# MODULAR REFLECTOR CONCEPT STUDY

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## THE THREE CANDIDATE MODULAR CONCEPTS

The primary objective of this study was to investigate the feasibility of constructing large space structures, specifically a 100-meter paraboloidal R.F. reflector, by individually deploying a number of relatively small structural modules, and then joining them to form a single, large structure, in orbit.

The advantage of this approach is that feasibility of a large antenna may be demonstrated by ground and flight tests of several smaller and less costly sub-elements (modules). Thus, initial development costs are substantially reduced and a high degree of reliability can be obtained without commitment to construction of a very large system.

The three candidate structural concepts illustrated in Figure 1 are investigated:

1. The Deployable Cell Module (DCM)

2, The Paraboloidal Extendable Truss Antenna adapted to modular assembly (Mod-PETA)

3. The Modular Extendable Truss Antenna (META)

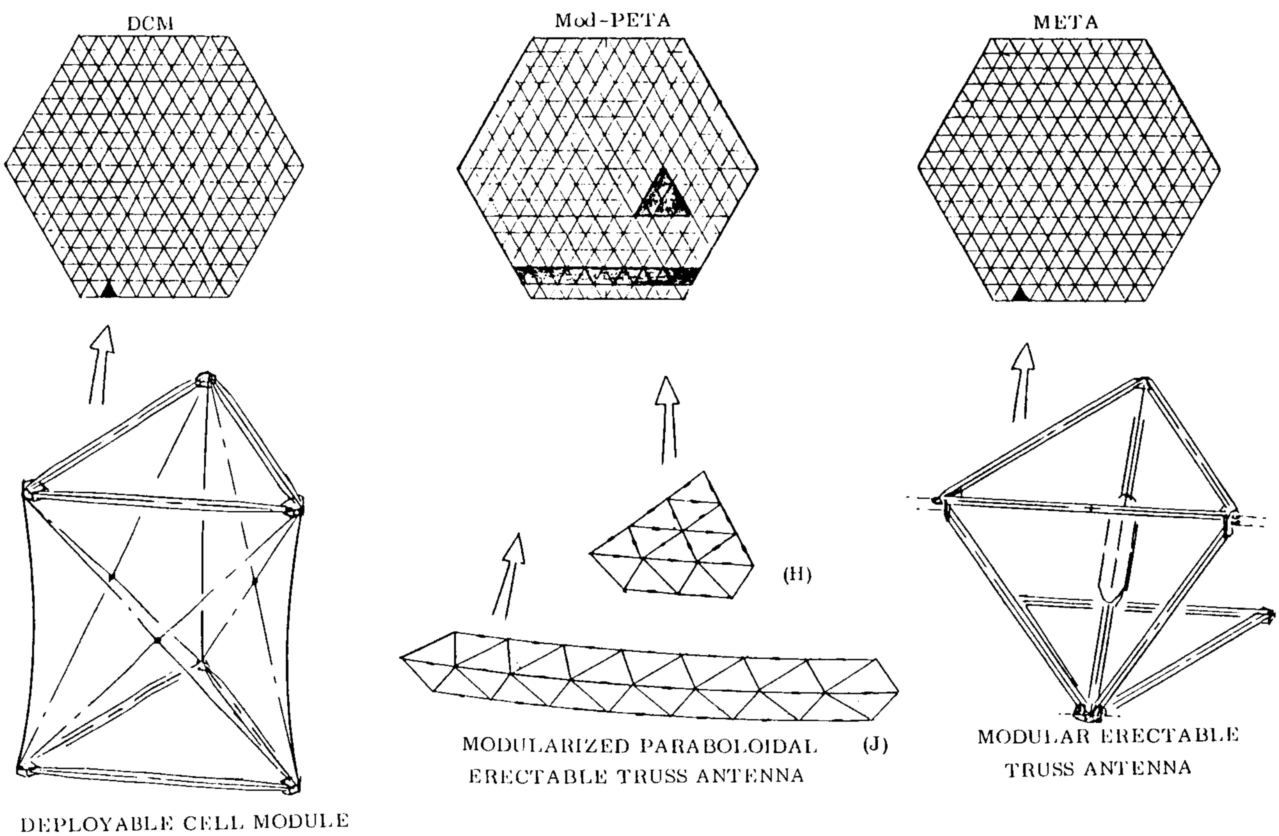



Figure 1

DCM, 100-METER, 721 MODULE REFLECTOR

The reflector configuration shown in Figure 2 is optimized for the minimum number of component structural modules.

Due to the desired paraboloidal shape of the reflector (f/d = 1.0) the component structural elements of the modules vary slightly in length. The double dimensions shown in Figures 2 and 3 indicate the limits of this variation which is generally within ± 2.06% of the median dimension. Optimization ensures that the largest module, when packaged is compatible with transverse stowage in the STS Orbiter payload bay diameter. Space is allowed for the stowage pallet, as shown in Figure 4.

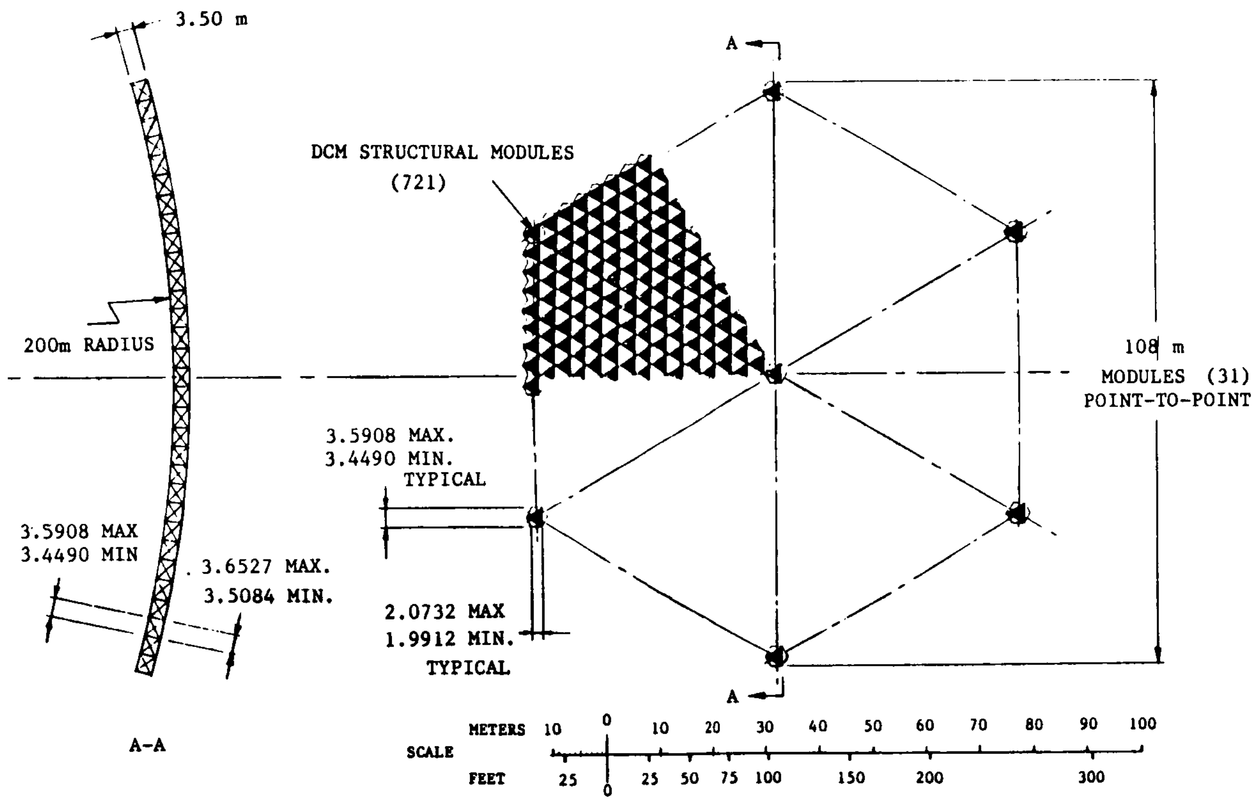



Figure 2

DCM - TYPICAL MODULE IN DEPLOYED CONFIGURATION

Figure 3 shows the typical module configuration. The two triangular frames and the six cross ties are the prime structural elements of the module. The structural performance of the total reflector is dependent on the strength and stiffness of these elements. The three prebuckled column members that separate the two triangular frames act as compression springs and provide a simple means of preloading the prime structural elements. The geometric stability of the DCM module is dependent upon this preloading, which puts the six cross ties in a state of sustained tension, and the triangular frames in sustained compression. In practice, the magnitude of this required preloading must be determined for each specific application to satisfy two critical requirements: 1) Preloading must be sufficient to ensure that the tension in the six ties remains positive for all conditions of externally applied structural loading, and 2) Preloading must not be so large as to exceed allowable column strength of the triangular frame elements (tubes) under conditions of additive applied structural loading.

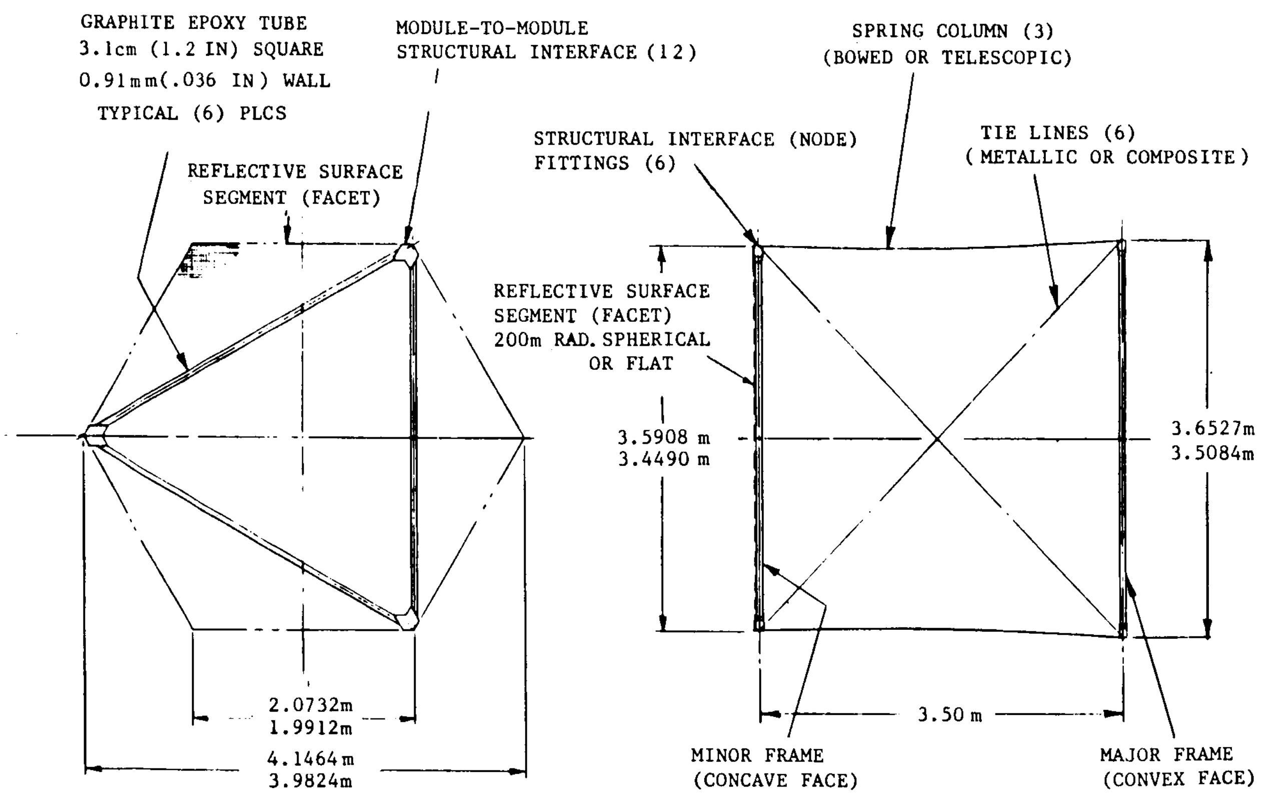



Figure 3

## DCM - STOWAGE OF PACKAGED MODULES IN ORBITER PAYLOAD BAY

The module configuration shown above in Figure 3 permits it to be mechanically folded to occupy a much lesser volume. The two, rigid, triangular frames maintain their size and shape, but when one frame is rotated, in plane, relative to the other, the three intermediate columns lean over through 90° drawing the two frames together. The overall height of the module thus shrinks from its deployed height of 3.5 meters to a packaged height of only 6.2 centimeters. This packaging capability permits 270 such modules to be stacked in a 16.7 meter increment (90%) of the Orbiter payload bay. As shown in Figure 4, each module is supported within the cradle by three "shoes" one at the bottom center line and one more on either side just above the horizontal centerline. The shoes are keyed into troughs that run the full length of the cradle, and individually engage an endless belt. In orbit the modules are dispensed one at a time from the front end of the cradle. To dispense a module the three endless belts are advanced, simultaneously, a distance equal to the overall thickness of one module. This causes the entire module stack to advance a similar distance resulting in the release of the dispensed module.

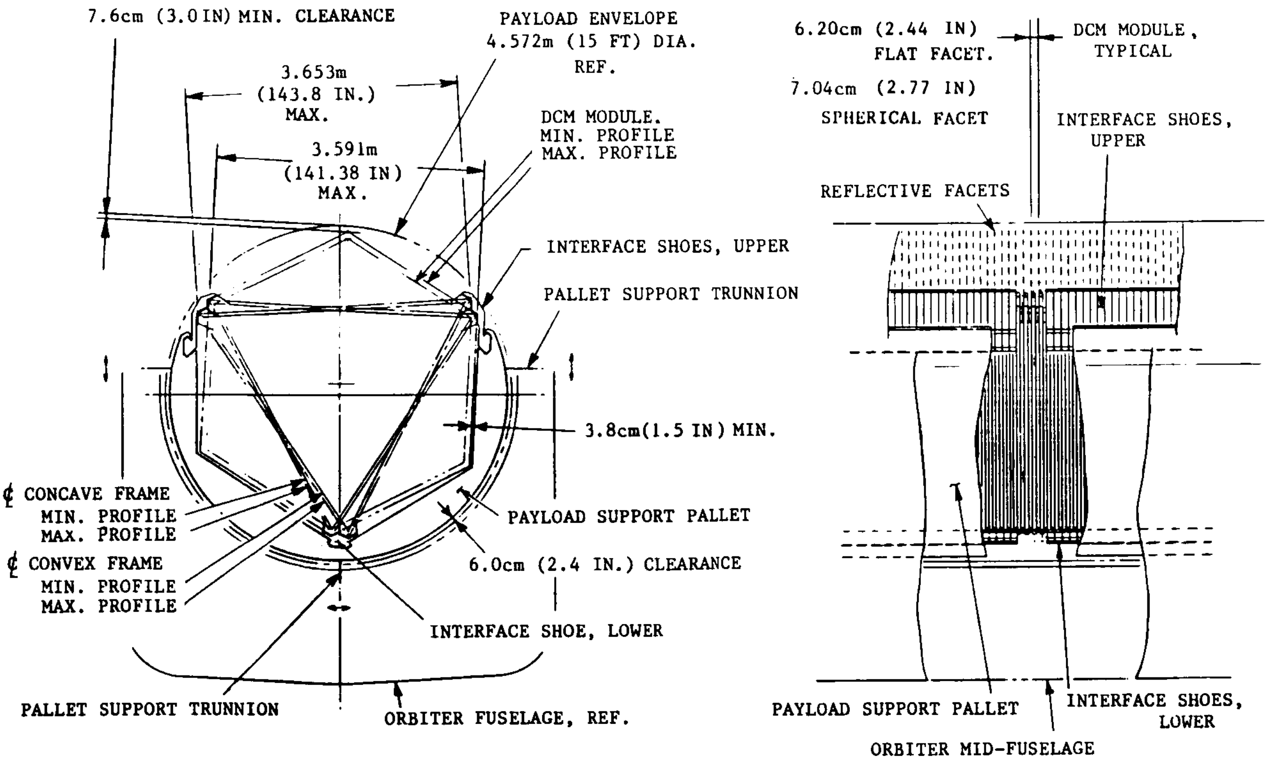



Figure 4

## DCM - PAYLOAD SUPPORT PALLET (PSP) IS ELEVATED AND SUPPORTED BY TWO ARTICULATED ARMS

The Payload Support Pallet (PSP), containing the packaged structural modules and all handling and assembly support equipment is removed as a unit from the payload bay. It is supported in an attitude and at a distance from the Orbiter that will enable observation and monitoring from the Orbiter crew compartment and that will incur minimum risk to the Orbiter.

The first stage of the in-orbit deployment sequence is release of the PSP tiedown latches and elevation of the PSP from the Orbiter bay by means of two articulating support arms (Figure 5). These arms may subsequently be locked to establish a rigid relationship between the PSP and the Orbiter. However, in order to prevent excessive loading at these support interfaces as the mass moment of the evolving structure becomes large, it may be necessary to provide a sprung (non-rigid) interface that would accommodate oscillatory movements yet maintain the mean relationship at nominal. A superimposed effect would be correction of orbital tumbling by means of the Orbiter attitude control systems.

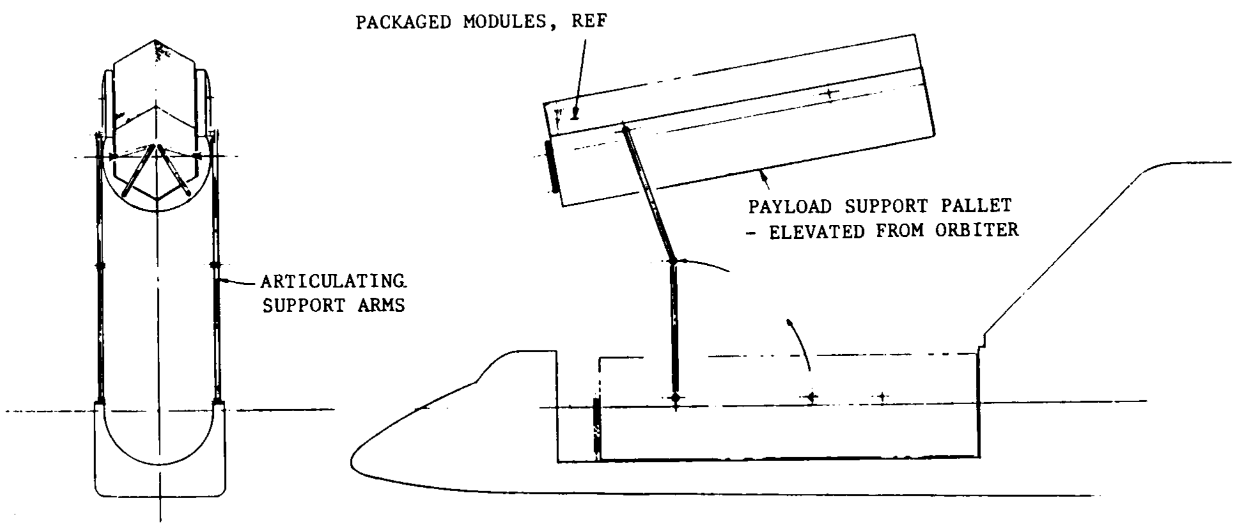



Figure 5

DCM - EFFECTOR HEADS ON THE TWO HANDLING AND JOINING ARMS (HJA) ENGAGE, ALIGN AND JOIN MODULE NODE FITTINGS BOTH FRONT AND BACK

The individual modules are advanced to the extreme end of the PSP, as described above, and driven into deployed configuration by applying moments to the three intermediate columns.

The two HJA then engage the node fittings of the modules and position the modules side-by-side.

When the required alignment is achieved the Link Trigger Unit (LTU) rotates down to engage the node fittings and to actuate the link trigger mechanism, which effects the mechanical joining of the structural interface. The exact logic of this function is not defined but is visualized either as a latching link, built into one node fitting, which extends across the structural interface to engage the mating node fitting, or as a separate part ejected from the LTU to snap over the anchor pins in the node fittings. For the latter approach the usual undesirability of loose parts may be offset by the potential simplicity of the structural features involved.

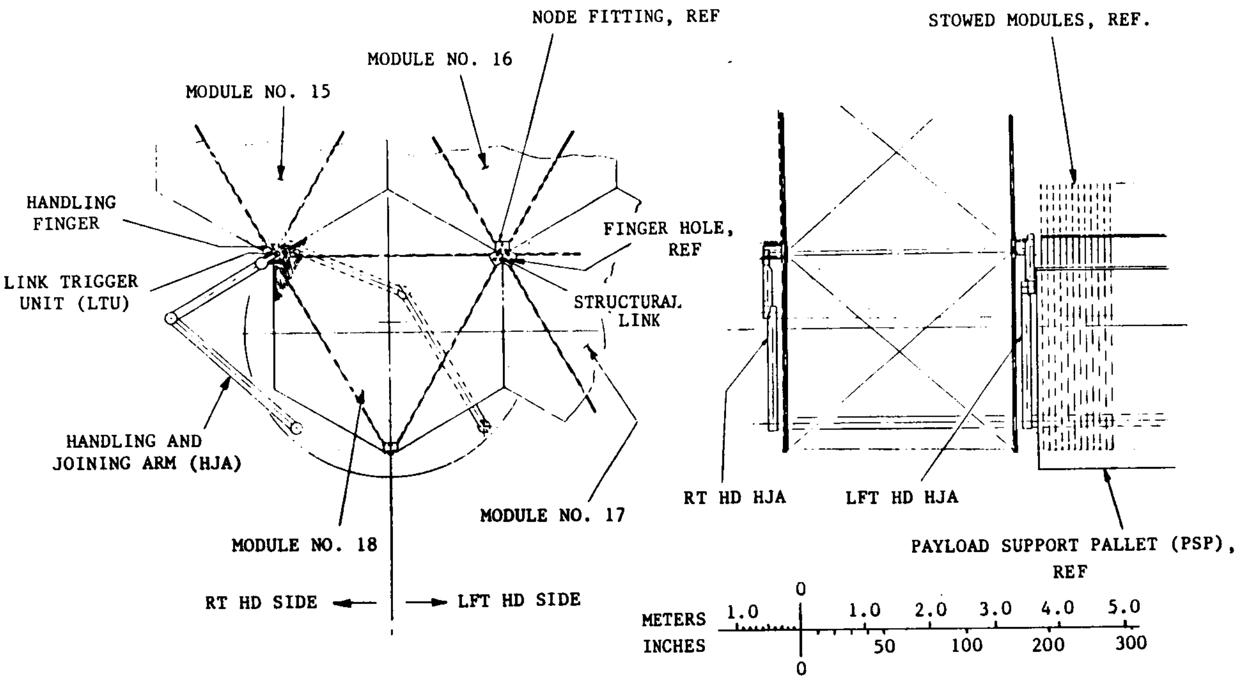



Figure 6

DCM - THE BUILD-UP PROCEEDS IN A ZIG-ZAG MANNER TO LAY DOWN
A TOTAL OF 721 MODULES IN 31 ROWS

By means of a complex sequence of motions the HJA manipulators integrate each subsequently deployed module into the evolving structure.

The total reflector structure is built-up, thus, row by row, following a zig-zag course from top to bottom.

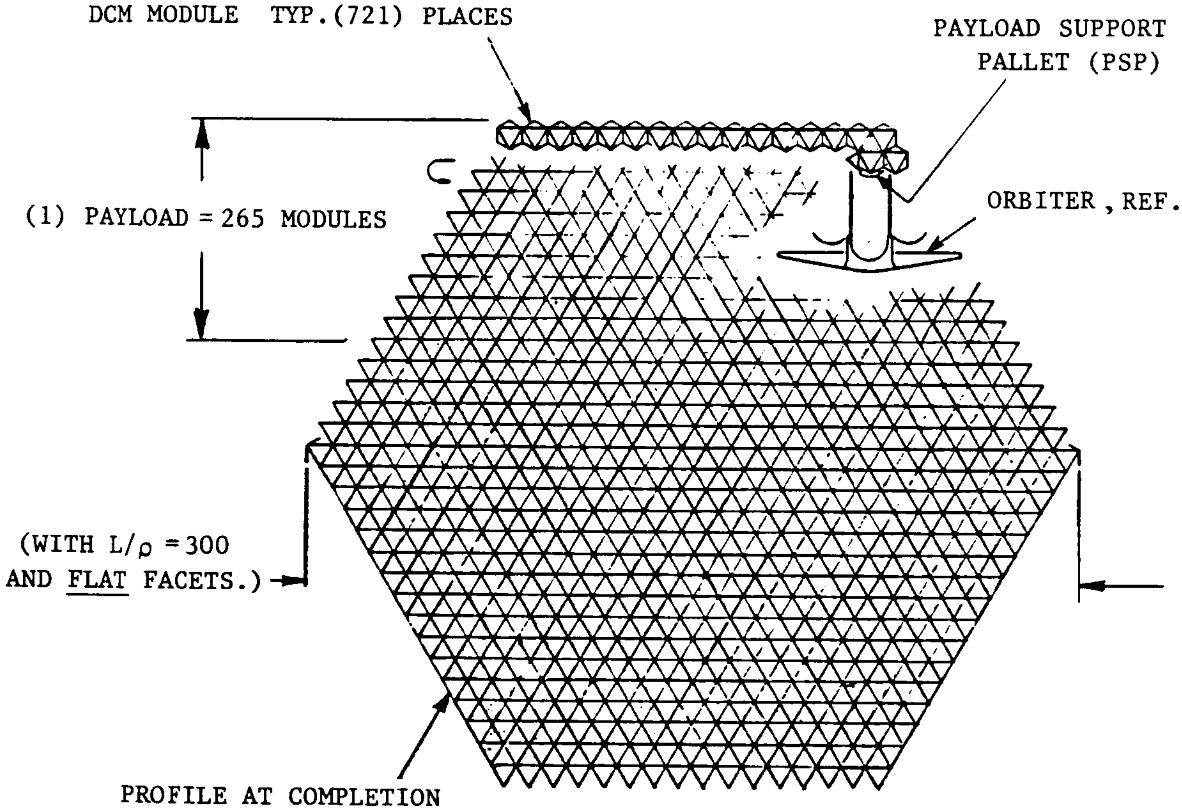



Figure 7

MOD PETA (TYPE "H") - A MODULARIZED
24 BAY "PETA" RELFECTOR CONSISTING OF 96 MODULES

The concept of deploying several such PETA structures in space, and subsequently joining them to produce a single larger structure has potential and is presented in this study as an alternative to the DCM approach.

The 100-meter, modularized PETA reflector shown in Figure 8 consists of 96 individual, triangular structural modules joined at their edges to form a single, integrated structure. In order to achieve matched geometry at the structural interfaces modules are alternately "male" and "female".

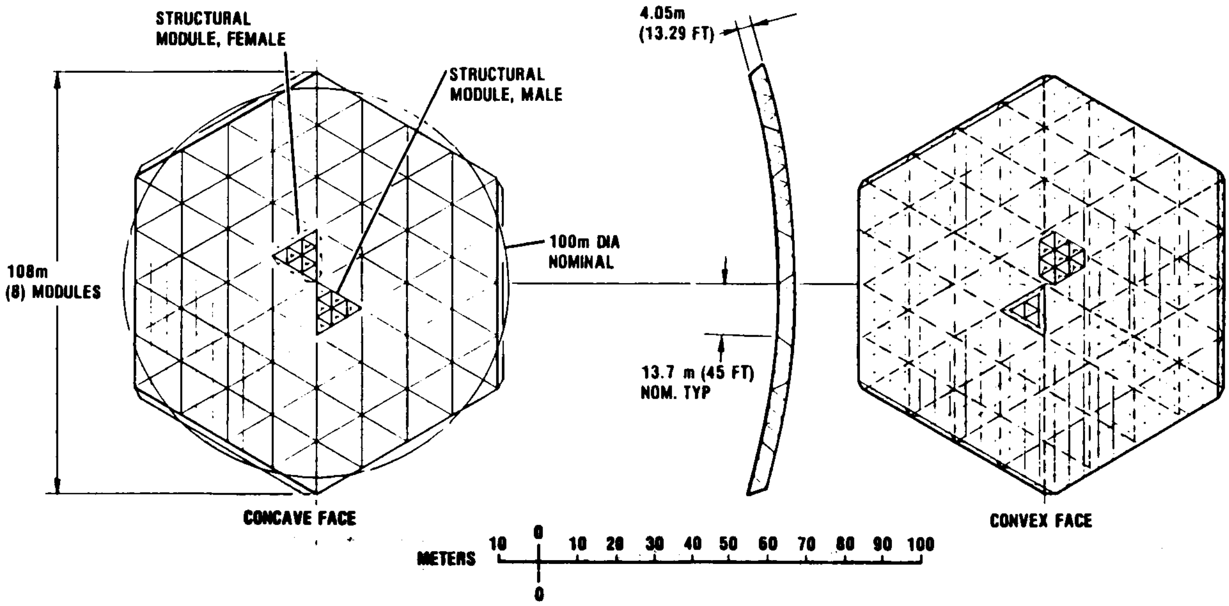



Figure 8

## MOD PETA, THE ELEMENTAL TETRAHEDRAL STRUCTURE OF SIX STRUTS

The structural system of the PETA design is, in essence, a mechanical assembly of tubular structural members joined at their ends and arranged to form a multiplicity of tetrahedrons. The pivotal capability of the end joints and the mid-span hinges that are provided in certain members enable the structure to be mechanically folded into a high density package in which all members lie in parallel orientation (Figure 9). The mid-span hinges may be spring loaded so that when circumferential restraints are released from the package, the structure automatically unfolds radially until it locks-up its fully deployed configuration.

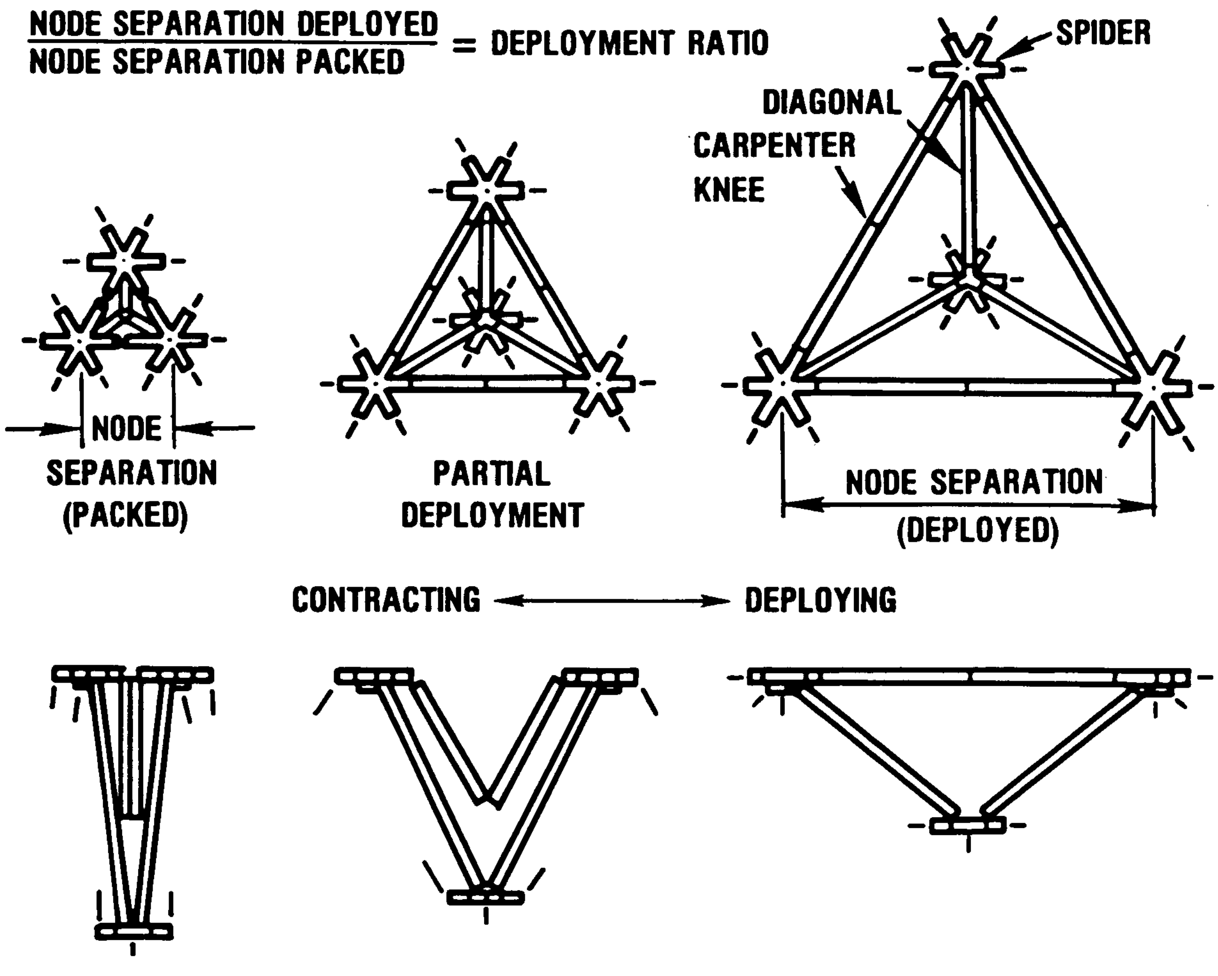



Figure 9

## MOD PETA (H), MODULE STRUCTURAL DETAILS

The typical module is triangular and encompasses three bays of structure.

The concave (meshed) face of all modules is identical, but "female" modules are larger overall than the typical male module, shown below, since their side faces flare outward rather than inward.

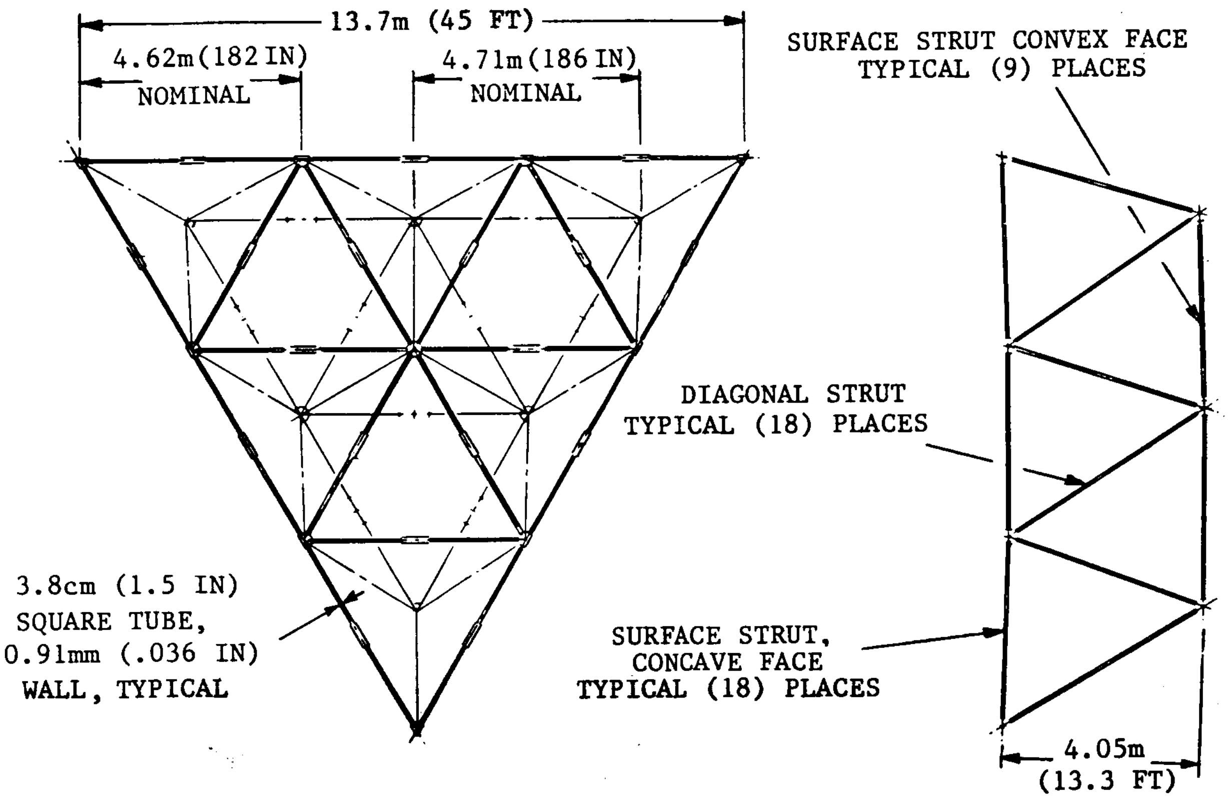



Figure 10

MOD PETA (H), THE PACKAGED MODULE

The modules typically fold to approximately one fifteeth their deployed size when packaged for stowing in the Orbiter payload bay. The hexagonal node fittings meet to form solid end faces to the package; the folded "surface" struts rest securely between the parallel "core" struts, and the reflective mesh surface collects in a bundle atop the upper node fitting standoffs.

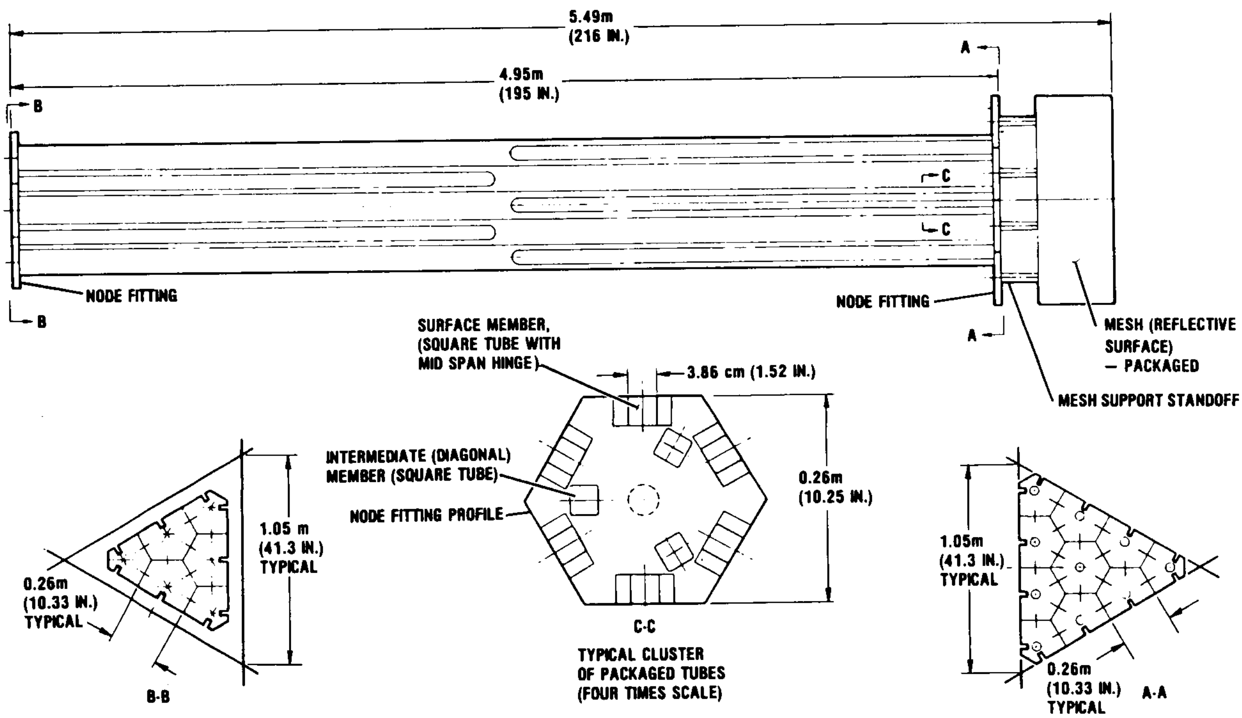



Figure 11

## MOD PETA (H), STOWAGE REQUIREMENTS ARE PROPORTIONAL TO SELECTED STRUCTURAL DEPTH

As with the DCM concept studies, it is assumed that 10% of the Orbiter payload bay length is reserved for support equipment, leaving 16.46m (54 ft.) available for stowage of the packaged reflector. Thus, the PETA reflector structure, described above stows in clusters, with 24 modules per cluster. This arrangement permits three clusters to be accommodated within a single payload. A second flight is required for the fourth cluster. Total stowage space required, therefore, is equivalent to 1.3 payload bays.

**It is conceivable that all four clusters can be accommodated in one payload (Study Case "D", Figure 12), by shortening each packaged module to 4.1m (162 inches). While such shortening is feasible, it must be considered that this results in corresponding reduction of deployed structural depth, structural** stability (dynamic and thermal), surface shape accuracy and, therefore, potential R.F. capability.

Figure 12 presents three typical cases, Study Cases "D", "E", and "F" to illustrate the relationship between payload volume (length) and deployed structural depth, for a 100-meter structure. It will be noted that reducing structural depth also results in a significant increase in component part count due to corresponding increase in the number of structural bays.

It is seen that Orbiter flights required are 1, 2, and 4, respectively.

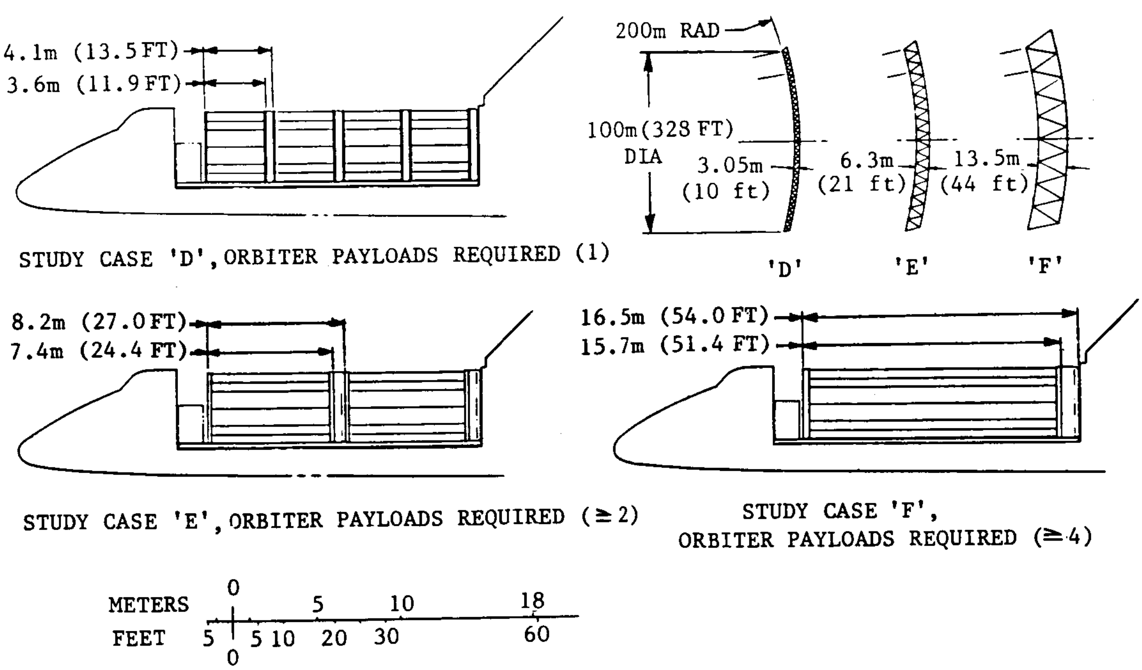



Figure 12

MOD PETA (J), AN ALTERNATIVE MODULE CONFIGURATION

The essential difference in this approach is that the triangular tetrahedral truss modules are replaced by high aspect ratio (beam) tetrahedral truss modules of minimum width and maximum length. The structure folds and deploys by the same basic mechanism described above in Figure 9.

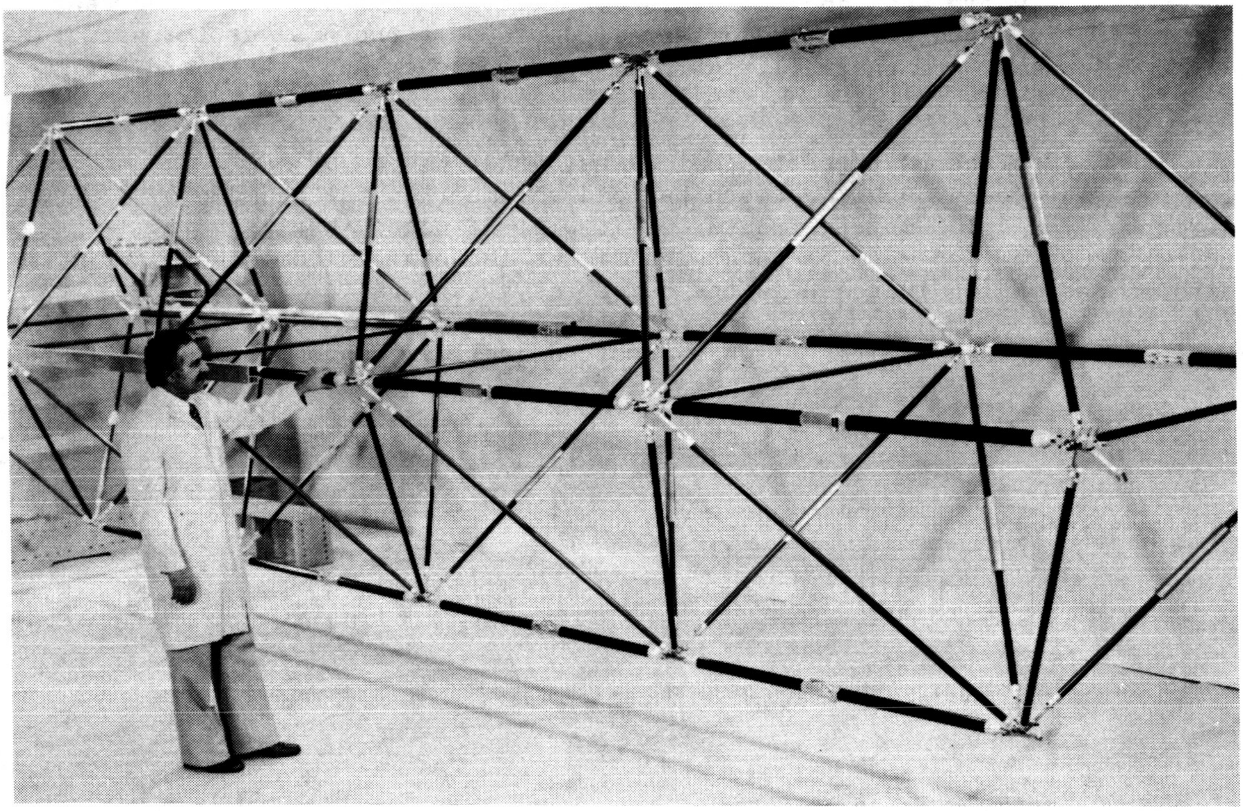
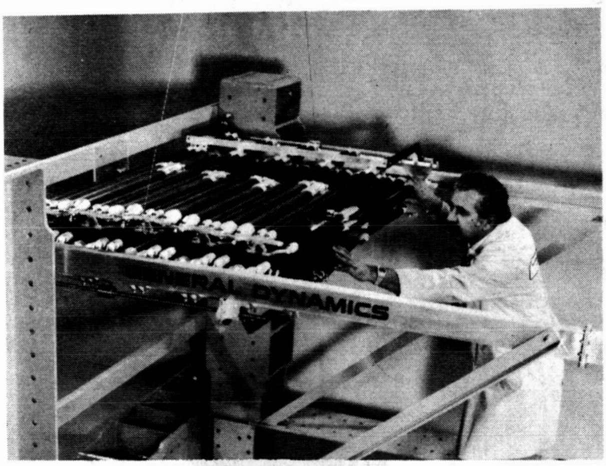


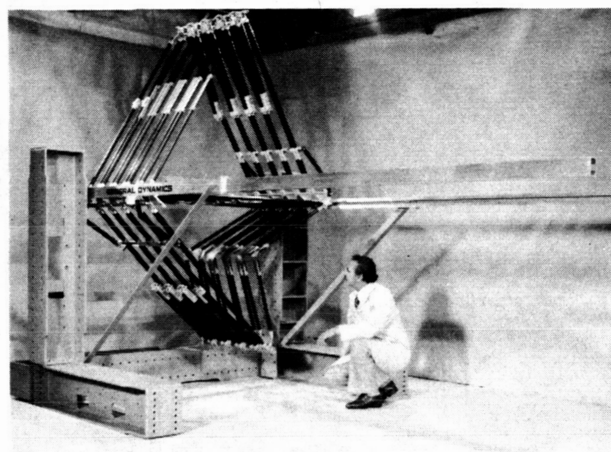
Figure 13

MOD PETA (J), CONTROLLED DEPLOYMENT OF BEAM MODULES

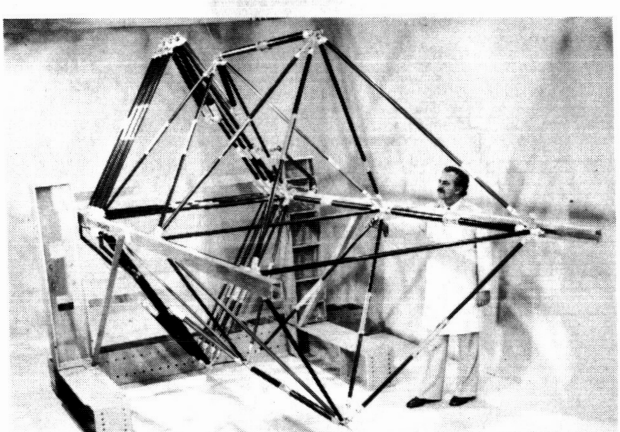
The mechanical sequence of deployment of the beam module is shown below. Figure 14a shows the typical "flatpack" with all tubular elements lying in parallel orientation. In Figure 14b, both the upper and lower layers of the structure transition vertically to form a diamond section shape. In Figure 14c, deployment occurs in the longitudinal direction as the structure extends bay-by-bay forming a series of tetrahedrons. In Figure 14d, the fully deployed beam (module) assumes its fully triangulated truss configuration.



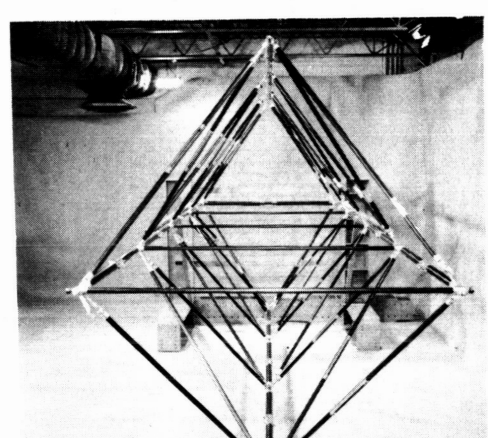
a



b



c



d

Figure 14

MOD PETA (J), HANDLING AND JOINING MECHANISMS (HJM) REMOVE MODULE "FLAT-PACKS" FROM ORBITER AND HOLD THEM ERECT FOR DEPLOYMENT

For launch in the Orbiter the "flat packs" are stowed in two stacks of twelve modules each. Each stack is provided with a Handling and Joining Mechanism (HJM). These remove the modules from the payload bay one at a time, control deployment, bring the modules together, and join them.

In Figure 15, the initial stages of erection are shown. The forward HJM is seen to have engaged the second module preparatory to removing it from the payload bay. The aft HJM has already removed the first module and has positioned it ready for deployment. In the right-hand view, this module is shown supported vertically on six finger probes.

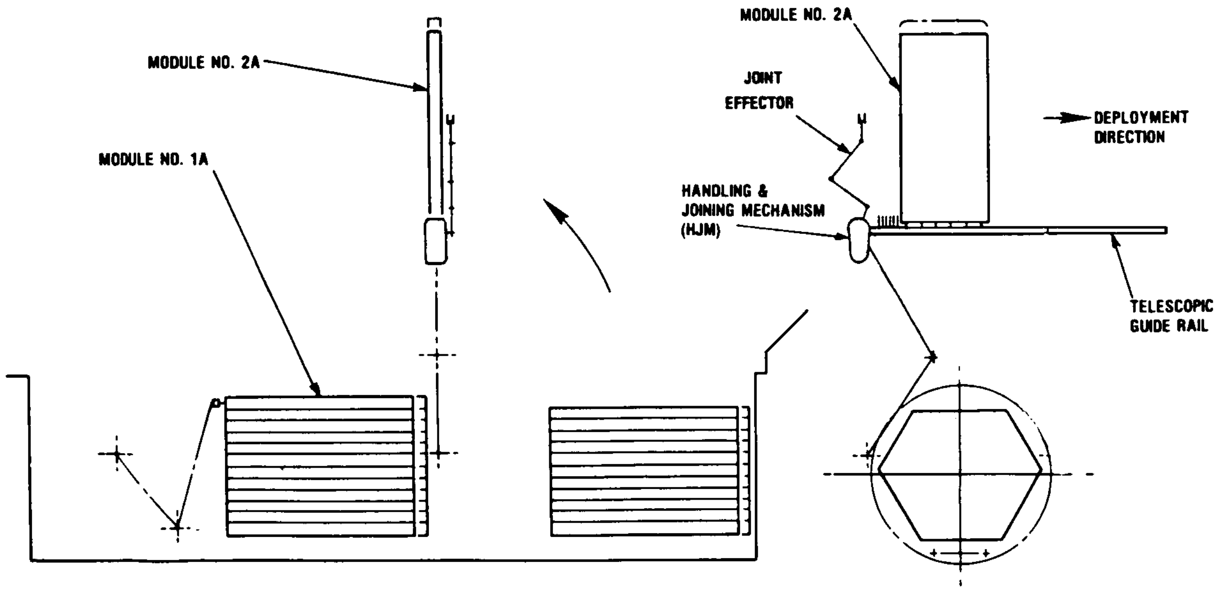



Figure 15

MOD PETA (J), MODULE DEPLOYS IN TWO PHASES. FIRST OPENING TO A DIAMOND SECTION, THEN LONGITUDINALLY, BAY-BY-BAY

Figure 16 illustrates the first increment of deployment of the module. This step repeats, bay-by-bay until the fully deployed module extends in cantilever fashion, from the guide rail. The left-hand view of Figure 16 shows the deployed section shape of the module.

The aft HJM differs from the forward HJM in that it is provided with a joint effector subsystem which is capable of reaching both the lower and the upper node fittings of the modules and of performing the structural joining of the mating node fittings, as shown in Figures 17 and 18.

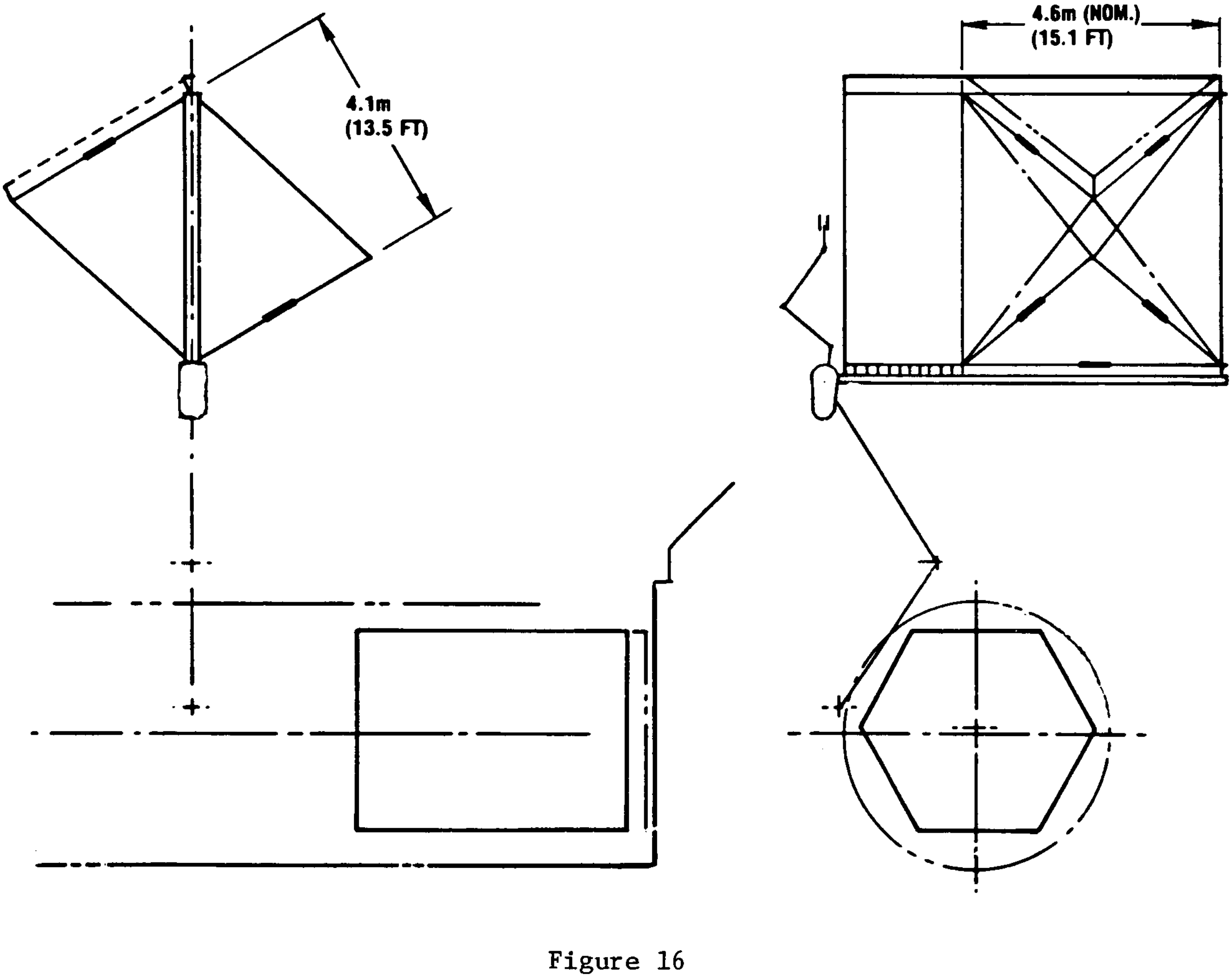



Figure 16

MOD PETA (J), INITIAL TWO MODULES DEPLOY INDIVIDUALLY, THEN JOIN

Two modules are fully deployed, one from each HJM, which then moves them into side-by-side contact for structural integration.

Joining of all node fittings along the interface is accomplished by longitudinally translating the modules across the payload bay by hand-over-hand operation of the two HJM's. As the integrated modules pass over the payload bay the joint effector reaches upward, into the structure, and effects the locking of the mating node fittings.

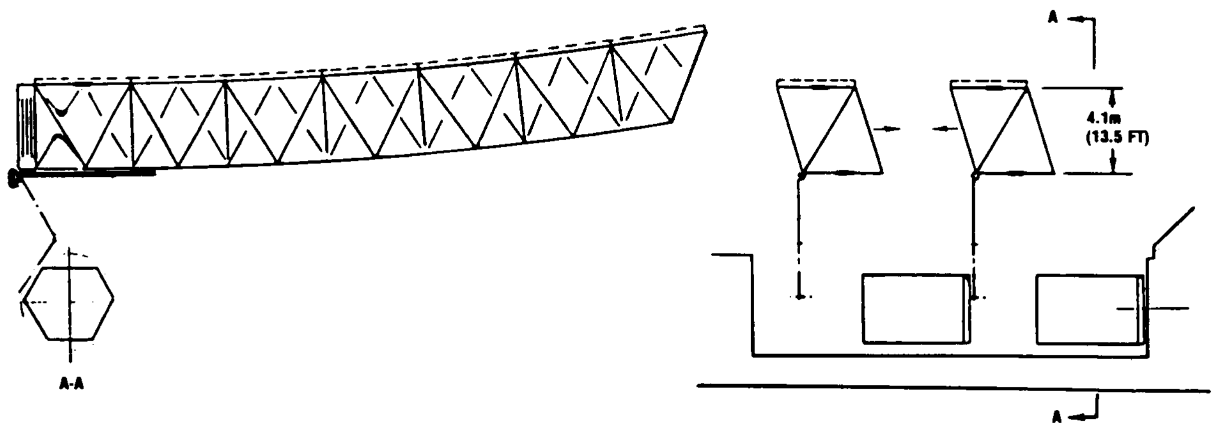



Figure 17

MOD PETA (J), HALF REFLECTOR IS ASSEMBLED BY DEPLOYING AND JOINING THE FIRST PAYLOAD OF 24 MODULES

The third module is deployed in the opposite direction to the first two modules and the construction thus proceeds in a zig-zag mode, as indicated in Figure 18 where the reflector is shown a little more than quarter complete. Thirteen modules have been deployed and joined, and the fourteenth is deployed and about to be joined.

When twenty-four modules have been joined, the reflector is half complete and the initial payload is exhausted.

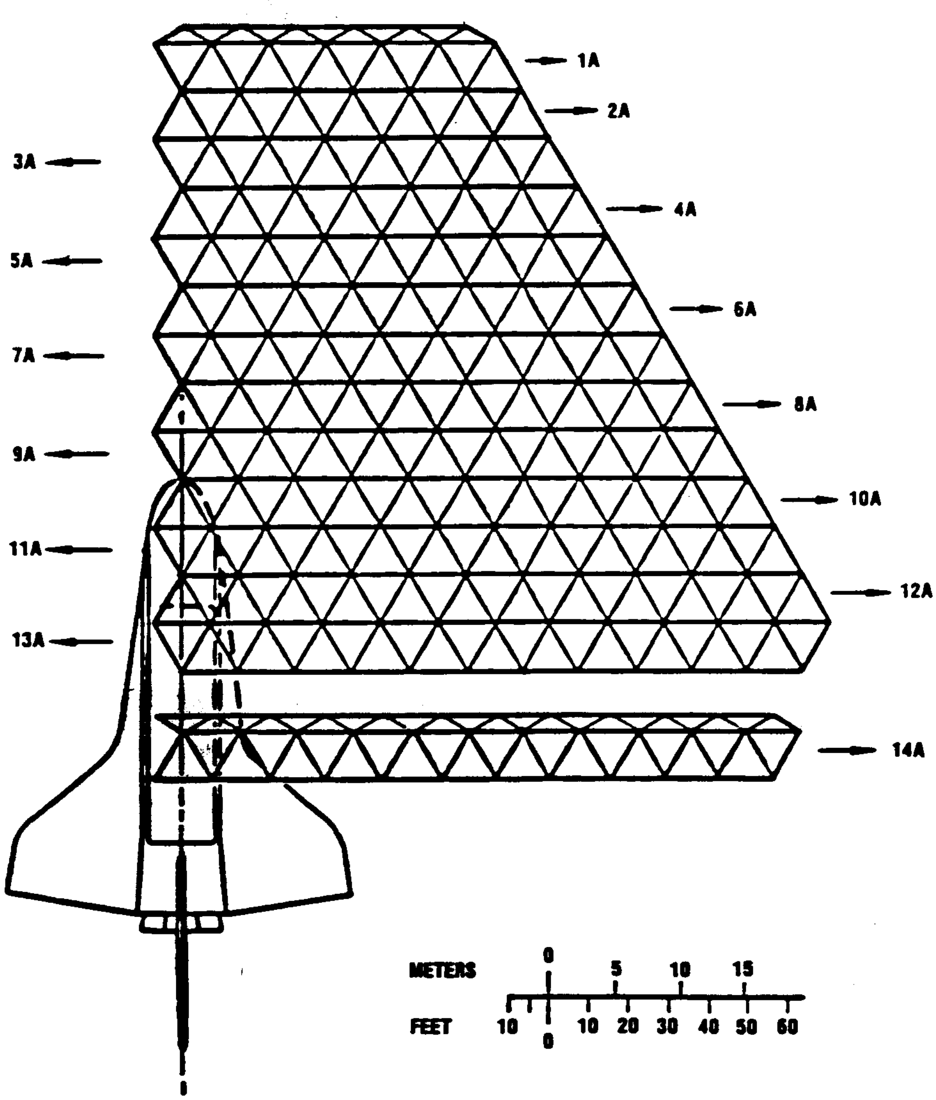



Figure 18

MOD PETA, COMPLETION OF A 100-METER PARABOLOIDAL ANTENNA

The second flight produces the second half of the structure. Integration of the two halves is a final function performed by the second flight, or integration can be performed concurrent with assembly of the second half.

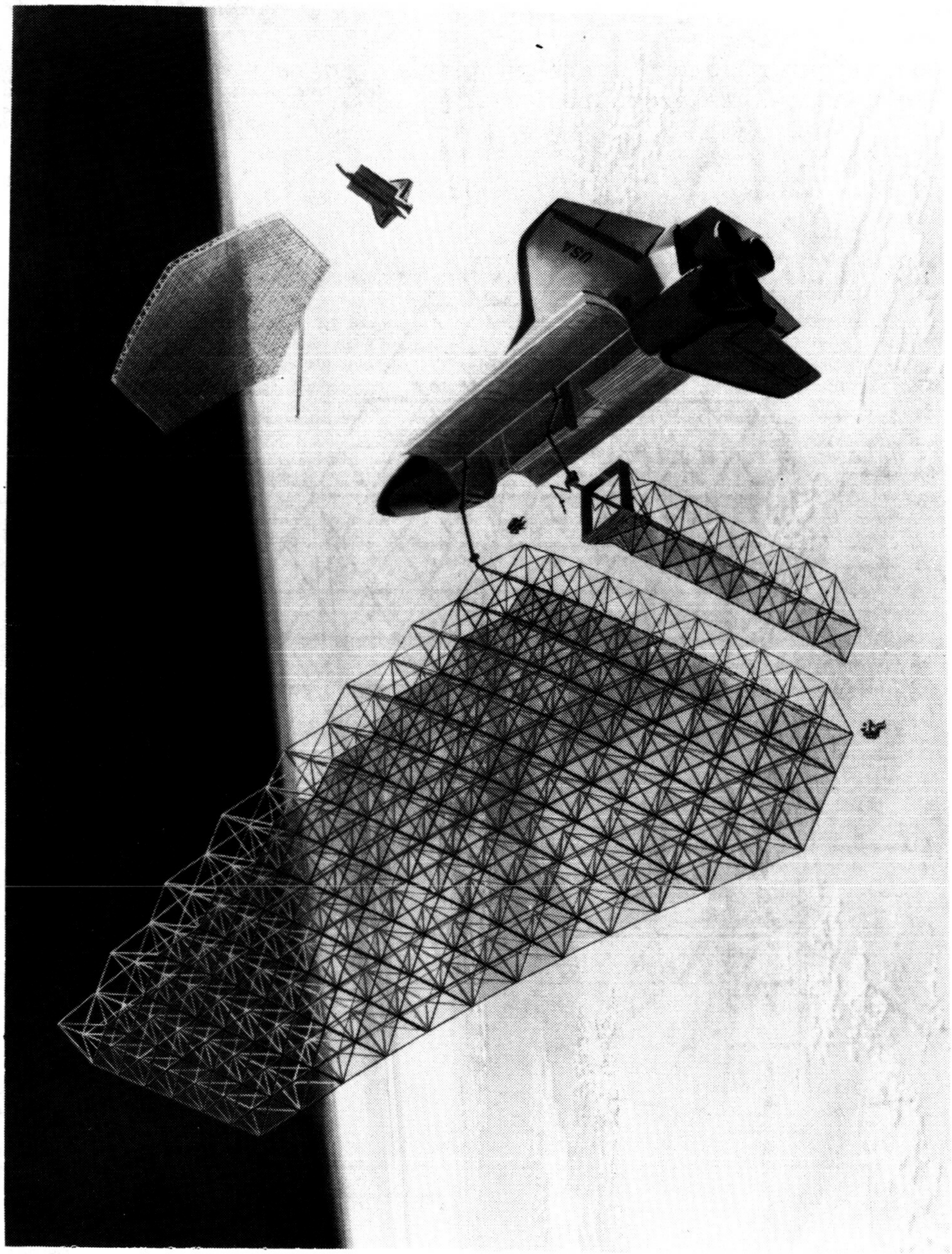


Figure 19

THE MOD PETA CONCEPT PROVIDES LARGE
STRUCTURES OF OUTSTANDING PERFORMANCE

The mode of modularization (H or J) does not significantly affect the structural characteristics of the completed Mod-PETA structure, and the estimated data presented in Figure 20 can be considered generally typical for large, hexagonal, modular Mod-PETA reflectors and platforms.

As a reflector, the structural thermal stability is more than adequate for operation at 1 GHz, but marginal at 15 GHz.

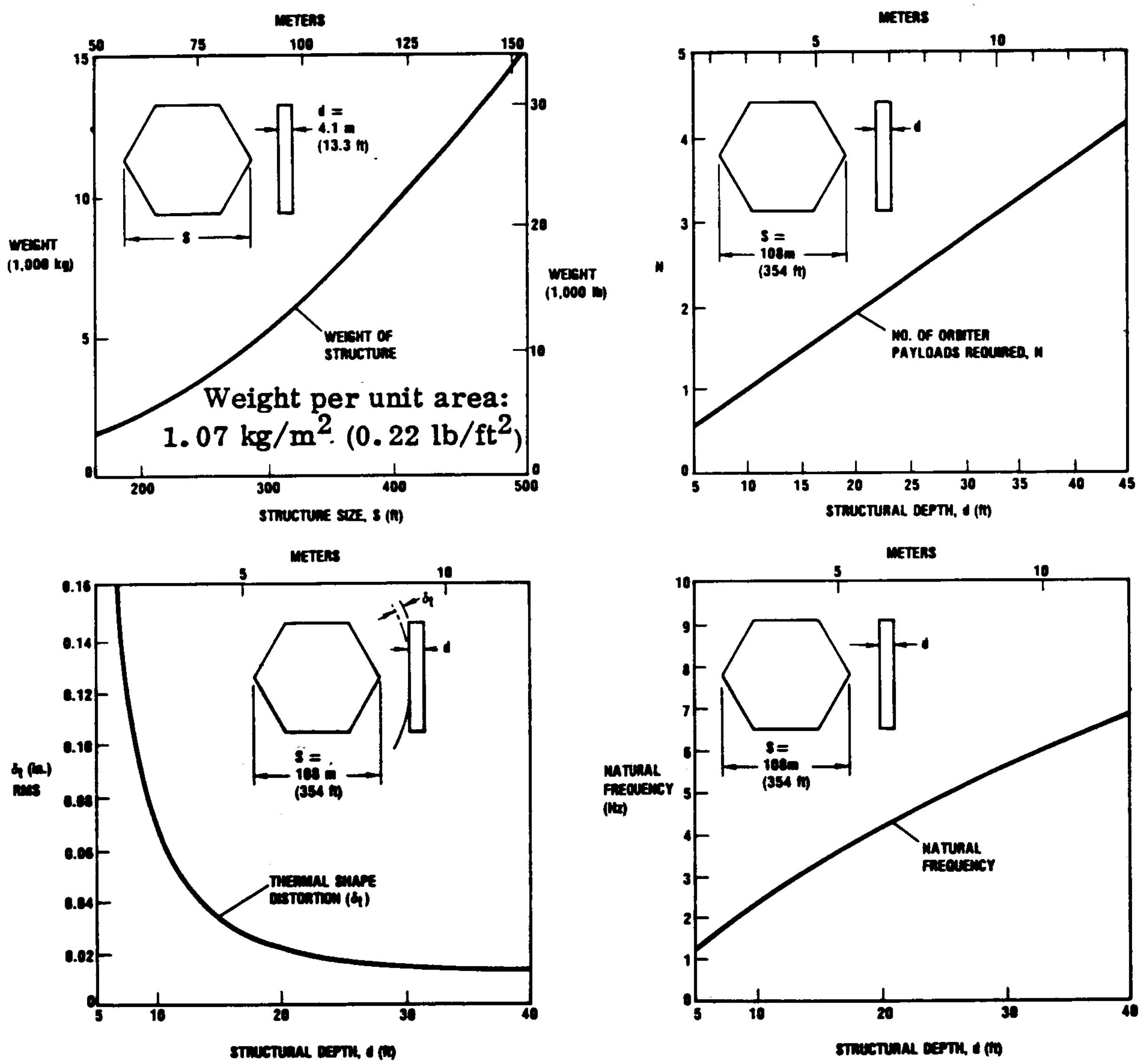



Figure 20

MOD PETA, ACHIEVABLE FIGURE ACCURACY PERMITS OPERATION AT 15 GHz

High structural shape, accuracy and stability permit operational use at high R.F. frequencies. Shape distortions result from designed approximations of the ideal reflector figure, thermal strains due to varying temperature, changes in applied structural loads, and deviations from nominal shape, during space erection, due to fit tolerances (i.e., repeatability). Initial or corrected figure accuracy is limited by the achievable accuracy of measuring the figure and effecting corrections.

Figure 21 presents the figure error budget, the RMS value of the error, and equates this to R.F. capability.

| Item | | δ mm (inch) RMS |
|---|---|---|
| 1. Geometry (design) | | |
| – Common flat facets | | 1.14 (0.045) |
| 2. Thermal Strains | | |
| – Structure | | 1.12 (0.044) |
| – Mesh system (10%) | | 0.11 (0.004) |
| 3. Static Loading Strains | | — |
| 4. Measurement Accuracy | | 0.03 (0.001) |
| 5. Adjustment Accuracy | | 0.25 (0.01) |
| 6. Repeatability | | 0.76 (0.03) |
| Total RSS (half path error) | | 1.79 (0.070) |
| RSS correction (10%) | | 0.18 (0.007) |
| Adjusted total RSS (δ) | | 1.61 (0.063) |
| | = | λ/187 at 1 GHz |
| | = | λ/12.5 at 15 GHz |

Figure 21

## META, MODULAR ERECTABLE TRUSS ANTENNA

The META concept possesses a combination of the key characteristics of both the DCM and the PETA concepts. Individual modules are very similar to DCM modules in their general size and shape, in their manner of deployment, and in their reflective surface installations. The essential difference is found in the relative arrangement of their component structural elements. In META the structural component arrangement is directly related to the tetrahedral geometry of the PETA. A reflector structure assembled from META modules produces an overall structure geometry basically idential to PETA structure.

As with the DCM concept, the META modularization approach does not result in structural duplication. META has a lower part count than the DCM (6489 tubes versus 10,815 tubes and ties).

The principal disadvantages of the concept are its lower packaging density, requiring 3.9 Orbiter flights to construct the full 100-meter reflector, its high module count (721), and its relatively small structural depth, which is limited to 3.1 meters compared to 3.5 meters for the DCM.

Although mechanical movements involved in deployment of the typical META module are different from those for deploying the DCM, the overall time required to deploy/assemble the full 100-meter META structure is estimated to be similar, i.e., 240 hours, approximately.

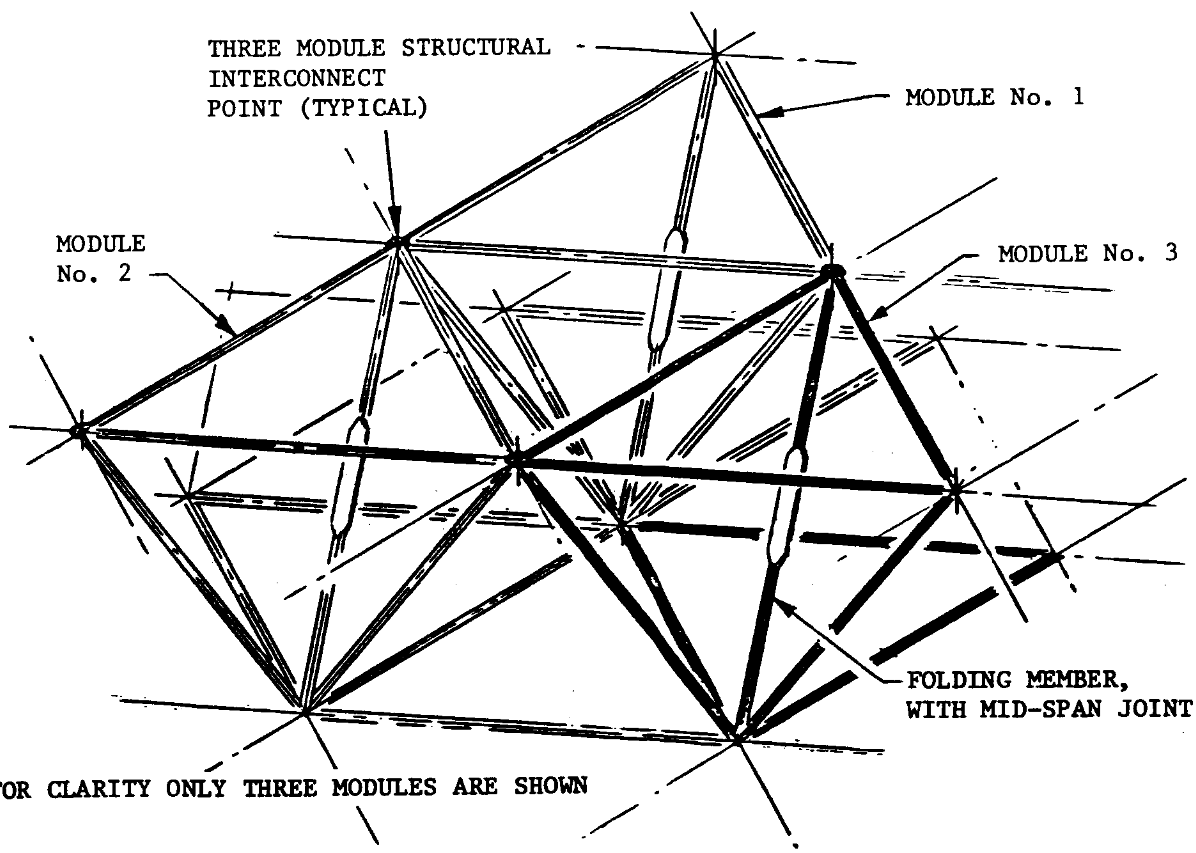



Figure 22

## CONCEPT ANALYSIS OUTPUT DATA

Figure 23 presents analytical output including LASS computer program output data.

The total number of individual tubular elements in the Mod-PETA (Study Case H) is 5,440 versus 10,815 tubes and ties in the DCM. The PETA H and J require 1.3 and 2.0 Orbiter flights, respectively, versus 2.6 for the DCM. Total number of in-space structural connections to be effected for PETA (H and J) is approximately 2,200 and 900, respectively, versus 8,460 for the DCM. The total weight of PETA Study Case H is 8,125 kg (17,916 lb), versus 9,399 kg (20,725 lb) for the DCM.

| Output Data | Concept Study Case | | | |
|---|---|---|---|---|
| | DCM (C) | PETA (H) | PETA (J) | META |
| Orbiter payloads required | 2.6 | 1.3 | 2.0 | 3.9 |
| Total reflector weight, kg (lb) | 9399 (20,725) | 8125 (17,916) | 8183 (18,043) | 7515 (16,573) |
| Structural depth, m (ft) | 3.5 (11.5) | 4.05 (13.3) | 4.05 (13.3) | 3.10 (10.17) |
| Fundamental frequency ($f_1$), hertz | 1.78 | 2.20 | 2.20 | 1.80 |
| Surface accuracy, RMS, mm (in.) | 2.83 (0.11) | 1.61 (0.063) | 1.61 (0.063) | 2.92 (0.114) |
| Surface accuracy at 1 GHz | $\lambda/107.4$ | $\lambda/187$ | $\lambda/187$ | $\lambda/103.6$ |
| Surface accuracy at 15 GHz | $\lambda/7.2$ | $\lambda/12.5$ | $\lambda/12.5$ | $\lambda/6.9$ |
| Length of packaged module, m (ft) | 0.07 (0.23) | 5.49 (18.0) | 5.49 (18.0) | 0.1 (0.34) |
| Surface strut column strength, newtons (lb) | 2131 (480) | 2895 (652) | 2895 (652) | 2131 (480) |
| Average 'concave strut length, m (ft) | 3.62 (11.8) | 4.62 (15.2) | 4.62 (15.2) | 3.52 (11.50) |
| Average 'convex' strut length, m (ft) | 3.68 (12.1) | 4.71 (15.5) | 4.71 (15.5) | 3.58 (11.55) |
| Average 'diagonal' strut length, m (ft) | 5.05 (16.6) | 4.84 (15.8) | 4.84 (15.8) | 3.8 (12.5) |
| Number of surface struts | 4326 | 3610 | 3361 | 4326 |
| Number of 'diagonal' struts | – | 1830 | 2112 | 2163 |
| Number of cross bracing ties | 4326 | – | – | – |
| Number of spring loaded columns | 2163 | – | – | – |
| Number of 'in-space' structural connections | 8460 | 2200 | 900 | 8460 |

Figure 23

COMPARATIVE ANALYSIS OF THE THREE CONCEPTS

Figure 24 presents judgment scoring of the three candidate concepts against pertinent evaluation factors. Weighting factors are presented in the final column and are applied prior to summation. In all columns, higher values indicate superiority and lower values inferiority.

The data indicates the Mod-PETA to be the superior concept despite its structural duplication and the relatively greater challenge of manipulating and joining its large modules.

| | Concept/Study Case | | | | |
|---|---|---|---|---|---|
| Item | DCM (C) | PETA (H/J) | META | Weighting Factor | Remarks |
| • Shape accuracy | | | | | |
| - as manufactured | 5 | 5 | 5 | 8 | Flat facetted surfaces on all concepts |
| - as assembled in space | 3 | 7 | 3 | 5 | PETA has fewer intermodular joints |
| - in-space correction | 10 | 10 | 10 | 8 | All concepts can be "shape tuned" |
| - effect of time | 4 | 7 | 7 | 5 | DCM structure is in constant stress state |
| • Thermal stability | 9 | 10 | 8 | 8 | META has the least structural depth |
| • Dynamic stability | 8 | 10 | 8 | 8 | PETA has greatest structural depth |
| • High strength | 9 | 10 | 8 | 8 | Tends to be proportional to structural depth |
| • Density of packaging | 7 | 10 | 3 | 10 | META has lowest packaging density |
| • Reliability of deployment | 9 | 8 | 10 | 8 | PETA modules are few but more complex |
| • Reliability of assembly | 5 | 5 | 5 | 8 | DCM and META very repetitive. PETA more complex |
| • Ease of assembly | 8 | 5 | 8 | 10 | PETA modules are large |
| • Minimized assembly time | 5 | 5 | 5 | 10 | All require prolonged on-orbit time |
| • Minimized support equipment | 5 | 5 | 5 | 8 | All concepts require sophisticated provisions |
| • Low cost | | | | | |
| - fabrication | 3 | 7 | 10 | 8 | DCM has largest component part count |
| - in-space assembly | 7 | 10 | 3 | 10 | PETA requires fewest orbiter flights |
| • Surface continuity | 10 | 5 | 10 | 5 | PETA requires surface joining at interfaces |
| • Low total weight | 8 | 9 | 10 | 5 | META is lightest |
| Total | 899 | 1000 | 892 | | |

Figure 24