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SSD 83-0094-1

DEVELOPMENT OF DEPLOYABLE STRUCTURES FOR LARGE SPACE PLATFORM SYSTEMS

Executive Summary Volume I

NASA/MSFC CONTRACT NAS8-34677
OCTOBER 1983

Shuttle Integration & Satellite Systems Division

Rockwell International
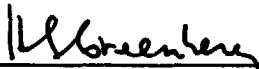
Development of Deployable Structures for Large Space Platforms

Executive Summary
Volume I

Submitted by

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Study Manager

Approved

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Study Cor. NASA / MSFC

Rockwell International

FOREWORD

This volume summarizes the major achievements of Parts 1 and 2 of the study titled "Development of Deployable Structures for Large Space Platform Systems." A detailed description of the Parts 1 and 2 study development is presented in Volume II, SSD 83-0094-2. An appendix containing the developed design drawings is presented in Volume III, SSD 83-0094-3.

This study was managed by Marshall Space Flight Center (MSFC) and was performed by the Shuttle Integration and Satellite Systems Division of Rockwell International Corporation located at Downey and Seal Beach California. The study COR was Mr. Erich E. Engler. The study manager was Mr. H. Stanley Greenberg.

The Part 1 study was initiated on October 16, 1981 and was completed nine months later on July 16, 1982. The Part 2 study was started August 6, 1982 and was completed fourteen months later on October 7, 1983.

The major contributors to this study are listed below:

o Design   -   R. Hart (Lead, Part 1)
                R. Barbour (Lead, Part 2)
                B. Mahr
                A. Perry
                J. Keech
                W. Wiley
                C. Lang
                G. Buhler
                P. Buck
                T. Clegg

o Stess Analysis - G. Lesieutre
                     W. A. Bateman

o Thermal Analysis - T. Tysor

o Materials Analysis - R. Long
                         C. Brownfield

o Mass Properties - C. Griesinger
                      W. Morgan

o Electrical Power/Data Management - A. Gordon

o Electrical Utilities Integration - A. LeFever

o Guidance and Control - R. Oglevie

o Technology Development - A. M. Pope

This volume summarizes the major achievements of the Parts 1 and 2 study activities related to deployable structures for large space platforms. These activities included development of a building-block design for the automatic construction of deployable platforms such as those shown in Figure 1, and the development of deployable volumes, i.e., habitat and OTV hangar concepts for potential Space Station applications.
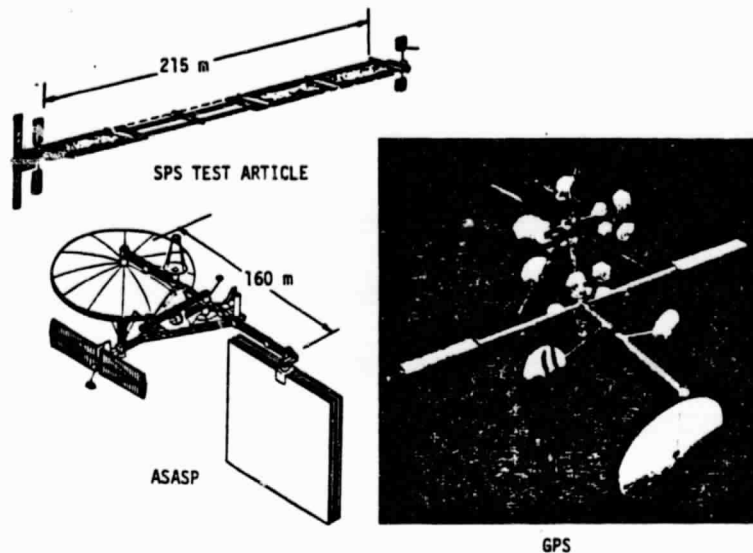

215 m

SPS TEST ARTICLE

160 m

ASASP

GPS

Figure 1. Focus Mission Platform Systems Configurations

The preponderance of study effort was devoted toward the deployable platform systems study which has culminated in the detailed design of a ground test article for future development testing. This design is representative of a prototype square-truss, single-fold building-block design that can construct deployable platform structures in the manner suggested in Figure 2.

This prototype design was selected through a comprehensive and traceable selection process applied to eight competitive designs. The selection process compared the competitive designs according to seven major selection criteria, i.e., design versatility, cost, thermal stability, meteoriod impact significance, reliability, performance predictability, and orbiter integration suitability.

In support of the foregoing, a materials data base, and platform systems technology development needs were established.

In the deployable volumes study effort an erectable design of an OTV hangar was selected and recommended for further design development. This design was selected from five study-developed competitive single-fold and double-fold designs including hard-shell and inflatable designs. Also, two deployable manned module configurations, i.e., a hard-shell and an inflatable design were each developed to the same requirements as the composite of two
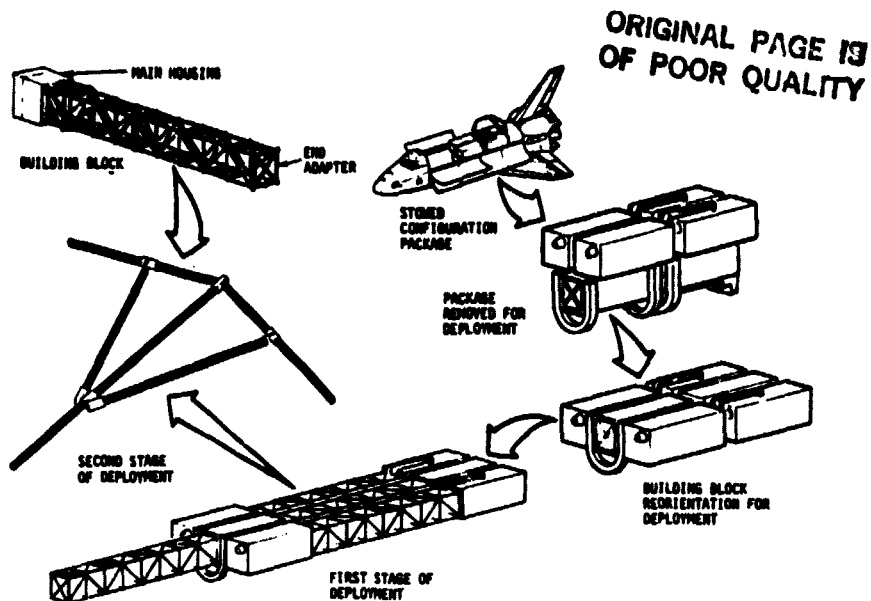
Figure 2. Potential Construction Application of Building Block

Space Station baseline habitat modules. For each of these deployable module designs, atmospheric sealing suitability was of sufficient concern to offset the potential launch cost savings. Hence, no further activity was recommended pertinent to deployable manned modules.

SUMMARY OF DEPLOYABLE PLATFORM SYSTEMS STUDY

The deployable platform systems study efforts culminated in a "fabrication ready" detailed design of a Ground Test Article. The detailed design consists of a set of top assembly and subassembly drawings (Volume III) and supportive analysis (Volume II).

The configuration, overall size, and major components of the complete test article are shown in Figure 3.

This configuration was derived to satisfy, at NASA/MSFC direction, the SASP deployable structure configuration requirements (Figure 4) and the following NASA/MSFC specific requirements:

o Develop ground test article design using Part 1 selected design

o Provide automatic deployment and retraction

o Use 1.4 m x 1.4 m truss cross section

o Provide support for four 3636 Kg simulated payload carriers

o Provide minimum natural frequency of 0.10 Hz

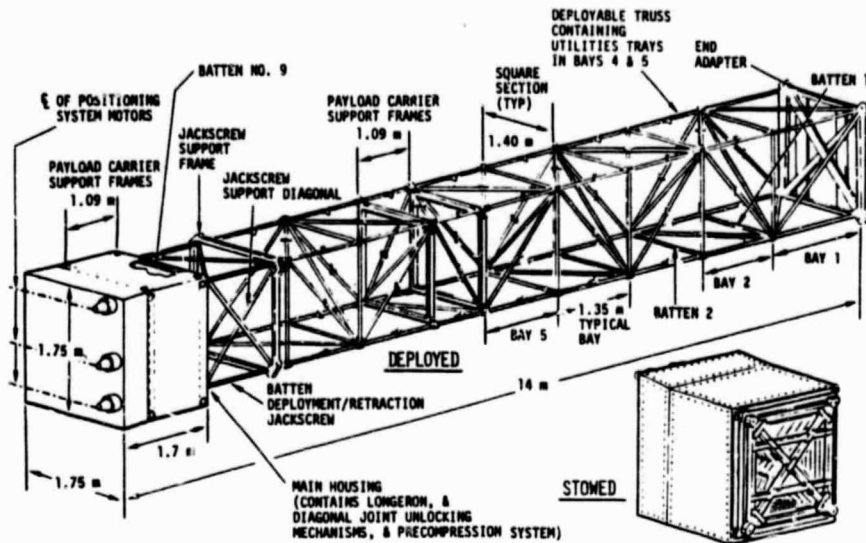o Sustain limit load, equivalent to 0.04 g, at payload c.g.

2

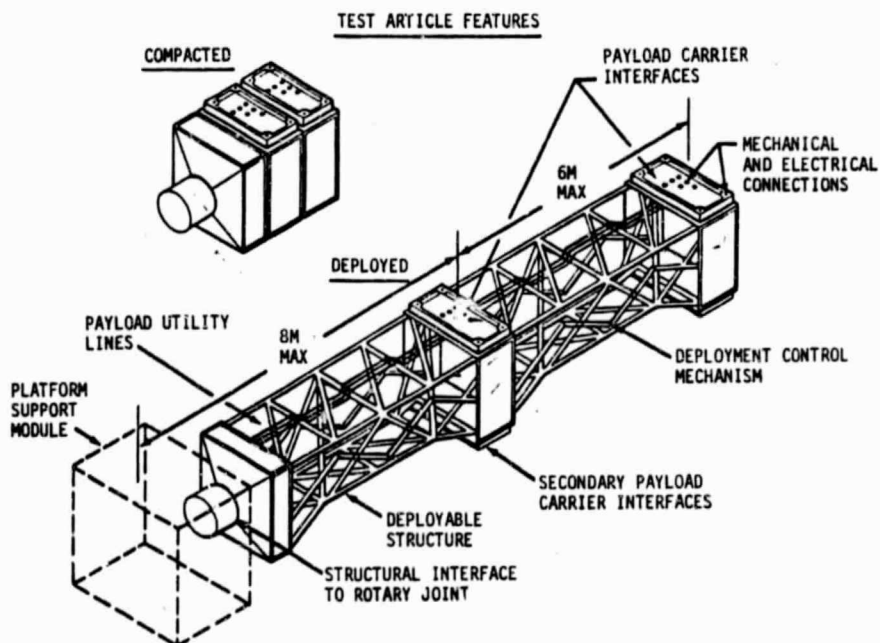Figure 3. Test Article Design Configuration

Figure 4. SASP Deployable Ground Test Structure

The test article is designed for a room temperature/ground test
verification of deployment and retraction capability, stiffness, strength, and
modal frequency characteristics. For minimum development cost, the square

truss structure will be constructed of aluminum and miscellaneous commercial steels. The mechanism drive motors, tachometers, and encoders are heavy-duty industrial products that are not designed for the Shuttle and space environmental requirements. The major components of this test article are as follows:

1. The square truss (Figure 5) containing folding utilities trays in Bays 4 and 5 (Figure 3) with provisions for future installation of power, data, and fluid lines.

2. A mechanization system (Figure 6) consisting of: (a) A batten deployment/retraction jackscrew system which translates the battens one at a time, (b) A diagonal latch unlocking system, and (c) A longeron latch unlocking system.

3. A jackscrew support frame assembly that supports the cantilevered ends of the batten deployment/retraction jackscrews (Figure 6).

4. \ positioning system to precisely control the bay-by-bay deployment and retraction operations (Figure 9).

5. A precompression system to eliminate structure joint backlash (Figure 11).

6. An end adapter at the end of the truss with provisions for attachment to a NASA/MSFC test fixture (Figure 3).

7. An aluminum skin and frame main housing (Figure 12).

The housing and payload carrier frames shown contain inserts for attachment of the NASA/MSFC simulated payload carriers. Also, in the stowed configuration illustrated in Figure 3, the jackscrew frame is nested to the main housing forward frame (Figure 6) and the end adapter is nested against the jackscrew support frame. Four manual locking devices secure the end adapters to the main housing forward frame.

Figure 5 illustrates the deployable truss major design features. The deployable truss contains square battens stabilized by compression diagonal braces. Each batten contains a half nut at each of the four corners. Through engagement with each of the four batten deployment retraction/jackscrews, counterclockwise rotation of the jackscrew imparts outward linear motion to the batten (deployment), while the opposite rotation imparts inward motion to the batten (retraction). With the exception of the first bay, deployment or retraction is respectively accomplished by holding the aft batten with detents while deploying or retracting the forward batten. During deployment, each of the four longerons is unfolded and each of the four telescoping diagonals is extended. The longerons and diagonals each have spring-activated locking pins in latches at their center joints that, upon unlocking, provide axial and moment structural continuity. Both designs have end rod fittings with spherical bearings and turnbuckles for precise member length adjustment. The aforementioned center joint spring-activated pins must be unlocked to permit retraction. This is accomplished with each of the diagonal and longeron unlocking systems (Figure 7) that contain tripping devices that rotate cammed surfaces on the latch mechanisms to depress the locking pins.
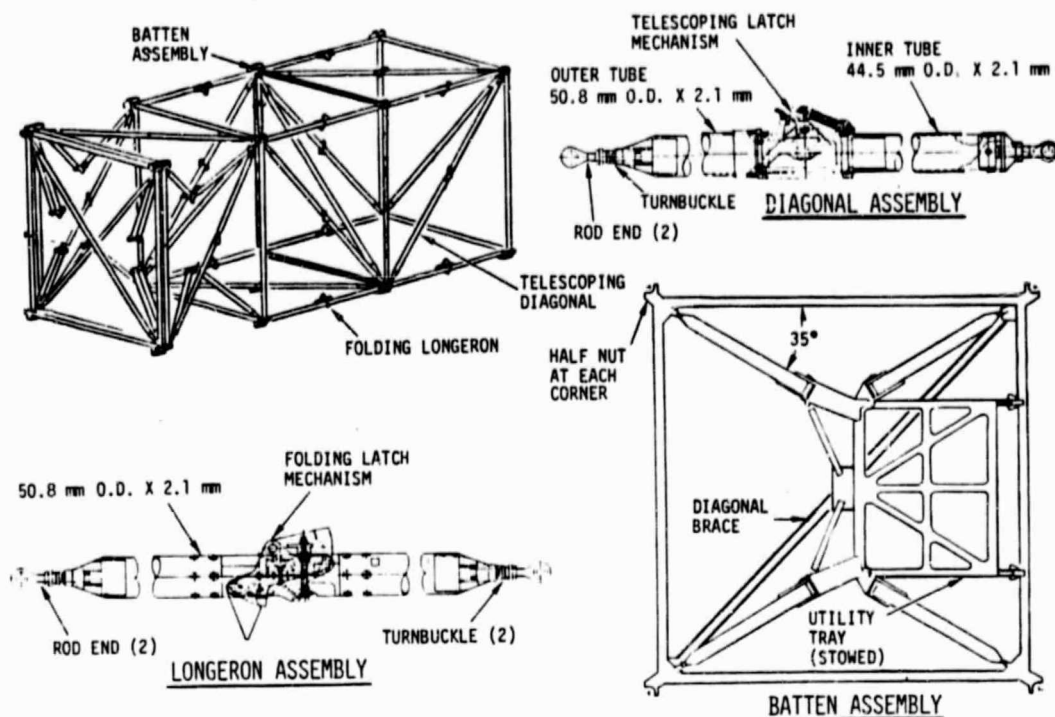
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Figure 5. Deployable Truss and Utilities Trays Concept

The truss design also contains trays for Bays 4 and 5 onto which a
generous complement of electrical power, data, and fluid lines can be
mounted. Specifically, space is available for six 1/0 cables, three No. 8
AWG, six No. 12 AWG, six coax, 28 No. 22 twisted pairs shielded, and four 12.5
mm flexible coolant tubes. The trays are hinged from the batten frames and
fold as shown at the lower right (Figure 5). During the Shuttle launch of a
prototype design trays in each bay would provide lateral support to the folded
longerons. Longitudinal support of the longerons is provided by tight
packaging and appropriate end transverse beams in the adapter and main housing.

Figure 6 illustrates (in the deployed configuration) the major features
and orientation of the test article mechanization system. For clarity, the
ten-bay truss structure is not shown. This system provides fully controlled
bay-by-bay deployment/retraction capability with maintenance of root strength
throughout all phases of deployment. The mechanism includes the batten
deployment/retraction jackscrew system, the longeron unlocking system, and the
diagonal unlocking system. The batten deployment/retraction system (Figure 7)
consists of four assemblies of guide rail, splined shaft, and jackscrew
mounted in a slide carriage. These assemblies are located at each of the four
corners of the main housing. In the first stage of deployment, i.e., Bay 1,
clockwise rotation of each of the spline shafts advances the slide carriage
and jackscrews out of the housing into the configuration shown. Concurrently,
the jackscrew support frame assembly is advanced to the configuration shown
with automatic locking of the telescoping diagonals. A controller-driven
single motor, slaved to a chain and sprocket system, drives all four systems.
The longeron unlocking system (Fig. 7) consists of four assemblies of guide
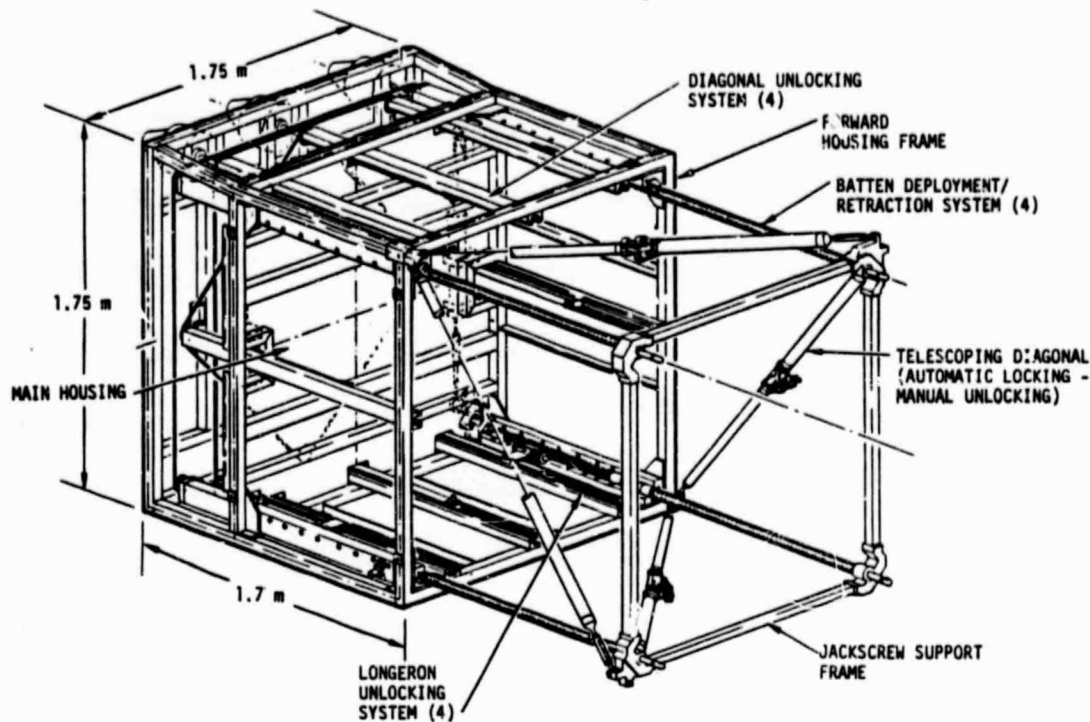
Figure 6. Deployment/Retraction Mechanism Concept

rail, jackscrew, carriage, and tripping device. These systems are located adjacent to the individual batten deployment/retraction assemblies. The diagonal unlocking assemblies are the same as that of the longeron unlocking system, except for the tripping devices, and are located at the center of the housing sidewalls. The longeron and diagonal unlocking systems are each controller-driven by a single motor slaved to a chain and sprocket system to drive all four assemblies.

Figure 7 further describes the deployment/retraction mechanism. The batten deployment/retraction jackscrew shown illustrates one of the four jackscrew assemblies. The jackscrew, carriage, and spline assemblies are cradled within a rigid rail. A splined bushing at the aft end of the 50-mm-diameter jackscrew encircles a splined shaft that extends nearly the entire length of the jackscrews. The jackscrew splines extend beyond the aft end of the rails where a chain and sprocket are attached.

Encircling the rotating jackscrew is a carriage fitting that has external ears that engage matching grooves running the length of the rails. The carriage is pulled forward with the jackscrew, during deployment of Bay 1 (Figure 3), until a hole in the side of the carriage engages a spring-operated pin mounted near the forward end of each rail, thereby locking the carriage. During retraction of the final bay the pin is manually retracted from the carriage, thus allowing the jackscrew to be retracted into the housing.

One of the longeron and one of the diagonal unlocking assemblies are each shown (Figure 7) in the partially deployed configuration. In the stowed configuration the carriages are entirely within the main housing. The
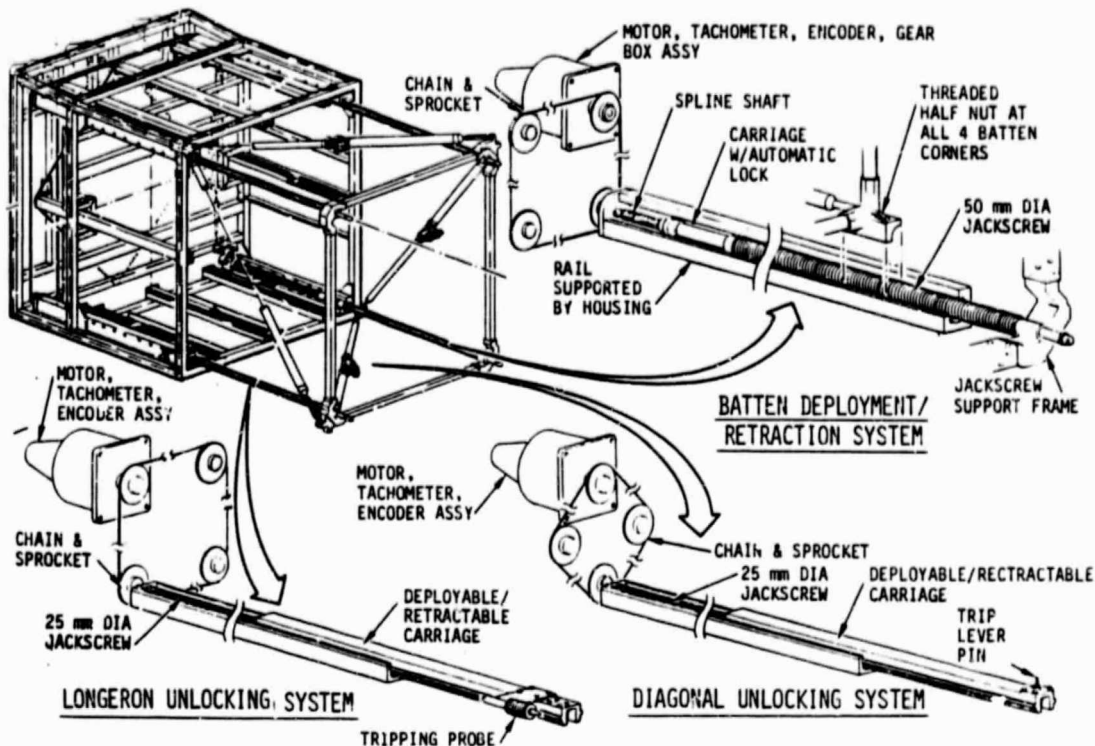
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Figure 7. Deployment/Retraction Mechanism Details

separate longeron and diagonal unlocking systems are activated only during
retraction and are respectively used to unlock the longeron and diagonal
center joint latches just prior to the start of the batten retraction. The
diagonal and longeron center joint latches are unlocked by forward motion of
the trip lever pins and tripping probes mounted on the deployable/retractable
carriages installed within rails and driven by the 25-mm-diameter jackscrew.

The positioning system requirements for this program are a version of
standard motion control (robotics) used in industrial machine control
applications.

Motion profiles are built up as sequenced indexes. Each index consists of
a direction, acceleration time, deceleration time, feed rate, and travel
distance. The controller calculates acceleration rates, deceleration rates,
and the position to begin deceleration. The mechanization uses encoder and
tachometer sensing with overrated motors and mechanization to ensure precise
position control without overshoot in the presence of varying output loads.
The motion profiles for the test article are shown in Figure 8.

The three-axis system selected will allow totally separate positioning of
(1) the batten deployment/retraction system, (2) the longeron unlocking
system, and (3) the diagonal unlocking system.

In addition, the system includes a programmable output option that allows
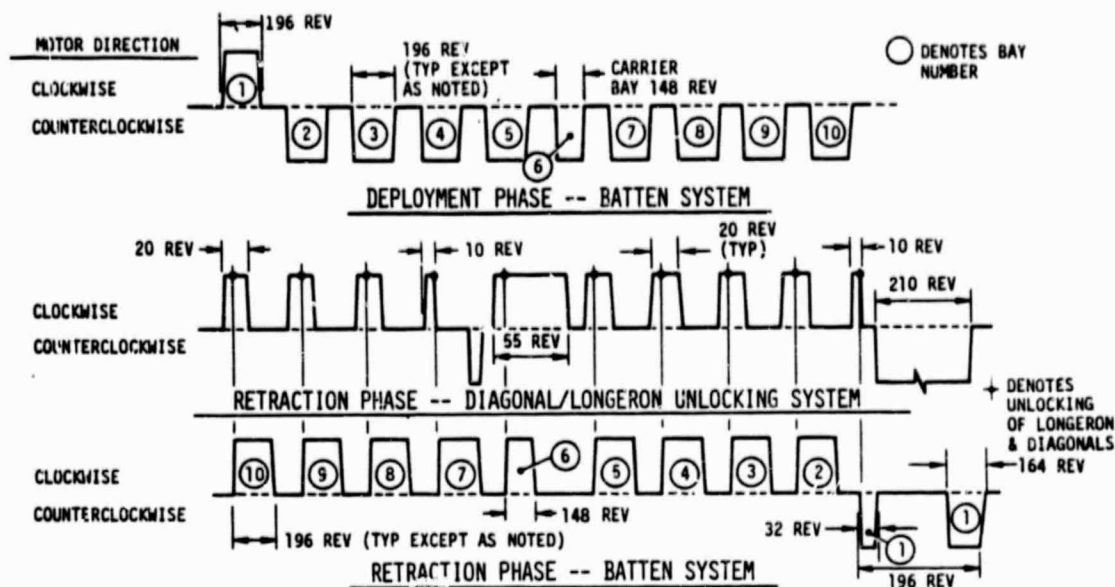the batten deployment axis to sequence the longeron and diagonal unlocking

Figure 8. Positioning System Motion Profile

axes. The system consists of a standard main frame chassis with three standard motor control modules, position feedback modules, and digital input/output modules. In addition, three machine logic simulators are included for all motion functions on any axis; for example, jog, run, hold, and high or low speed.

The batten deployment/retraction axis controller will use a direct-drive dc servo motor rated at 27 Nm (240 lb-in.) continuous operation up to 225 rpm. The motor will be driven with a standard pulse-width modulated drive. Positioning resolution will be to within 0.001 revolution which is equivalent to a longitudinal accuracy of 0.0064 mm (0.00025 in.) on the 6.35 mm pitch jackscrew. The deployment/retraction profile will be achieved as a series of ten indexes entered into a specific program.

The diagonal and longeron unlocking controllers will be configured with identical hardware and software. Again, direct-drive dc servo motors will be used rated at 3.7 Nm (33 lb-in.) continuous up to 2400 rpm. The motor contains an integrally mounted encoder and tachometer. Each of the motors will have its own pulse-width modulated drive and dc drive power supply. These controllers will be to within 0.0025 revolution which is equivalent to a longitudinal accuracy of 0.0127 mm (0.0005 in.) on the 5.08 mm pitch jackscrew to which they will be mounted.

All of the hardware, except the motors, the remote programming panel and cabling will be mounted in a standard 914 mm by 914 mm by 305 mm enclosure.

Figure 9 shows an illustration of typical components.
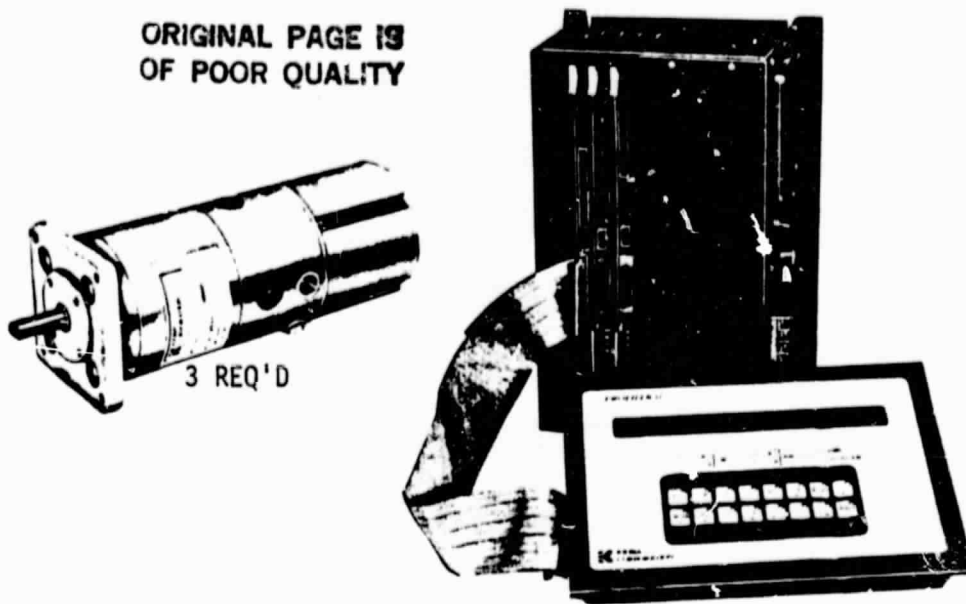
Figures 9. Positioning System Components

Figure 10 illustrates the key discrete stages of deployment and retraction. Starting from the stowed package (View 1) the end adapter, which is the forward batten of Bay 1, is forward of the jackscrew support frame. The first stage of deployment positions and locks the jackscrews and the jackscrew support frame diagonal struts, and develops (View 2) Bay 1. At this point, the Batten 1 (Figure 3) half nuts are engaged with the aft end of the jackscrew thread. The batten deployment/retraction system jackscrews are reversed to start the deployment of Bay 2 (View 3).

Batten 2 (Figure 3) is held in place by spring-loaded detents until Bay 2 is fully extended and locked, and is later overwhelmed by the jackscrew starting the deployment of Bay 3. In this manner, each of the bays is deployed one at a time until the fully deployed truss configuration is achieved (View 4). At this point, precompression of the longerons can be applied and removed by manual activation of the precompression system.

In the retraction phase the eight longeron and diagonal unlocking carriages are initially positioned such that each of the tripping probes is 25 mm away from the longeron and diagonal latch trip levers. The four diagonal and four longeron latches in Bay 10 are tripped after ten clockwise revolutions of the unlocking system jackscrews. After a number of milliseconds (to be determined in the future ground tests) the batten deployment/retraction system motors are rotated clockwise until Batten 9 (Fig. 3) is placed on the rail. As each bay is retracted, the carriages on the unlocking systems are advanced to the next unlocking position (Figure 8). This proceeds from Bay 10 through unlocking of Bay 1 (View 6).
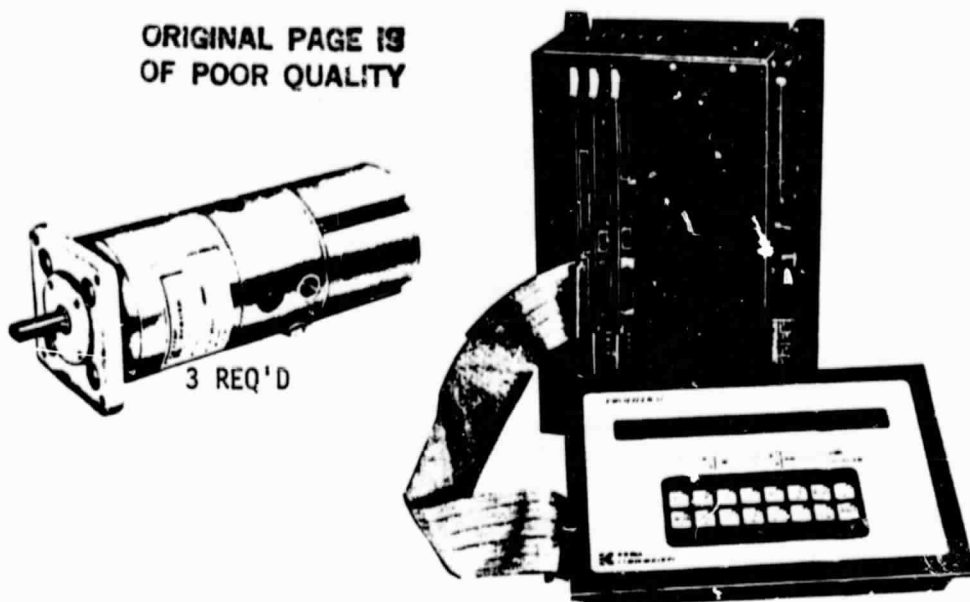
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the unlocking systems are advanced to the next unlocking position
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Figure 10. Deployment/Retraction Major Phases

Upon unlocking the longerons and diagonals of Bay 1, the batten
deployment/retraction jackscrews are rotated counterclockwise 32 revolutions.
The extended diagonal and longeron unlocking systems are then retracted into
the housing to permit the final retraction of Bay 1.

Figure 11 describes the major features of the precompression system
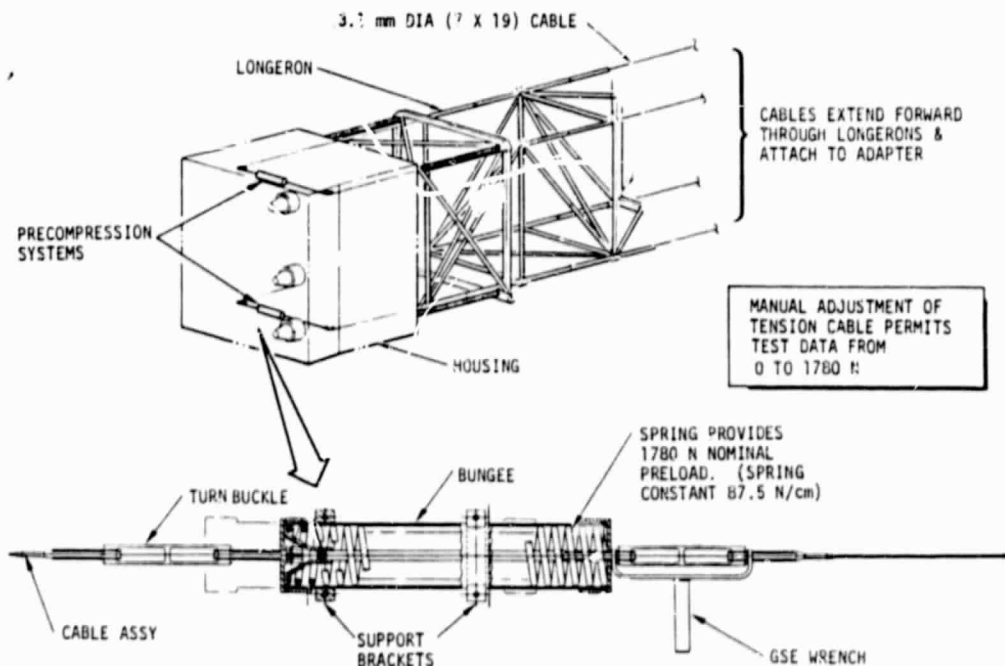

Figure 11. Precompression System to Eliminate Joint Backlash

provided to eliminate joint backlash in both the longerns and diagonals. A cable/bungee system, with a cable pretension of 1780 N, will apply up to 1425 N of compression in each of the four truss longerons. This compression load will, through compatible strain, provide up to 260 N of precompression in the diagonals.

The precompression system consists of two spring bungee assemblies mounted on the aft end of the main housing. From either end of each bungee threaded rods are extended that mate with a turnbuckle. From the opposite end of each turnbuckle is another threaded rod swagged to a long cable. The two cables from each turnbuckle traverse laterally until they engage a pulley near the axes of the longerons. The cables wrap around the pulleys 90 degrees and extend forward where they enter the longerons located at the four corners of the truss. The cables continue forward through the longerons of all ten bays. The cables exit the longerons of Bay 1 and engage another pair of fairleads mounted within the adapter. These fairleads are canted in such a way that the cables continue toward the geometric center of the adapter within its diagonal braces. Swagged balls on the cables attach to fittings whose mounting locations are adjustable within the adapter.

The bungees are supported on the rear of the housing by two pairs of brackets that partially encircle the cylindrical body and still allow the body to move along its axis as the turnbuckles are utilized to pretension the cables to their final 1780 N load.

Figure 12 illustrates the major parts of the main housing which is a
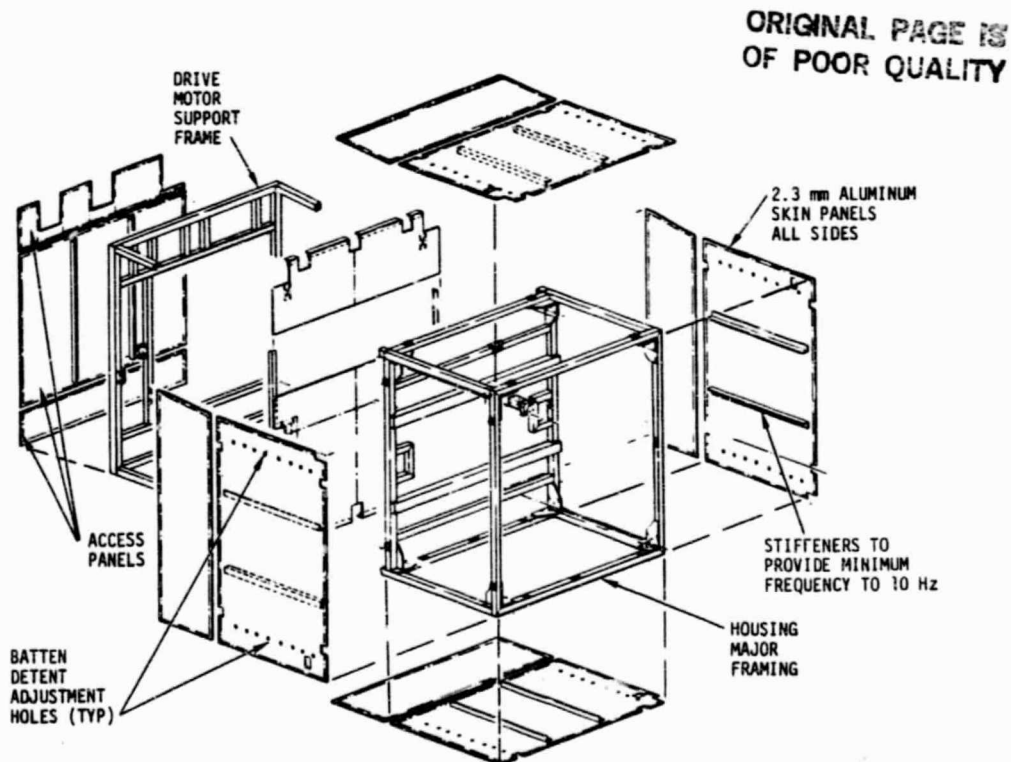
Figure 12. Main Housing Structure

combination welded, riveted, and bolted assembly into which all other major assemblies are installed. A welded frame consisting of 50 mm square aluminum 6061-T6 tubing has numerous skin and stringer subassemblies riveted to it.

Panels on the aft side of the housing are removable to provide access to the precompression system and the three chain-and-sprocket drive systems located near the center of the housing. Access holes along the four sides of the housing align with the batten retaining detents to provide adjustment capability.

A rectangular pattern of threaded inserts is provided on the four sides of the housing for the future attachment of the NASA/MSFC simulated payload carrier structures.

The foregoing described test design is representative of a square-truss-single-fold prototype building block design from which potential space platforms (Figure 1) or space station structures can be constructed. This building block has the following significant characteristics:

o   Automatic bay-by-bay deployment and retraction to facilitate identification of problem (in the event this occurs)

o   Maintenance of root strength during deployment/retraction - permits orbiter berthing and orbiter VRCS firing, (if necessary)

o   Longitudinal deployment/retraction within cross-section envelope

o   Components for retraction easily removable (if appropriate)

o   All inter-building-block electrical connections in place prior to orbiter installation

o   In-space inter-building block structural connections made automatically without fixture.

o   Housing permits ground installation of docking ports

o   Payloads and propulsion modules attached using RMS or MAFA, or both

o   No other fixtures required

The prototype design was selected through a comprehensive/traceable comparative study of eight candidate building block concepts represented by the truss configurations shown in Figure 13.

For each of the truss concepts shown, a total building block concept consisting of main housing, mechanism, deployable truss, utilities integration system, and end adapter were developed (Fig. 14).

The major thrust of the comparative study consisted of configuring each of the eight building blocks to construct a study developed generic platform (Fig. 15) to satisy the adopted strength and stiffness requirements (Table 1); integration of the adopted power and data requirements (Table 2); integration
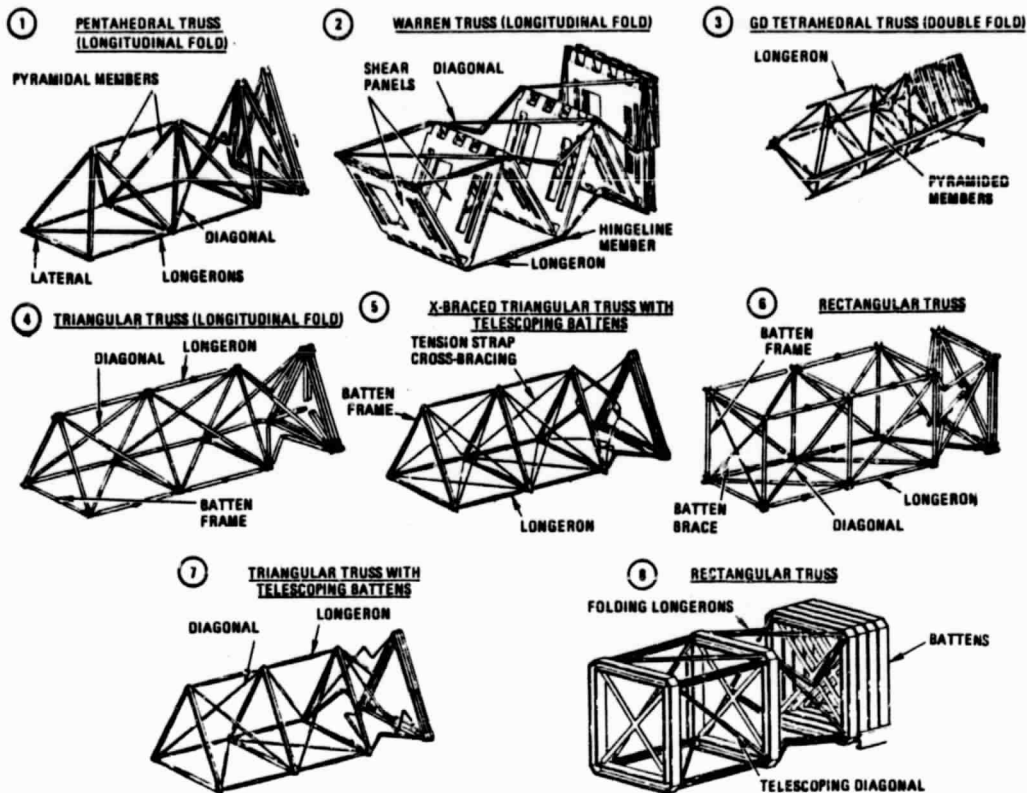
Figure 13. 8 Competetive Candidate Building Block Concepts
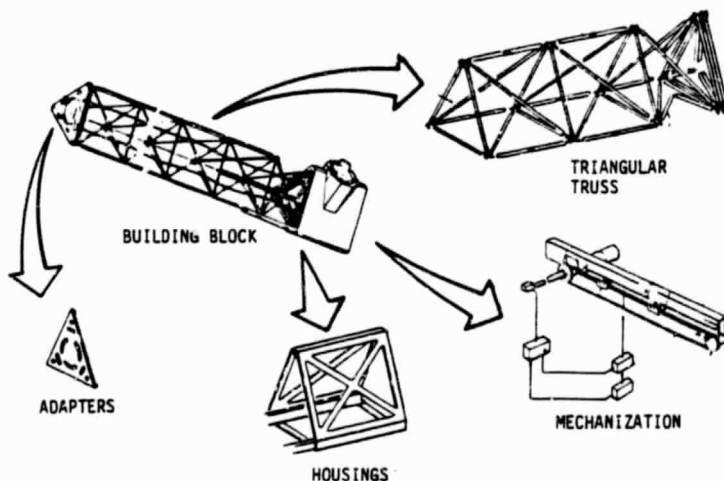
Figure 14. Major Building Block Components

of two 2cm diameter (or equivalent) fluid utilities; and packaging into the orbiter. However, to assure the selection of a design concept that is most suitable across the spectrum of platform size, strength, stiffness, and compliment of utilities variations, numerous sub-trades were performed and were included in the overall concept selection process. The scope of this selection process is suggested by Table 3, and Figure 16, and Tables 4 and 5.

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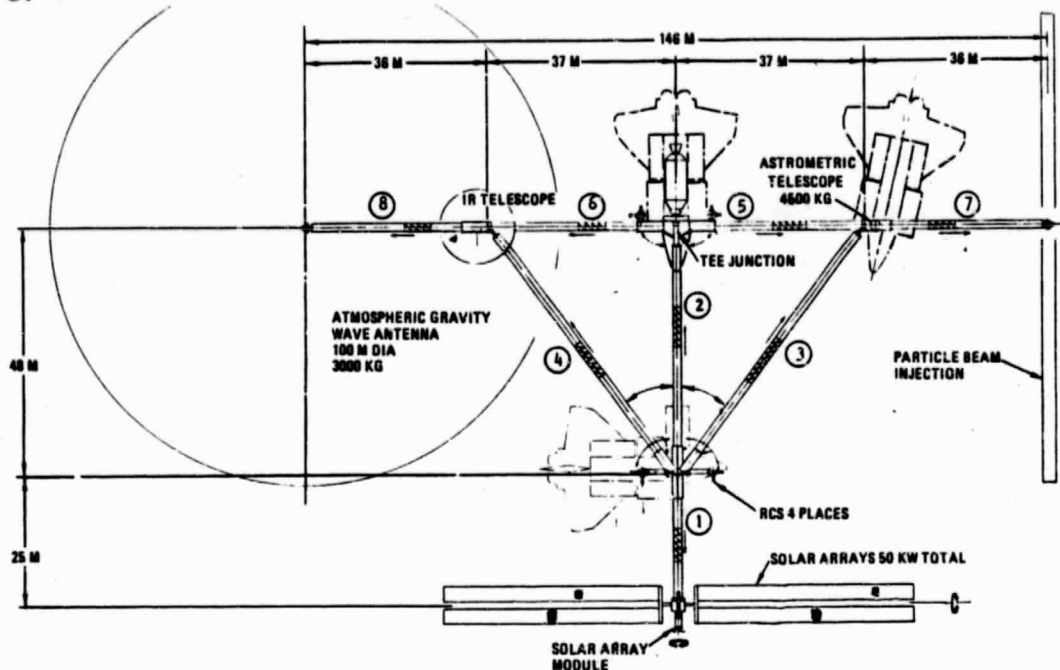
Figure 15.   Generic Platform

Table 1.   Adopted Loads (Limit)
and Stiffness Requirements

PARAMETER / PLATFORM	SPS	ASASP	GSP ALT. 1	GSP ALT. 4
•FLEXURAL STIFFNESS (Nm²)	17.3×10^6	2.0×10^8	2.8×10^6	2.0×10^8
•TORSIONAL STIFFNESS (Nm²)	4.4×10^4	0.50×10^7	8.2×10^4	0.5×10^7
•BENDING MOMENT (Nm)	808	9000	6570	0.25×10^5
•TORSIONAL MOMENT (Nm)	18	7050	3500	1.0×10^4
•AXIAL LOAD (N)	200	500	4660	3700
•SHEAR (N)	400	200	660	5400
☐ DENOTES ADOPTED STRENGTH AND STIFFNESS				

Table 2.   Adopted Complement
of Power and Data Utilities

SYSTEM FUNCTION	ASASP	GPS	SPS	ADOPTED REQUIREMENTS
INTERFACES				
• POWER	6 NO. 0 28 NO. 2 4 NO. 14	6 NO. 3 4 NO. 13 20 NO. 18	396 NO. 10	6 NO. 0 16 NO. 2 4 NO. 14
• DATA	35 F.O.	34 NO. 18 TSP 58 NO. 26 TSP 144 F.O.	4 NO. 22 TSP	90 NO. 22 TPS 2 COAX 108 F.O.

Table 3 illustrates the major criteria used in the selection process and
Figure 16 illustrates the methodology used to determine the points within each
criterion. In this method, qualitative data were converted to points

Table 3. Major Criteria of the Selection Process

|	
1. DESIGN VERSATILITY (WITH DISTINCTIONS BETWEEN LEO AND GEO) OF STRUCTURAL CONCEPT A. ACCOMMODATION OF ADOPTED POWER AND DATA UTILITIES REQUIREMENTS B. ACCOMMODATION OF REDUCED POWER AND DATA UTILITIES REQUIREMENTS C. ACCOMMODATION OF FLUID UTILITIES: TWO 2-CM LINES (OR EQUIVALENT) D. SATISFACTION OF ADOPTED STRENGTH AND STIFFNESS REQUIREMENTS E. SATISFACTION OF STRENGTH AND STIFFNESS REQUIREMENTS THAT ARE EACH 1/10 OF THE ADOPTED VALUES F. SATISFACTION OF THE ADOPTED STRENGTH REQUIREMENT AND 10 TIMES THE ADOPTED STIFFNESS REQUIREMENT G. PLATFORM CONSTRUCTION H. ACCOMMODATION OF ALUMINUM AND GRAPHITE COMPOSITE MATERIALS	2. COST OF TOTAL BUILDING BLOCK IN GENERIC PLATFORM A. LAUNCH COST B. FABRICATION COST C. ORBIT TRANSFER TO GEO D. TECHNOLOGY DEVELOPMENT DIFFERENTIAL (NEGLIGIBLE) 3. THERMAL STABILITY OF STRUCTURAL CONCEPT 4. METEOROID IMPACT SUITABILITY OF STRUCTURAL CONCEPT 5. RELIABILITY OF DEPLOYMENT (BUILDING BLOCK) A. BASIC TRUSS STRUCTURE B. HOUSING C. ADAPTER D. DOCKING PORT STRUCTURE E. MATERIALS VARIATION F. MECHANIZATION 6. PREDICTABILITY OF PERFORMANCE OF STRUCTURAL CONCEPT 7. INTEGRATION SUITABILITY OF BUILDING BLOCK

Figure 16. Methodology—Point Assessment for Quantitative Data
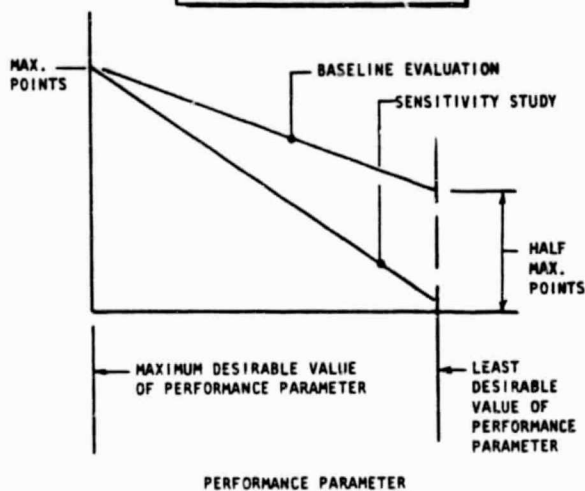
Table 4. Strength and Stiffness Accommodations (LEO)

CONCEPT	STRENGTH AND STIFFNESS ACCOMMODATION						TOTAL ACROSS ALL REQMTS 40
	REDUCED STRENGTH AND STIFFNESS		ADOPTED STRENGTH AND STIFFNESS		INCREASED STIFFNESS		
	PACKAGING EFFICIENCY (PE)		PACKAGING EFFICIENCY (PE)		PACKAGING EFFICIENCY (PE)		
	PE	POINTS	PE	POINTS	PE	POINTS	
	MAXIMUM POINTS 10		MAXIMUM POINTS 20		MAXIMUM POINTS 10		
1	22	5	15	10	8	5	20
2	32	10	21.6	17	8	5	32
3	26	7	20	15	20	9	31
4	26	7	20	15	10	6	28
5	25	6	25	20	25	10	36
6	31	9	20	15	10	6	30
7	25	6	25	20	25	10	36
8	28	8	22	17	14	7	32

Table 5. Total of Normalized Points (LEO)

CONCEPT	(1) DESIGN VERSATILITY MAX POINTS 100	(2) COST MAX POINTS 40	(3) THERMAL STABILITY MAX POINTS 20	(4) METEOROID IMPACT SUITABILITY MAX POINTS 40	(5) RELI- ABILITY MAX POINTS 100	(6) PREDICT- ABILITY MAX POINTS 20	(7) ORBITER INTEGRATION MAX POINTS 60	TOTAL MAX POINTS 380
1	87 √	22	11	20	97 √	20 √	46	303
2	94 √	20	12	32	91	14	47 √	310 ③
3	60	24	20 √	40 √	77	15	41	277
4	78	34 √	12	20	96 √	20 √	49	309 ④
5	80	40 √	11	20	67	10	56 √	284
6	83	22	10	40 √	94 √	20 √	46	315 ②
7	84	36 √	10	20	70	20 √	56 √	296
8	88 √	24	10	40 √	89	18	47 √	316 ①

NOTES:
CIRCLED NUMBERS IN TOTALS COLUMN DENOTE RANKING
√ FOR TOP 3 VALUES IN EACH CATEGORY

15

judgementally, while quantitative data are converted to points using a linear system as shown in Figure 16. Regarding the line marked "baseline evaluation" the most desirable concept is awarded 100 per cent and the least desirable concept is awarded 50 per cent. The other concepts are graded on a linear basis between the two extremes.

Table 4 illustrates the sub-trade data for criteria 1d, 1e, and 1f which together with the remaining criteria compile the total value for design versatility, i.e., Criteria 1 in Table 5. As shown in Table 5, Concept 6 and 8, i.e., square-truss, single-fold designs placed first and second in this evaluation for LEO platforms. The same designs also placed first and second in the evaluation for GEO platforms (Volume II).

Subsequent to the foregoing the utilities accommodation advantages of Concept 8 and structural simplicity advantages of Concept 6 were incorporated into one design, i.e., the selected design.

It is pertinent at this point to note a significant building-block requirement that was uncovered during the studies of the construction of the generic platform. A design utilizing guide rails encounters a problem when extending a truss which has a payload or another building-block module sufficiently wide that the guide rails cannot straddle them (Figure 17). The rails, therefore, can not be unfolded until the truss has extended and moved the large payload or building block out of the way. The rails do not provide root strength during this phase.

The mechanism developed during this study avoids this problem entirely as is evident from Figures 6 and 7, and the description provided. Further, this is accomplished entirely within the lateral envelope of the main housing.
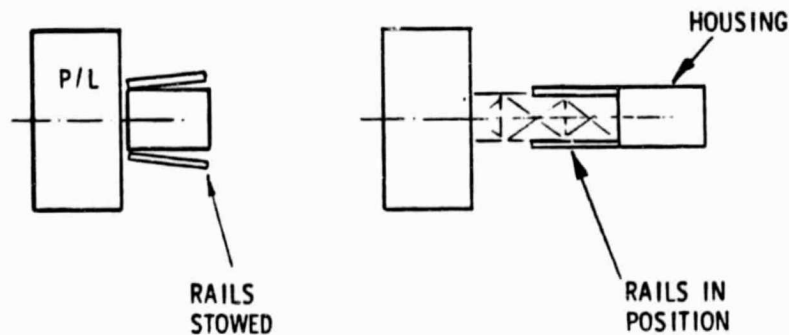

Figure 17. Deployment Problem with Guide Rails

DEPLOYABLE VOLUMES STUDY

The deployable volumes study encompassed the investigation of both hard-shell and inflatable structures for application to an OTV hangar and a

manned module of a Space Station configuration. OTV hangars are too large to be placed into the orbiter; conventional manned modules can be packaged into the orbiter but at a significantly greater launch cost than a deployable module.

As a result of this study it was recommended that the most suitable OTV hangar design, worthy of future development, is an erectable design.

For the manned modules the conventional baseline metal hard-shell design is the most suitable. The foregoing recommendations resulted from the following studies.

OTV HANGAR DESIGN STUDIES

Table 6 illustrates the major requirements derived to direct the OTV hangar designs and Figure 18, the baseline OTV. On the basis of these requirements, the five mature design concepts shown in Figure 19 were developed. These designs are presented in detail in Volume II. The five designs are briefly discussed below. All the designs utilize an Astromast to draw the OTV into the hangar, and deployable side braces (mounted in the docking ring) to laterally support the Astromast structure by the OTV hangar during OTV docking operations. All the designs also contain a docking device containing access from the Space Station to the hangar. Further all the designs require EVA activity to develop the structural continuity between the work platforms, i.e., to render the platforms to be effective as frames.

Table 6. OTV Hangar Requirements

- LIFE OF 20 YEARS
- DOCKING PROVISIONS FOR ATTACHMENT TO SPACE STATION
- PERMIT CREW INGRESS/EGRESS FROM SPACE STATION
- PROVIDE FOR OTV BERTHING OR DOCKING, AND INGRESS/EGRESS
- PERMIT CAPABILITY OF ATTACHMENT OF OTV SERVICING, LIGHTING, ELECTRICAL POWER EQUIPMENT
- PROVIDE WORK PLATFORMS AND CLEARANCE (1 TO 1.5 m) FOR WORK SPACE
- PROVIDE CAPABILITY TO STORE SERVICE EQUIPMENT AND/OR SPARE PARTS
- PROVIDE DEBRIS/MICROMETEOROID PROTECTION FOR OTV
- PROVIDE RADIATION SHIELDING FOR CREW AND STORAGE EQUIPMENT
- PACKAGE WITHIN ORBITER DYNAMIC ENVELOPE AND SUSTAIN LAUNCH ENVIRONMENT
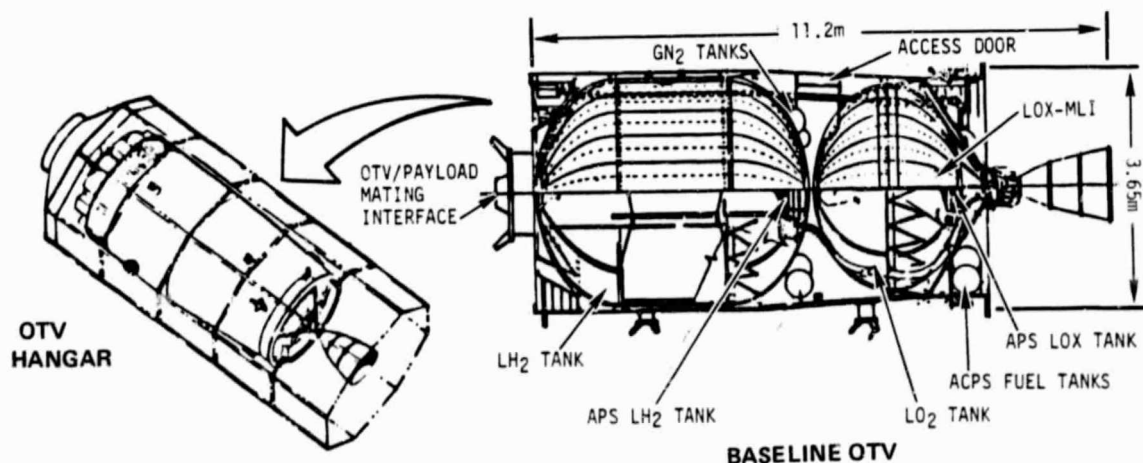
Figure 18. Baseline OTV Characteristics
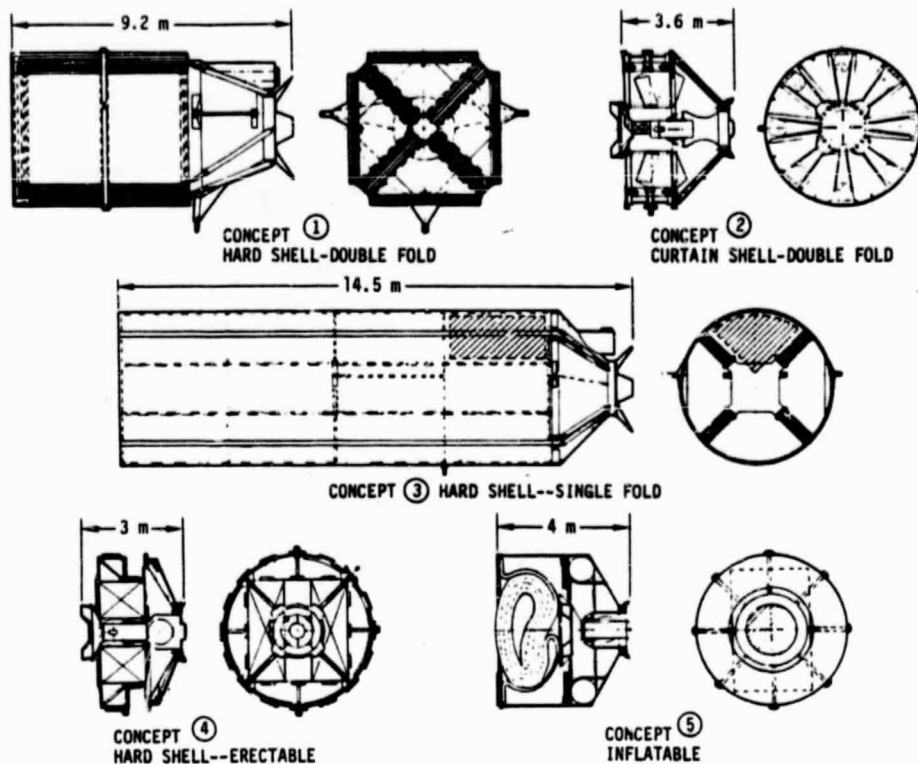
Figure 19.   Candidate OTV Hangar Concepts

o   Concept 1 uses twenty-four 50mm deep graphite composite faced
    sandwich structure panels that fold for storage as shown in
    Figure 19.

Deployment is accomplished first by extension of the telescoping braces
resulting in a lateral deployment to the configuration shown in Figure 20,
then to the configuration shown in Figure 21. To provide structural integrity
along the 40 mating panel edges, a total of 76 active locking devices is
required.
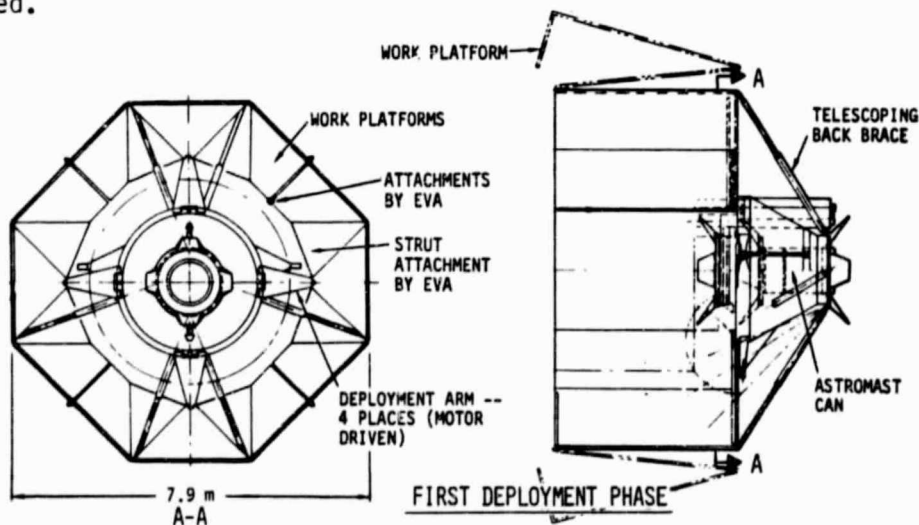
Figure 20.   Concept 1 - First Stage of Deployment
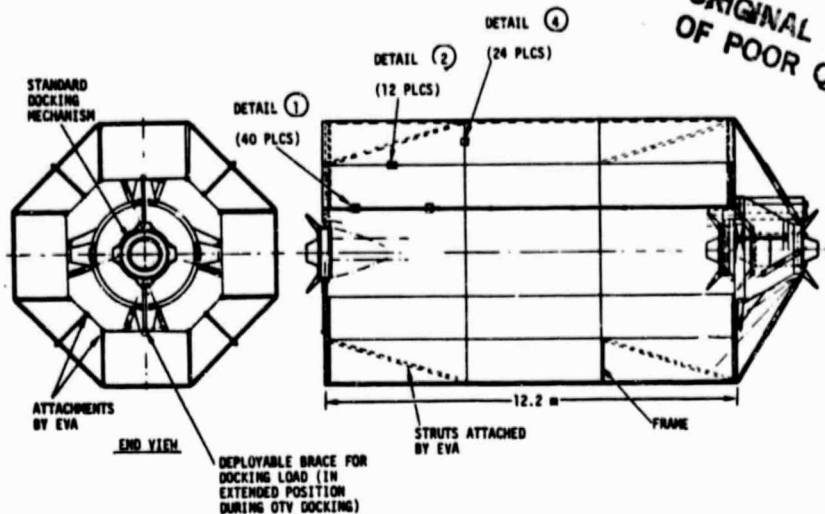
Figure 21. Concept 1 - Fully Deployed Configuration

o   Concept 2 utilizes a longitudinal folding curtain that is deployed
    by eight double-ended Astromast structures (Figure 22).   The curtains
    are constructed of aluminum faced 6.25mm deep panels. Folding frames
    are provided to laterally stabilize the Astromasts. A system of "X"
    bracing tensioned by the Astromast extension completes the basic shell
    octagonal truss work. Deployment is accomplished first laterally and
    then longitudinally.
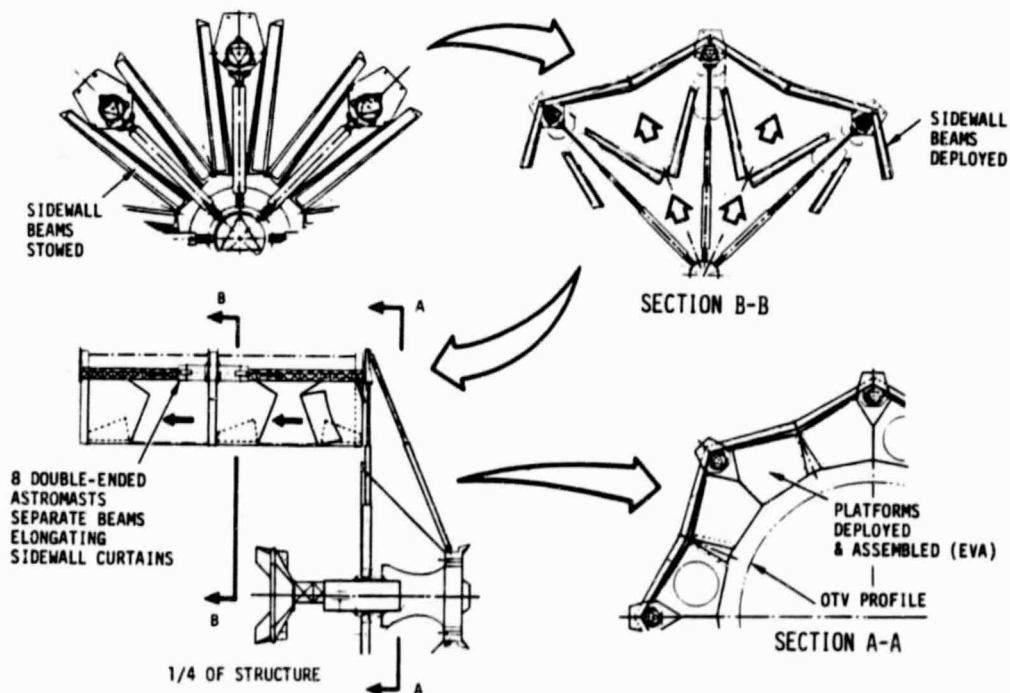
Figure 22. Concept 2 - Curtain Wall Configuration

o   Concept 3 is similar to Concept 1 except that since it is a single
    folded design, only the lateral mode of deployment is applicable.
    This concept, permits the use of 50mm deep aluminum faced panels.
    Volume is available for installation of service packages.

o   Concept 4 is an erectable graphite-faced honeycomb hard-shell design
    as shown on Figure 23. The complete configuration is comprised of
    88-18.8mm deep by 1.2 x 2.9m panels packaged as shown. Two astronauts
    can assemble the hangar as shown in less than 105 hours each (210 mh)

o   Concept 5 utilizes an inflatable structure and construction that
    deploys as shown in Figure 24.
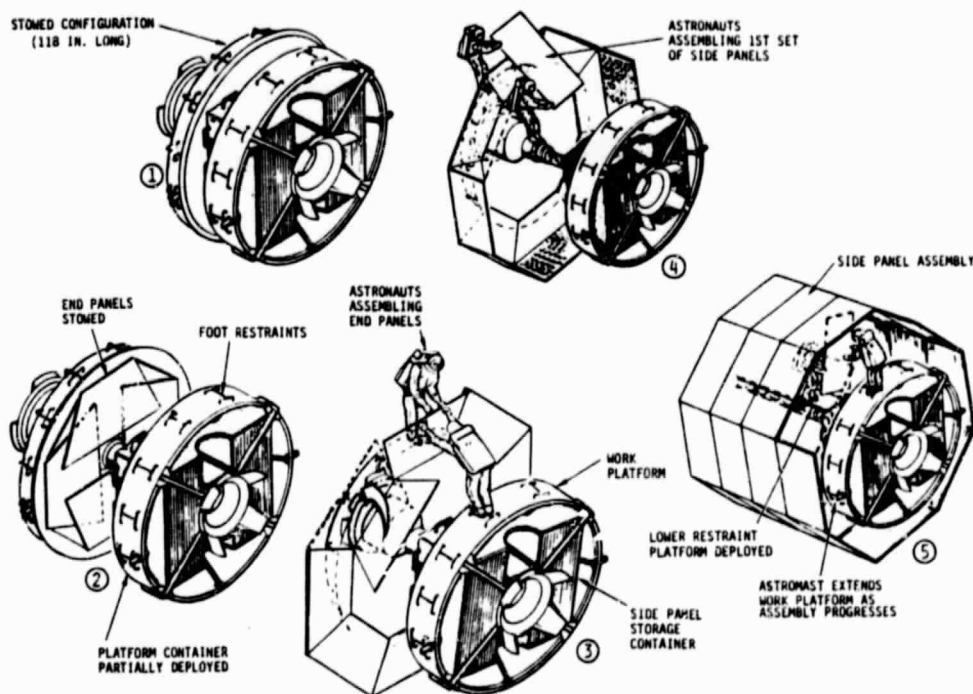
Figure 23.   Erectable Configuration

Essentially the same process selection methodology was employed in the
selection of Concept 4 (Figure 23) as that used in the deployable platform
systems.   Concept 4, i.e., the hard-shell erectable had the highest point
value, (Figure 25) least total cost, highest reliability, and the best
potential for technology transfer to other deployable structures.

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ASTROMAST PUSHES STOWED HANGER OUT OF CANISTER

ASTROMAST

AIR SUPPLY

STABILIZATION STRAPS INSTALLED BY EVA

② COVERED DOCKING PORT

③ INFLATABLE TUBE DEPLOYING FOLDED HANGER SHELL LONGITUDINALLY

⑤ COMPLETED OTV HANGER

CIRCUMFERENTIAL WORK PLATFORMS

STORAGE CANISTER

AIR STORAGE TANK

RADIAL SUPPORT ARMS ROTATE AS HANGER IS DEPLOYED

HANGER SHELL DURING RADIAL DEPLOYMENT

TWO PLIES OF FIBERGLASS

THICKNESS

63mm

① INFLATABLE HANGER STOWED

PAYLOAD CONFIGURATION

④

POLYURETHANE MESH CORE IMPREGNATED WITH GELATIN RESIN FOR RIGIDIZATION

CONSTRUCTION

TWO PLIES OF FIBERGLASS WITH THERMAL COATING

Figure 24.   Inflatable Shell Configuration

OTV HANGAR SELECTION PROCESS CRITERIA

(1) RELATIVE COSTS ($ MILLIONS)
  • LAUNCH   • TECHNOLOGY DEVELOPMENT
  • FABRICATION   • EXTRA VEHICULAR ACTIVITY
(2) DESIGN VERSATILITY
  • CAPABILITY FOR
    - GROUND INSTALLATION OF EQUIPMENT
    - ON-ORBIT INSTALLATION OF EQUIPMENT ON SHELL
    - ON-ORBIT INSTALLATION OF EQUIPMENT ON PLATFORMS
    - ADDED PLATFORMS
  • POTENTIAL FOR SIZE GROWTH
(3) ORBITER INTEGRATION
  • CONSTRUCTION SUITABILITY
  • CRADLE COMPLEXITY
  • LAUNCH LOCATION FLEXIBILITY
(4) RELIABILITY OF STRUCTURAL RIGIDIZATION
  • SIMPLICITY OF JOINING
  • CAPABILITY OF REMEDIAL EVA
  • CONTROL DURING CONSTRUCTION
  • NUMBER OF MOVING PARTS/FUNCTIONS
  • CONFIDENCE FROM GROUND TESTS
(5) DESIGN/EVA/TECHNOLOGY DEVELOPMENT/LIFE RISKS
  • LEAST DESIGN RISK
  • MINIMUM EVA RISK
  • MINIMUM TECHNOLOGY DEVELOPMENT RISK
  • MINIMUM STRUCTURE LIFE RISK

(1) RELATIVE COSTS ($ MILLIONS)
(2) DESIGN VERSATILITY
(3) ORBITER INTEGRATION
(4) RELIABILITY OF STRUCTURAL RIGIDIZATION
(5) DESIGN/EVA/TECHNOLOGY DEVELOPMENT/LIFE RISKS

CONCEPT	LEAST DESIGN RISK		MINIMUM EVA RISK		MIN TECHNOLOGY DEVELOPMENT RISK		MIN STRUCTURE LIFE RISK		TOTAL POINTS
	RANK	POINTS	RANK	POINTS	RANK	POINTS	RANK	POINTS	
	MAX POINTS 10		MAX POINTS 20		MAX POINTS 20		MAX POINTS 30		MAXIMUM 80
①	4	5	1	20	1	20	3	26	71
②	4	5	1	20	1	20	1	30	75
									80
									56
									43

TOTAL OF NORMALIZED SELECTION CRITERIA

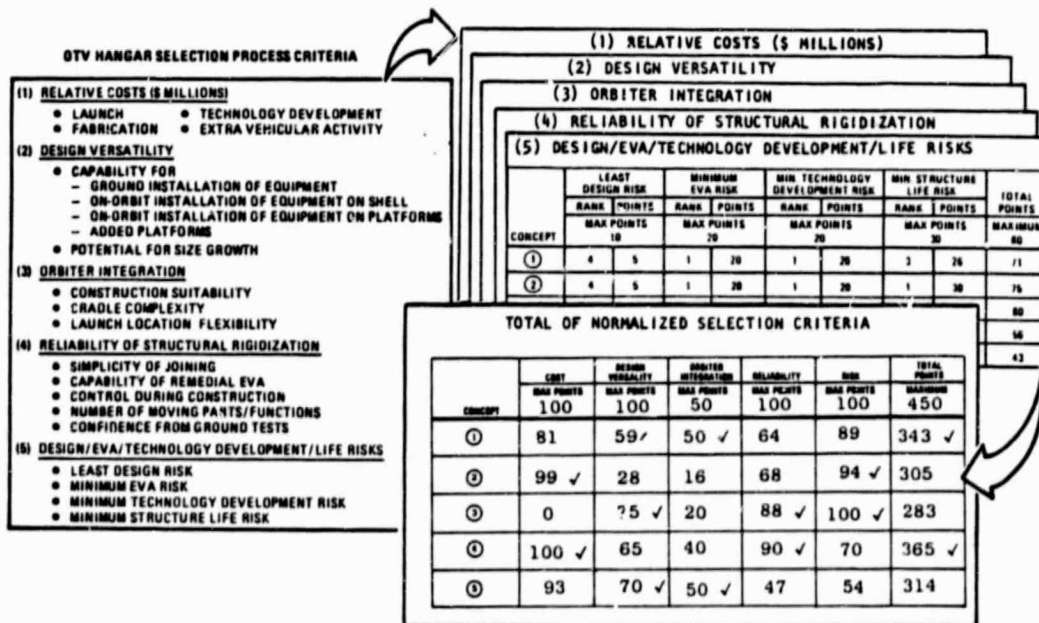| CONCEPT	COST MAX POINTS 100	DESIGN VERSALITY MAX POINTS 100	ORBITER INTEGRATION MAX POINTS 50	RELIABILITY MAX POINTS 100	RISK MAX POINTS 100	TOTAL POINTS MAXIMUM 450
①	81	59 ✓	50 ✓	64	89	343 ✓
②	99 ✓	28	16	68	94 ✓	305
③	0	75 ✓	20	88 ✓	100 ✓	283
④	100 ✓	65	40	90 ✓	70	365 ✓
⑤	93	70 ✓	50 ✓	47	54	314

Figure 25.   OTV Hangar Selection Process Methodology

MANNED MODULE DESIGN

The study-developed major requirements that directed the manned module development are shown in Table 7. Figure 26 illustrates the baseline manned module design which has a diameter of 15 feet and a length of 40.83 feet. The baseline design is a cylindrical pressure vessel design with toroidal transition sections to the conical shells on each end. The floor is structurally joined with the cylindrical shell to provide the shear load path to the drag fittings. The floor is constructed of integrally machined panels supported on longitudinal beams spanning to lateral beams provided at the frame stations. The outer wall construction is as shown in Figure 27. Since space debris impact requirements and design data are not available, the construction shown is not designed to that requirement. The implications of potential space debris impact, however, were judgmentally considered in the deployable volume design reviews.

Figure 28 presents the major configuration characteristics of a hard-shell deployable manned module configuration capable of replacing two manned modules such as shown in Figure 26. Section A-A illustrates the nesting of the deployable volumes during stowage and the cylindrical hinge lines A, B, C, and D. View B-B illustrates the end flat bulkhead developed which contains the fold-down and flip-out panels. Sealing is required at all the hinge lines shown.

Table 7. Manned Module
Requirements

|	
● LEO	● 20 years
● LAUNCH/PACKAGING	● Compatible with the orbiter
● CREW	● 4 to 8 crewmen for 90 days + 21 days emergency
● ENVIRONMENT	● 10.5 n/cm² and 18 to 24°C
● REDUNDANCY	● Two separate pressurized compartments ● Two routes for ingress/egress
● MAXIMUM LEAKAGE RATE	● 0.22 Kg/day
● EQUIPMENT	● Life support equipment ● Command Control Center ● Two docking ports
● METEOROID PROTECTION	● 1990 Kessler space debris and NASA SP8013 micrometeoroid model
● RADIATION PROTECTION	● 0.50 gram/cm²
● Manned module design commonality (design goal)	
● Compatibility with evolution from initial to growth configuration	
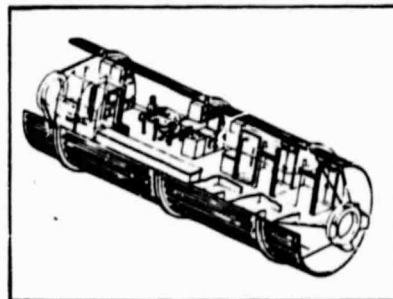
Figure 26. Baseline
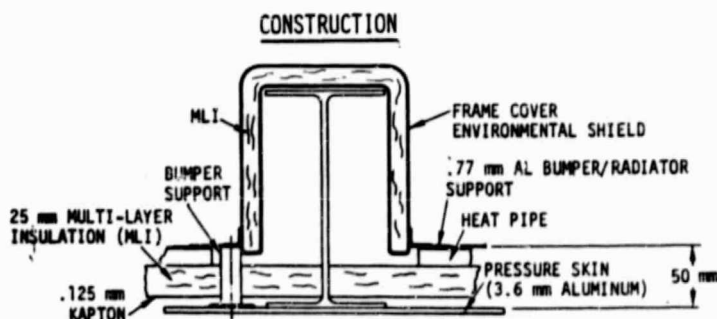Manned Module

CONSTRUCTION

Figure 27. Outer Wall Construction—
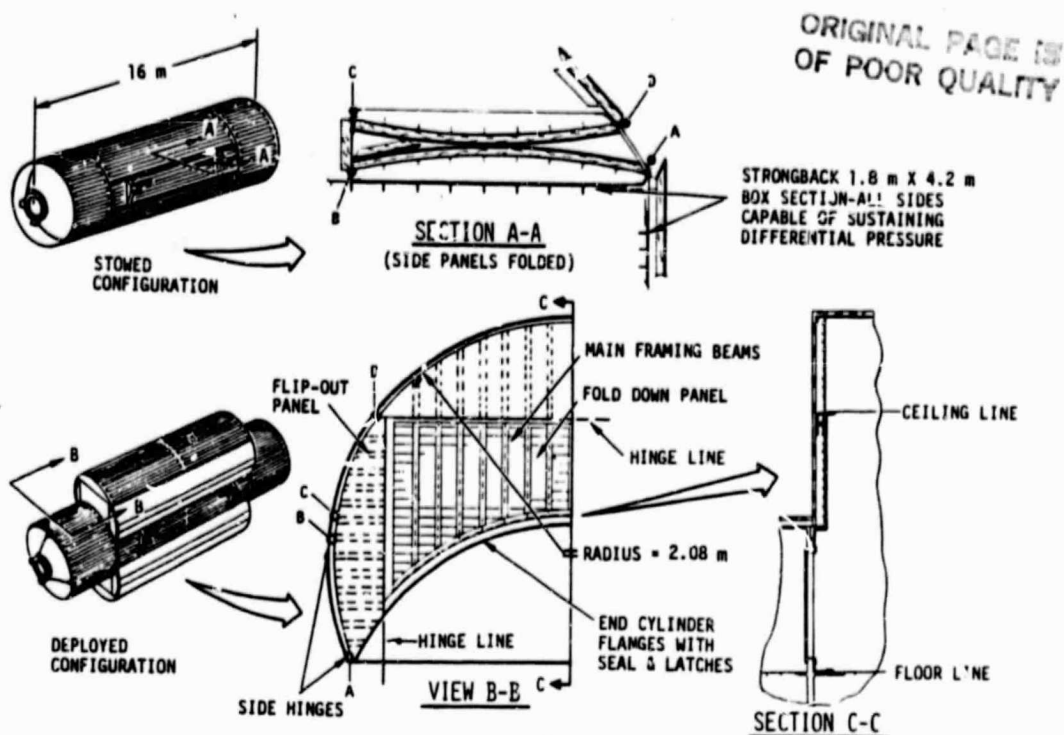Baseline Manned Module

Figure 28. Manned Module-Deployable Hard Shell Concept

The 1.8 x 4.2m strongback provides floors for each side of the module capable of sustaining any combination of differential pressures during normal or emergency situations. The strongback also contains the orbiter attach fittings and back-up framing.

This structural configuration presents no significant strength or stiffness design problems. However, during this study a reliable long-term sealing system could not be developed. (The attempts are documented in Volume II). The difficulty and importance of sealing are illustrated as follows:

o   The requirement is 0.22 kg/day per baseline module, or .44 kg/day for this design.

o   To minimize the leakage to .44 kg/day the largest equivalent circular hole permissible for the entire module is .12 mm in diameter. The difficulty of sealing can be appreciated.

o   A 2.2 kg/day increase in leakage rate will require an additional 16,060 kg of air supply over 20 years. The launch of that mass alone negates the launch cost savings achievable with the deployable volume configuration.

Figure 29 illustrates the major configuration characteristics of the inflatable manned module design. This design is similar to the hard-shell design previously discussed, except than an inflatable shell replaces the cylindrical shell and end flat bulkheads, while on the hard-shell design the
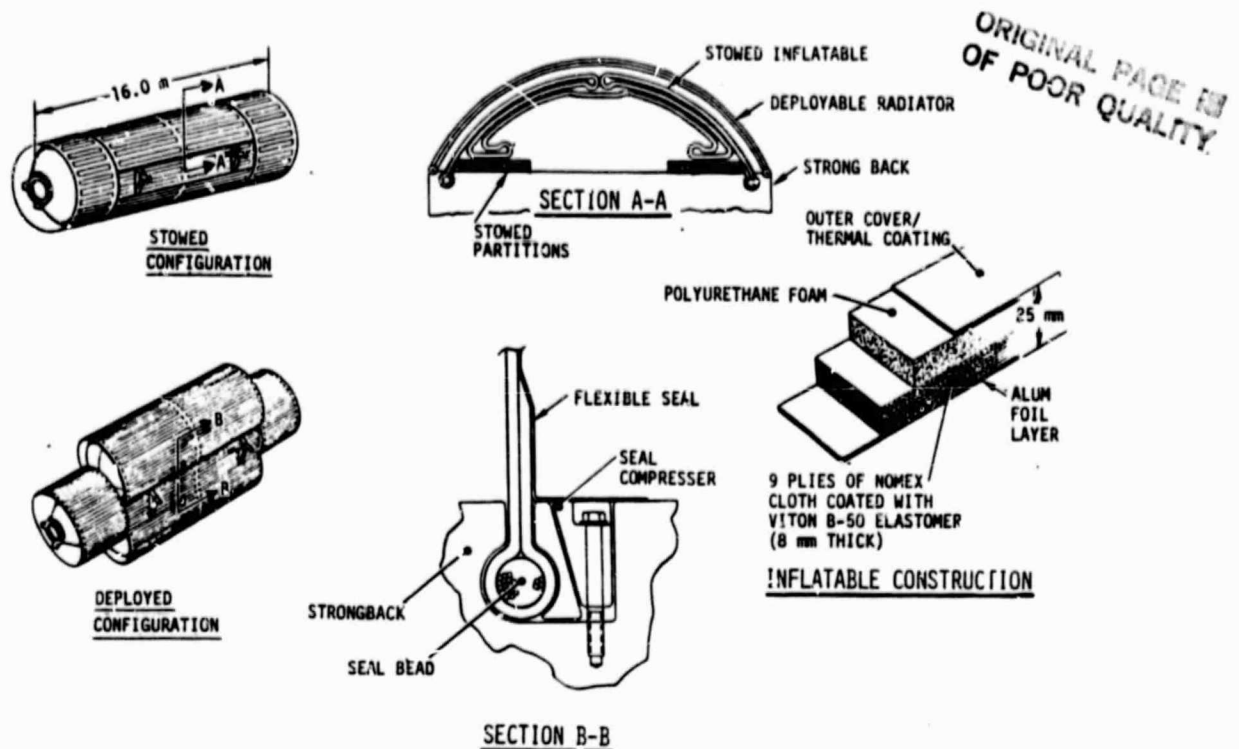
SECTION A-A

SECTION B-B

Figure 29.   Manned Module - Inflatable Concept

radiators are mounted directly to the structure shell. For this design, the
radiators are also deployable as shown in Section A-A and can act as a
meteoroid bumper.   Section B-B illustrates the typical joint at the
inflatable-to-strongback interface. Here too the reliability of the
construction shown to maintain leakage to within .44 kg/day is a great
uncertainty. There is no existing test data pertinent to the leakage rate.
In addition to the sealing concern, both deployable volumes require on-orbit
installation of partitions and other miscellaneous equipment that is to be
mounted on the floors.

Therefore, in view of the previously described considerations relating to
the implications of large leakage rates, it is recommended the study of
deployable volumes for manned modules be terminated.