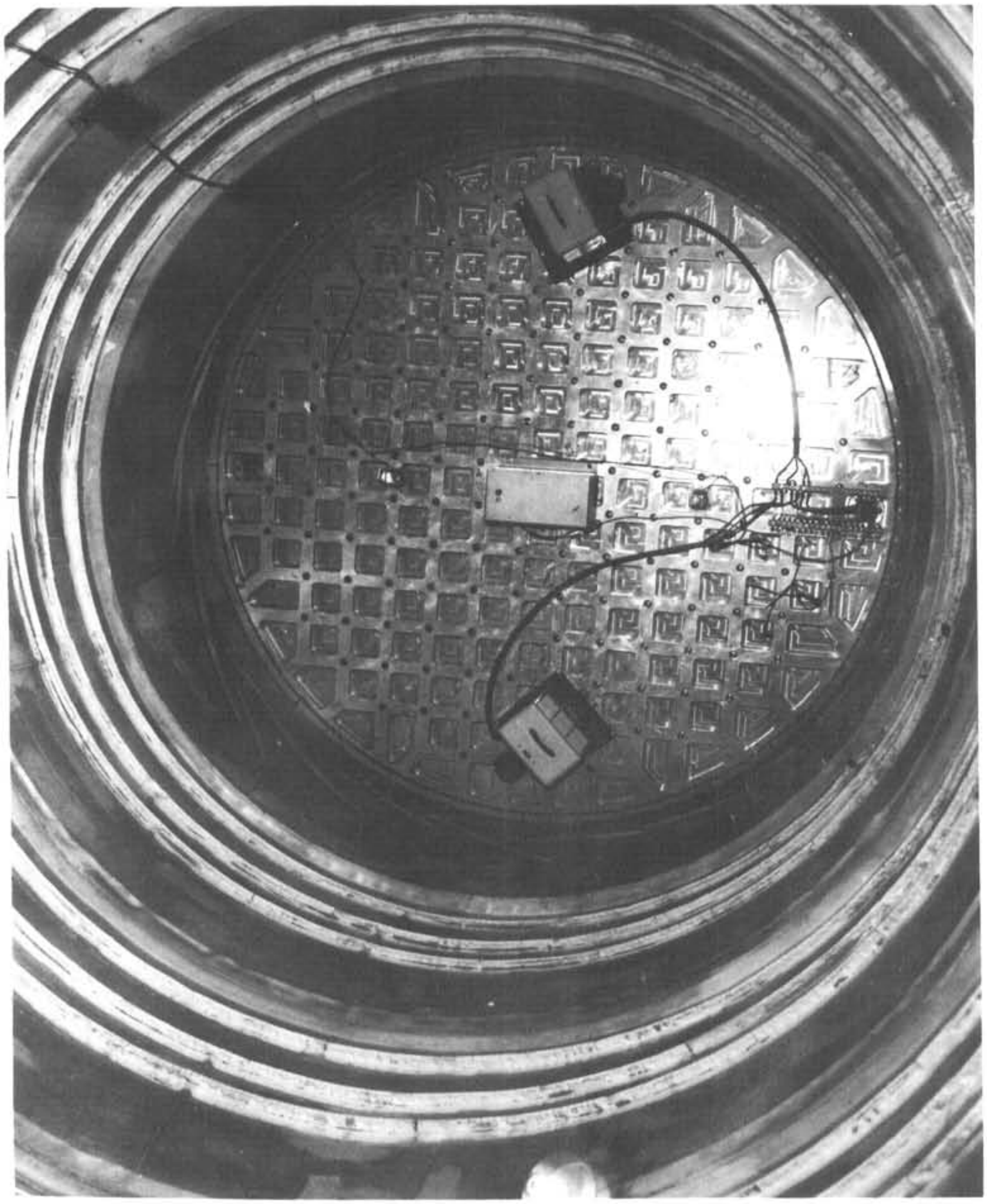

Fig. 1b. Interior View of Extended and Pressurized Vehicle Showing Bladder Extended

The foregoing test is the simplest which would provide necessary data. Additional features which may be tested could include:

(1) The ability to retract the structure in orbit. Since this is a function required by some applications, the potential should be verified by test in the zero-gravity environment. The retraction should be conducted with and without internal pressure and would require installation of a simple positive retraction system.

(2) A retractable structure could be easily modified to determine vacuum welding between various surfaces at the metal-to-metal contact points at each ring frame. The variation with time of contact may be a factor which is measurable through this technique.

(3) A retractable structure could incorporate several expansion control system designs to determine which provides the most satisfactory expansion characteristics.

(4) Other modifications require more extensive development, but could include: helical expansion and bladder folding with possible improvement of bladder stowage; intermittent bladder to provide seal at joints only and provide for installation brackets on side walls of structure; installation of additional sections to establish very long expansion arm characteristics and to study dumbbell stabilization; and installation of a large diameter rotating seal design in a special section to determine zero-gravity life and leakage characteristics in the hard vacuum.

Radiation Environment Effects

The Expandable Space Structure offers an excellent opportunity to conduct a realistic simulation experiment of the space cabin environment and to measure simultaneously the biophysical and physical parameters of space radiation. This experiment would use a tissue equivalent plastic manikin (plastinaut) and associated radiation sensors which have been developed and are available from the Air Force Weapons Laboratory, Albuquerque, New Mexico.

Considerable data are available describing the radiation environment to which a spacecraft is subjected in orbital flight. However, it is difficult to relate data which measures radiation flux with varying amounts of shielding in different spacecraft environments to the dosages that would be received by the critical organs of man. Even those attempts to measure dosage and RBE gave only the so-called "whole body values," which can be misleading. Simulation of the radiation environment on earth is unsatisfactory due to the variety of particles and energy levels encountered at various altitudes.

Consequently, it is important that a combined experiment be conducted to measure the radiation environment in a typical space cabin as well as the dosage in a simulated human body at the location of the critical organs and blood-producing centers. This dosage should be measured for sufficient time and over a wide enough range of altitudes to effectively sample the dose rates to which man may be exposed in earth orbits on possible future space missions. This requires that the experiment be highly comprehensive from the standpoint of instrumentation and time and extremely realistic as to uniformity of geometry and shielding. From such an experiment, criteria may be established for designing orbiting space vehicles over a wide range of orbital altitudes and missions.

The test would require that the plastinaut be mounted in the Expandable Space Structure in a location providing uniform shielding from the structure. The location chosen was below the elliptical dome, with the plastinaut mounted in a position normal to the longitudinal axis of the structure. The plastinaut is supported by a couch structure which also will support some of the external environment test instrumentation. The structure will be stabilized such that, in this position, the plastinaut will face in a direction opposite to the flight direction, with his feet toward the earth.

The orbit selected for test must provide a wide sampling range of the radiation environment of space vehicles. To obtain this range of dosage, and to effectively map out the orbital volume in which manned space vehicles may operate around the earth, the orbital altitude should extend to an apogee of greater than 1500 n mi with a perigee below the radiation belts.

After injection into orbit, the Expandable Space Structure is expanded. This expansion places the plastinaut approximately 9 ft, 6 in. above the operating equipment attached to the aft bulkhead. Shielding from the back thus occupies only a small solid angle. It is desirable to increase the shielding provided by the elliptical dome bulkhead. Shielding would be increased by increasing the mass to approximately 2 gm/cm^2 through the insertion of a false dome within the pressure dome. Other shielding mass can be used. If additional tests of a double wall structure are performed which would require modification of the structure by addition of the double wall on the dome, then the dome shielding would be approximately 0.5 gm/sq cm.

Several variations in the test procedure may be considered.

(1) The plastinaut may be moved to another position within the structure after the initial test period. A suggested position would be along the structure longitudinal axis with feet toward the aft bulkhead (Fig. 2). In this position, shielding would be uniform completely around the plastinaut and the equipment would be heavy around his feet, a situation that may exist in unmanned spacecraft. The most important feature of this test would be the ability to analyze data to determine the probable cause of any dosage anomalies that could not be explained from the

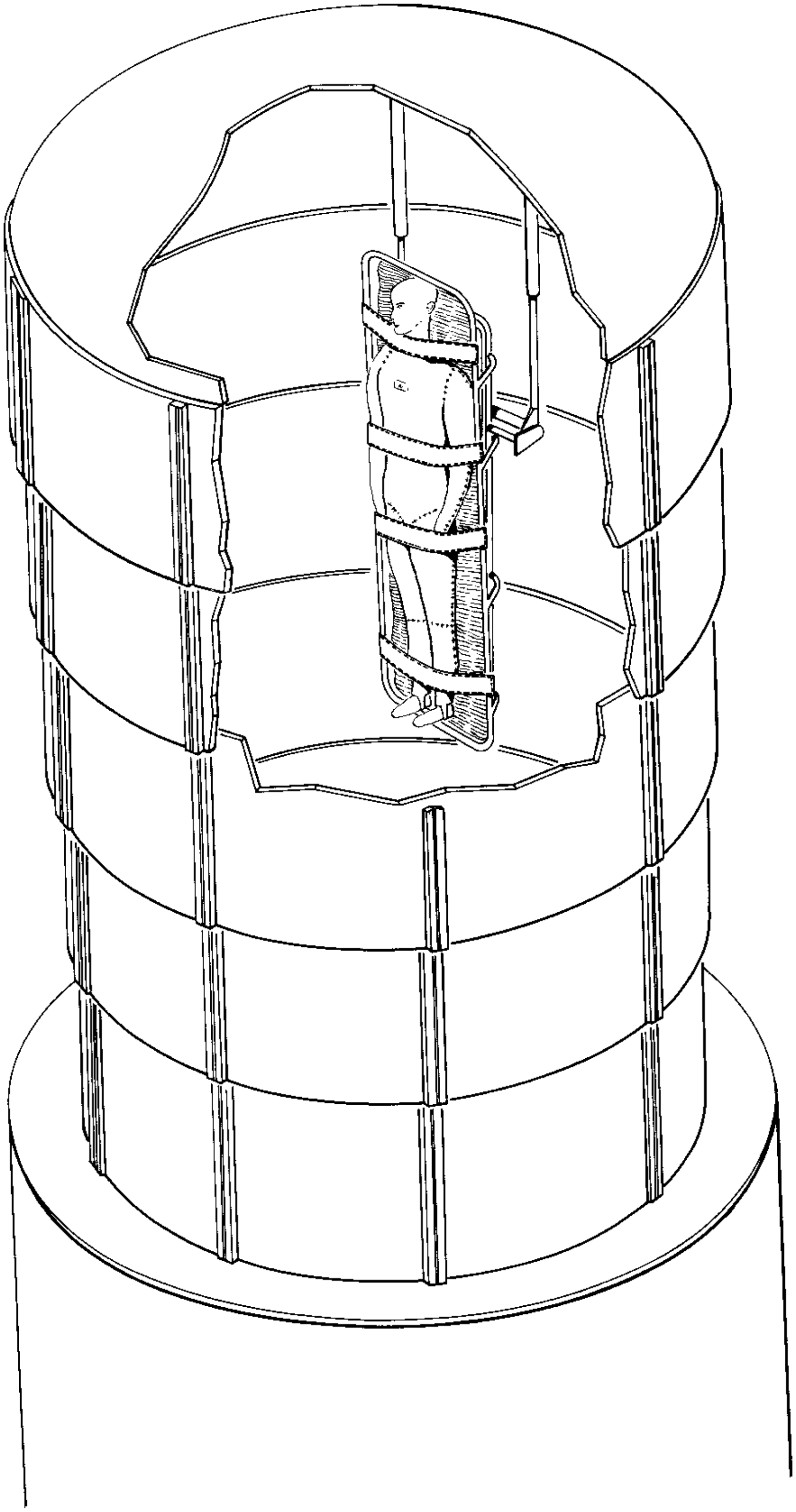

Fig. 2. Installation of Plastinaut in Structure for Test

first test. The internal volume of the structure is sufficient to perform this change in position. The plastinaut may also be rotated about his longitudinal body axis. This may be desirable to obtain various exposures, since the structure may be stabilized to a predetermined attitude in orbit.

(2) The duration of the test may be varied. The life of the space structure can be extended to 1 yr. During this life, the orbital volume may be mapped several times at extended intervals if desired. For a two-position test, an exposure of 7 days in each position is believed sufficient.

(3) Some of the orbital tests would more suitably simulate a manned space station environment if they were conducted in a near-circular orbit. Since this would limit the radiation flux range encountered, it may be undesirable to expend a plastinaut for these tests. However, data of the ambient dosage using the basic instrumentation and perhaps a section of plastic would provide a real correlation with other data provided from a plastinaut test and would establish the mission duration possible in such orbits. The advantage of these orbits is the extended duration expected to be feasible during such a test because the radiation exposure to equipment is reduced.

Micrometeoroid Effects

The large surface area and volume of the structure provides an excellent large scale simulation of the probability of impact and penetration to be expected in a manned space station. With the exception of Pegasus, previous satellites have provided meteoroid data on very small scale samples. Pegasus is designed to provide data from approximately 200 sq m of instrumented thin panels during a long duration flight. The problems of converting penetrations of the Pegasus shape and thin panel to probability of no penetration of a space station of another shape and double, walled structure indicate the desirability of a better simulation.

Another gap in the field of meteoroid penetration analysis is the wide range of analytical results that may be obtained by using different data sources. This makes penetration prediction very unreliable until consistent sets of data become available. For the present, then, the better the simulation of the structure and the environment that is possible, the more confidence can be placed in the ability of the space station design to perform with the required safety.

In addition, correlation between meteoroid penetration simulation tests in ground facilities and tests in satellites can be provided. Verification of the performance of a satellite structure, designed as the result of criteria defined by ground test, would be a step forward in defining safe design criteria for this characteristic of manned space station structures.

The structure provides several features which make it extremely suitable for testing micrometeoroid penetration characteristics (Fig. 3). It is designed to withstand micrometeoroid penetrations to attain a low probability of penetration over a 1-yr period through use of a double-wall meteoroid bumper construction. Also, the external panels are easily modified to mount meteoroid impact detectors both inside and out, and the design provides protection of these detectors both during ascent and while the structure is being expanded.

Estimated penetrations of an area of this magnitude would be 13.5 per day for a 0.005-in. thick detector surface or one penetration in 69 days for a 0.025-in. detector. These periods vary with the data used as a computational base. Therefore, a significantly long period is required for the test. A life of 1 yr appears satisfactory.

To conduct the test, meteoroid foil detectors could be installed on both surfaces of all removable external panels including panels to be installed on the dome. The 0.070-in. skin of the forward section could be replaced with thinner skin if the structure were covered by a fairing. All external skin panels could be made equal in thickness to the thickest panels on the meteoroid satellite. In this way, the two tests may provide better correlation. Each panel would be separately instrumented for a total of 48 segments (including dome segments). The number of penetrations and time of penetration for each panel may be recorded over the 1-yr life.

The low probability of penetration of the double wall requires only the monitoring of internal pressure to determine the existence of a leak. Should the leak occur at the same time as a penetration of the external panel a penetration through the double wall would be indicated. The size of hole would be indicated by the rate of pressure drop. Should no leaks occur from this cause during the 1-yr period, an effective bracket of structural requirements for missions of shorter periods being considered would be obtained.

Some additional instrumentation may be installed to obtain data of other events related to meteoroid penetrations or to obtain more complete instrumentation of the punctures. This could include:

1. Instrumentation to analyze the explosive effects of a meteoroid puncture in a large chamber with a high oxygen atmosphere.
2. Internal compartmentation could be installed to aid in detecting several punctures during the test life should they occur.
3. Variable panel thickness could be installed and may have some merit. However, a better simulation of a space station is believed possible with uniform panel thickness.

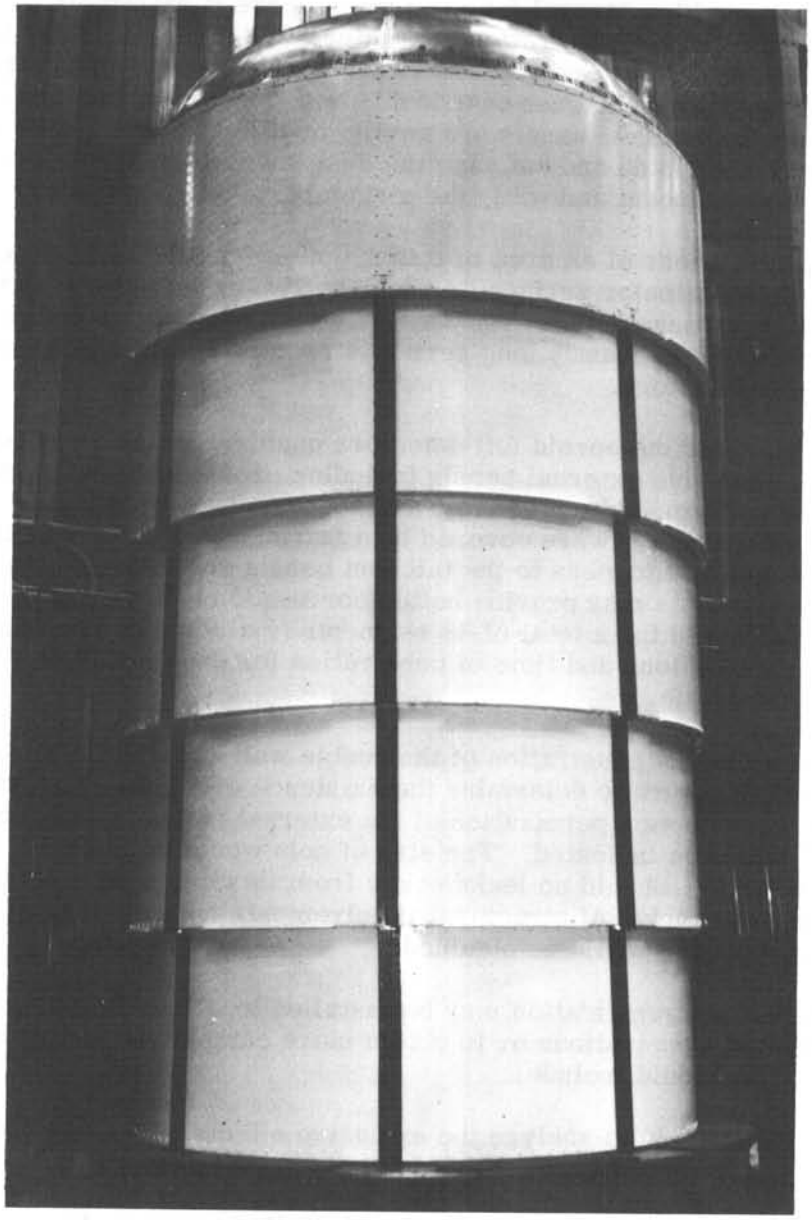

Fig. 3. Completed Expandable Space Structure Vehicle Fully Extended

Thermal Control Experiments

The thermal control of earth oriented orbital space stations is a most difficult problem to analyze precisely. The attitude and orbital variations and variations caused by structure and installed equipment all affect the thermal balance.

The extensive thermal analysis and laboratory tests of coatings conducted during the design of this expandable structure provide a basis for estimating the internal thermal environment in space.

More thorough analytical methods are available to determine the expected internal equipment and structural temperatures. However, the effect of the combined meteoroid and electromagnetic spectral environment over a 1-yr orbital life must be predicted. The need exists for data which verify these predictions and establish the validity of the experimental and analytical techniques. The expandable space structure provides a clean and uniform structure, yet complex enough to demonstrate applicability of analytical techniques. Coupled with the analyses and laboratory tests that have been conducted thus far, a test of the passive thermal control system devised for this vehicle would further verify the capability to design for similar space stations in the space environment.

The most enlightening data would be to verify the degradation of the passive thermal control coatings on a stabilized vehicle where one side receives greater exposure than others. The effect of the degradation of thermal control coatings on the internal temperature distribution (both on equipment and on a simulated astronaut) as well as on the internal atmosphere, should be determined. Such questions as the possibility of convection currents should be examined in this large volume to determine any possible secondary effects.

During the course of the test, the passive thermal control design would maintain inner wall temperatures within a specified temperature range determined analytically. This must be checked when internal heat sources are finalized. However, the time to recover from the initial cold internal atmosphere due to expansion by use of a stored gas system must be determined. To provide a satisfactory test, the forward dome must be insulated in the same manner as the side walls; the aft base plate may also be insulated, depending upon the equipment installed on its external surface.

Measurements would be taken of outer and inner skin temperatures, surface temperatures of critical equipment and the plastinaut (if installed) and the internal vehicle atmospheric temperatures at various points. The thermal instrumentation would be designed to continue operation in the event of loss of pressure. A fan would be provided to circulate the air to provide uniform internal temperatures for equipment thermal control, if desired. The fan would be used when convection current testing was completed, or as soon as damaging hot spots were detected.

Since thermal variations would change only slowly over the 1-yr life of the vehicle, the sampling intervals could be quite large after the expansion and orbital transients had been recorded during the first few days.

Several variations are possible in addition to the simple recording of thermal levels and internal airflow. These include the following:

(1) The thermal coatings could be varied at each telescoping section. While skin temperatures may vary, the internal atmosphere would keep the environment uniform for protection of equipment.

(2) A semipassive cooling system could be installed in conjunction with a heat source. To do this, the aft base plate may be used for radiator installation as well as the outside panels of the aft telescoping section. An alternative cooling method would be to use an internal vehicle liquid-to-gas heat exchanger, pass the internal vehicle atmosphere through it and reject heat through the vehicle walls by selection of a suitable coating. However, in the event of a leak in the structure, radiative cooling would be necessary to continue a test.

The capability to perform these experiments was verified by defining several test configurations. While these configurations were defined for a particular launch vehicle, they also serve to illustrate the variations possible for application to other vehicles. A summary of the data required is given in Table 2.

TABLE 2

Summary of Data Required

Configuration			
1	2	3	Data Required
X	X	X	Expanded length of ESS
X	X	X	Internal pressure
X	X	X	Internal temperature
X	X	X	Gas supply pressure (structural leak rates)
X	X	X	ESS acoustical intensity and frequency
	X	X	Radiation measurements with plastinaut
	X	X	Radiation measurements without plastinaut
		X	Meteoroid count
X	X	X	Verify equipment operation
		X	Meteoroid penetration count
	X	X	Destruct system

Minimum Test Configuration

Figure 4 illustrates a minimum test configuration. This configuration is designed to test the operation of the structure itself. The launch vehicle would inject it into a 100-n mi orbit and provide initial stabilization in orbit. After separation from the injection stage, the structure would be expanded by a pressurization system. The expanded length, internal pressure and temperature would be measured. In addition, all acoustic noise would be recorded to indicate unusual occurrences. All data would be transmitted to a ground station once each orbit for a total mission time of 48 hr. In this test, the low orbital altitude precludes long duration measurements. Therefore, the extension of the structure is the primary test. For this configuration as well as those following, the injection altitude was a launch vehicle constraint. Higher injection altitudes would permit redesign to incorporate other test objectives.

For this test, only minor installations are required. An adapter is used to connect the structure to the launch vehicle, and the external equipment, such as antennas, is mounted on this adapter structure. All internal equipment is attached to the interior of the base bulkhead. This includes a pressurization system, telemetry and command communications and a battery power supply. The only modifications required for the structure are the installation of a hold-down system to retain the structure in the collapsed position during launch and the installation of pressure relief and equalization valves. The weight of the complete payload is 2145 lb.

Radiation Dosage Configuration

Figure 5 illustrates the use of the expandable structure for the radiation dosage test already discussed. This payload is also injected into a 100-n mi orbit. However, a complete test requires sampling over a wide range of altitudes so propulsion must be added to the payload to inject it into an elliptical orbit with approximately a 2000-n mi apogee. Due to the confines of the allowable payload envelope, and other launch vehicle constraints, the solid rocket propulsion is mounted in an inverted position. This requires rotating the structure before ignition of this motor for injection into the elliptical orbit.

The structure is expanded after injection into the elliptical orbit and pressurized to 11 psi. All data is recorded continuously and read out to the ground station on command approximately once each orbit. This operation is repeated for approximately 7 days. The alternative plastinaut position may then be commanded and the mission repeated for an additional 7 days. Pressurization gas and power is supplied for a 14-day mission. Sufficient gas is supplied to make up for a loss of 2 lb/day which is assumed to give sufficient margin above test values for conservative design.

The design of this configuration requires several additional systems over those used for the minimum configuration. Propulsion necessitates the addition

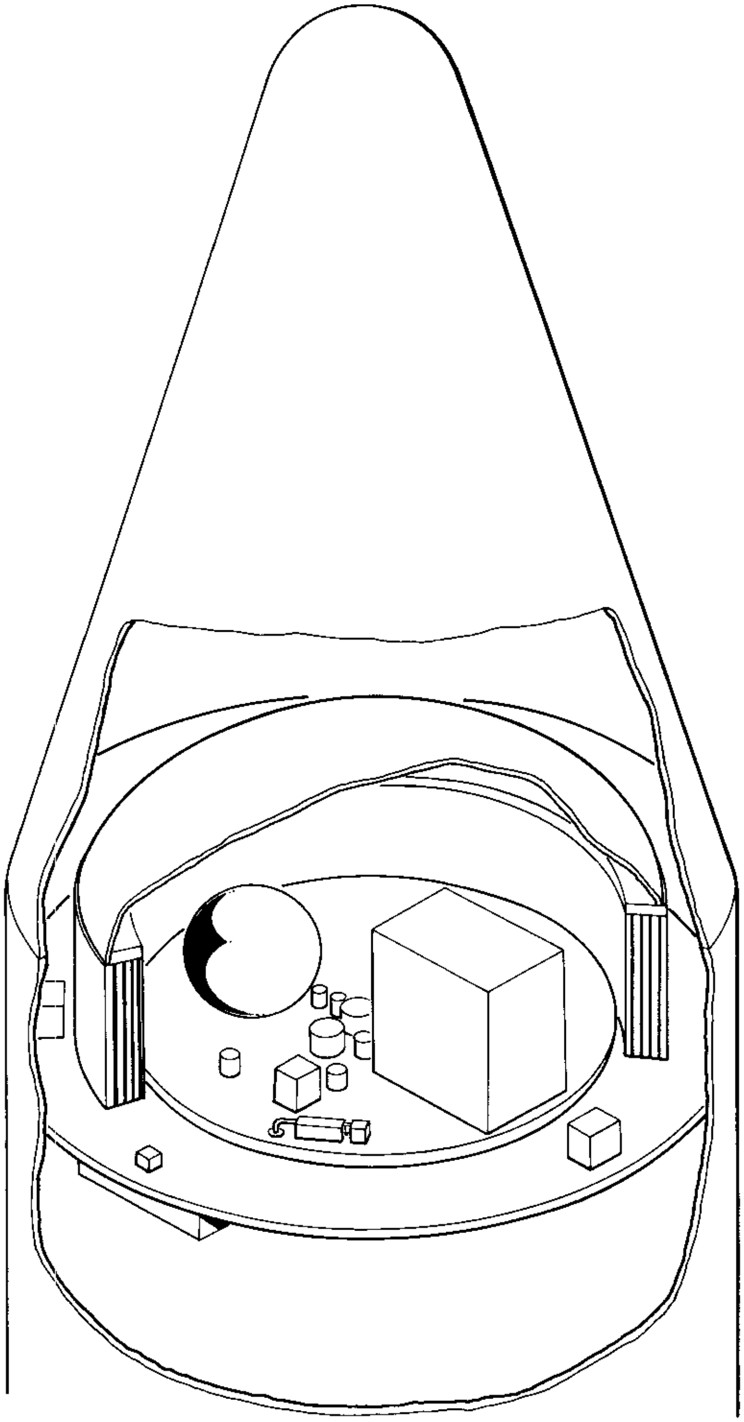

Fig. 4. Minimum Test Configuration

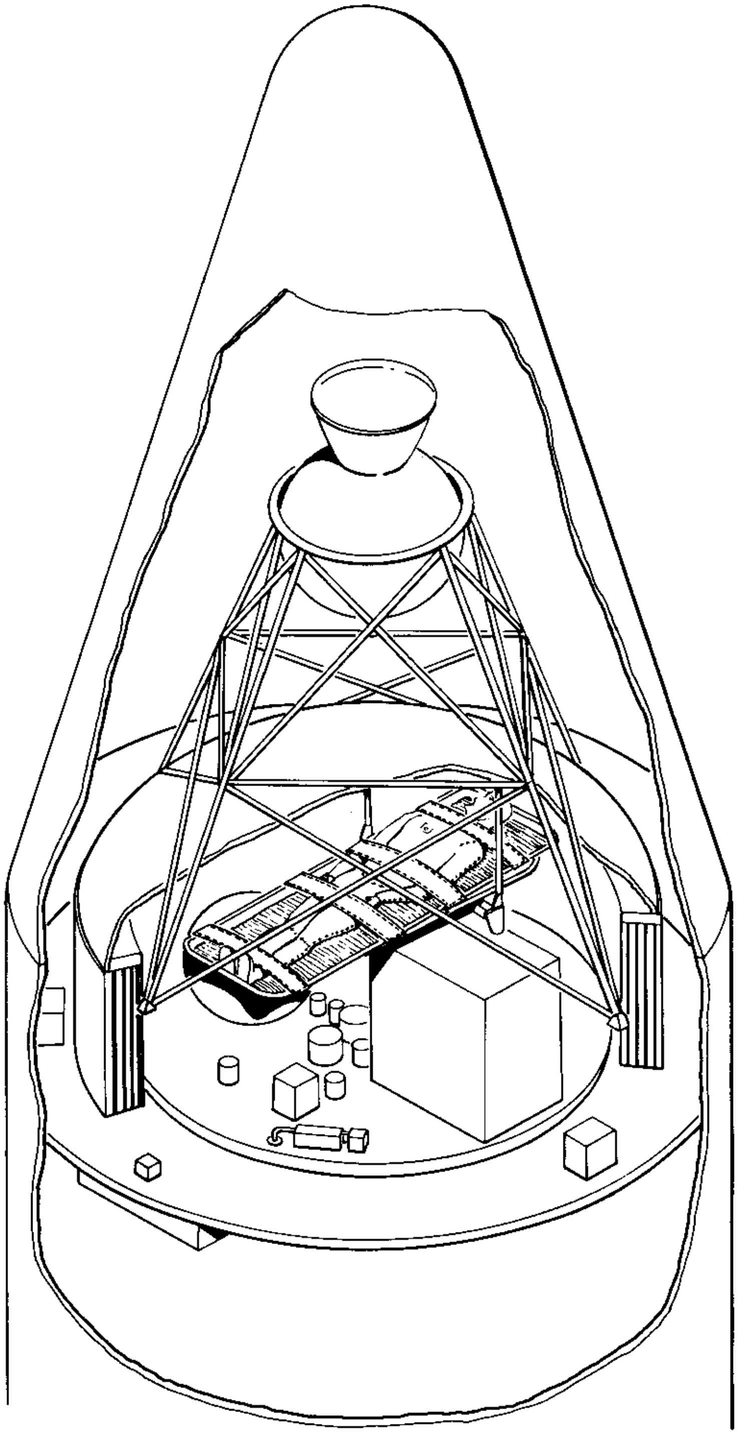

Fig. 5. Radiation Dosage Test Configuration

of stabilization and attitude control systems. These systems are also required to stabilize the structure during the 14-day mission and thereby assure a known position of the plastinaut and his instrumentation within coarse limits. The instrumentation, telemetry and command, and power systems all are significantly increased in complexity over the minimum test configuration although the power supply still requires only batteries. Structure installations include supporting structure for the propulsion system; the design and installation of the plastinaut couch assembly supported by the forward dome ring frame; installation of a propulsion separation system; installation of additional dome material as a false inside dome to increase shielding above the plastinaut and installation of a locking system to lock the structure in the extended position in the event of a gas leak. These installations can be made with only very minor modifications of the structure. The total weight of the assembled payload is approximately 4500 lb.

Long Duration Test Configuration

Figure 6 illustrates a long duration test configuration which incorporates a wide variety of tests. This configuration is designed to provide a 1-yr mission in an orbit with perigee at 120 n mi and apogee at 500 n mi. After injection into orbit at 100 n mi and separation from the launch vehicle, an impulse transfers the vehicle into an orbit with a 120-n mi apogee. Another impulse then transfers it into the final orbit. The propulsion system is then jettisoned. An apogee of 500 n mi is used to decrease radiation effects over the 1-yr life but simulate a range of space station orbits. The perigee increase is necessary to attain a 1-yr life. This mission complexity may be alleviated by proper choice of launch vehicle trajectory, and the elimination of the propulsion and its attendant stabilization requirement. However, this complex system illustrates the possible application of propulsion to the payload.

To provide a test payload capable of accomplishing this mission, a number of minor modifications were made. The installed systems included the expansion and pressurization system, a passive thermal control with circulating fan, separation and hold-down, destruct and telemetry and communications systems. The installation of propulsion, stabilization and attitude control requires added adapter structures and increased volume within the selected payload envelope. The plastinaut is installed to provide radiation dosage data over a long period. This test, however, cannot substitute for the highly eccentric orbit previously used for complete radiation data. Additional test equipment includes the installation of meteoroid test panels on all side panel sections and on the forward dome, and the installation of thermal instrumentation to conduct the thermal control test.

The pressurization gas is defined by leakage at 5.5 psi, and 708 lb are required for the 1-yr test. The power supply uses batteries for 31 w of nominal power over the 1-yr life for accomplishment of a minimum mission. A supplementary source from a solar cell panel provides an average of 45 w additional power to accomplish the complete mission. The solar panel is oriented to avoid

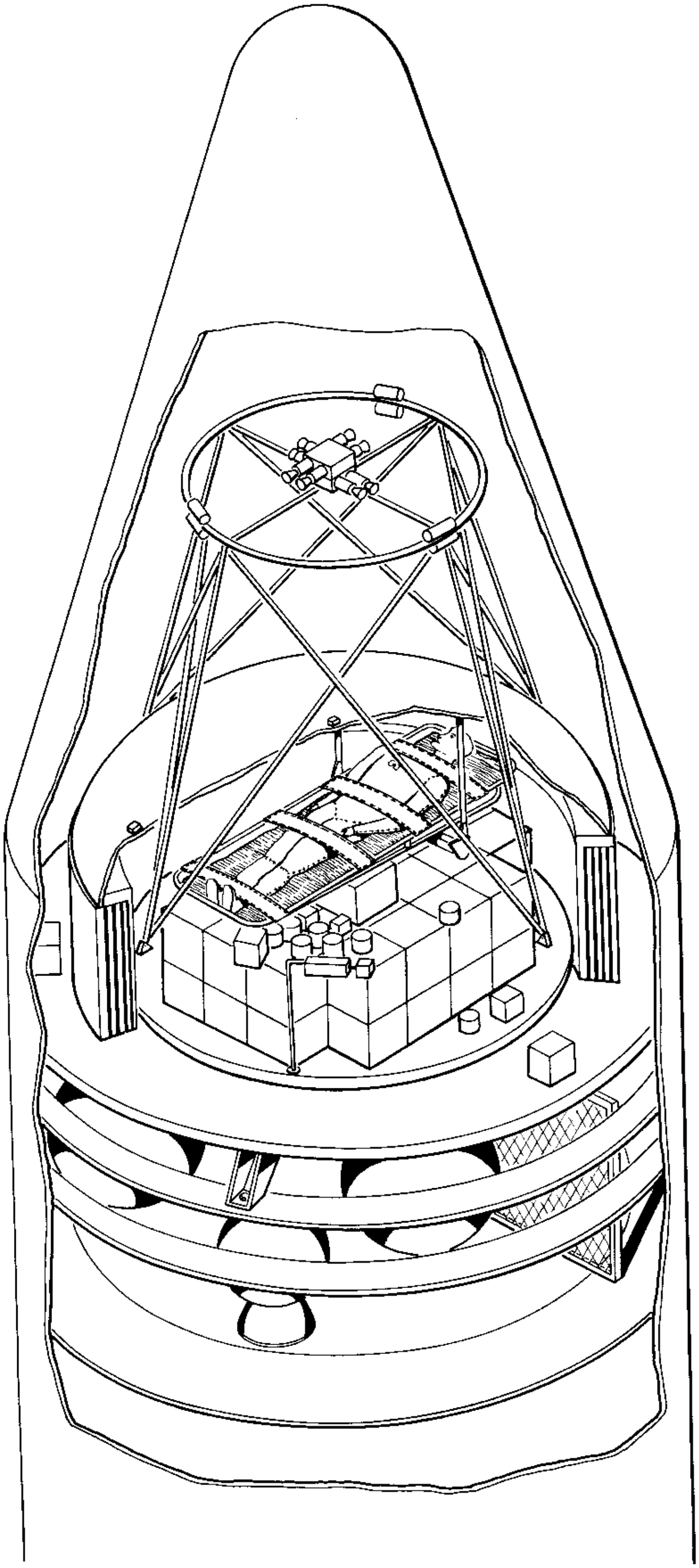

Fig. 6. Long Duration Test Configuration

shadowing any of the test structure panels and depends upon the attitude control of the structure to maintain correct solar orientation.

In general, the expandable space structure requires only minor modifications to accomplish this complex mission. The total payload weight is approximately 11,125 lb for the long duration mission.

Additional Applications

Although the utilization of this type of expandable structure for test purposes is an immediate potential application, the design for additional space applications is feasible and provides many advantages. The principal applications are found in conjunction with manned systems although several interesting unmanned versions have been defined.

Several types of manned space stations may use elongation along one axis to attain their design objectives. The question of the long term effects of zero gravity on man remains to be completely explored and, for missions requiring long periods between crew replacement, the need may exist for artificial gravity with low rotational rates. Several methods have been proposed to accomplish this, and the type of telescoping structure being considered herein is ideally suited for one of these methods.

In a two-body space station where permanent or temporary occupancy of both bodies is required, this structure provides a solution for moving the bodies far enough apart so that a low rotational rate will provide artificial gravity. This capability can be achieved without requiring any manual assembly in space. In this type of space station, a hub is usually required through which resupply and crew rotational functions are accomplished. This hub should be the rotational axis to allow docking of the resupply vehicles. The problem for the designer is to maintain this axis of rotation even though the mass of the two bodies may vary relative to each other during the mission. The capability of this type of expandable structure to retract as well as expand and still maintain its structural integrity allows a ready solution to the problem. In addition, the capability to transfer men between the elements of the space station without requiring movement through space outside of the station and air locks provides a major convenience for long term operations. If much transfer between station elements is required, the increased safety and reduced power and atmosphere losses due to air lock operations may be additional factors.

Another application is found when designing for long duration space station or space vehicle operations. The long duration requires stowage of an entry vehicle or vehicles for returning the crew. The need is self-evident that these vehicles must be maintained and protected from the space environment. External protection and maintenance, particularly of sensitive heat shields, appears to require some external covering of the entry body. Many types have been proposed. However, where a limited launch volume is restrictive, the ability to expand over the attached entry vehicle may be an advantage. Also, the need for a rigid structure to provide protection and shielding may be a necessity, particularly when deep space missions are also considered. The type of structure which telescopes within or outside of a cylindrical body provides many advantages in arrangement as well as conservation of volume and offers a fine solution to these problems.

An additional advantage for this application is found in the capability to retract. This permits the docking system to be cleared for approach of the entry vehicle within broad maneuver limits without the danger of damaging either the entry vehicle or space station. Design of the end closure becomes the principal design problem.

One of the most interesting applications of this telescoping structure is its possible use as a combined retractable air lock and docking tube. The present docking requirements necessitate fine attitude and velocity regulation between the vehicles being joined in space. The problems involve reducing the relative motion to approximately zero at a fixed relative position without undue danger of shock loads being imposed on either vehicle. Many methods of making an initial connection and bringing these vehicles together have been explored. Standoff techniques become attractive when the masses involved become large.

This type of telescoping structure introduces some interesting characteristics into this docking operation. First, it requires only a small extended mass to join two very large bodies, thus reducing potential shock loads to a negligible value. The structure can be designed to be quite flexible when not fully expanded so that some relative motion between the bodies can be tolerated. Second, once the attachment has been made, the structure can be fully expanded and pressurized to form a rigid, load carrying link between the bodies. The rigidity of this load path aids considerably in maintaining an accurate attitude in the space station--a factor of extreme importance in some missions. Third, the structure can be designed, with a very small weight penalty, to perform the functions of an air lock between the vehicles. This requires a hatch at either end of the expandable tube. The sealing technique used permits such hatches, and since closures are normally required, the introduction of hatches is a simple matter. In operation, one hatch must remain closed at all times unless a mechanical locking system is used. A fourth advantage is the ability to stow this appendage to the space station in a small volume during launch and then use it in space without additional assembly operations. This stowage feature also allows considerable leeway in space station arrangement.

These applications are but a few of the many that can be devised. When such missions as interplanetary manned exploration, deep space stations and similar long duration missions are considered the range of applications increases. The principal characteristics that become of value are the ability to provide shielding from harmful radiation and meteoroids, the rigid load path, the increased operating volume or convenient stowage arrangements in normally cylindrical structures and the capability to retract after having been expanded.