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STRUCTURAL CONCEPTS FOR LARGE SPACECRAFT

H. G. Bush, W. L. Heard, Jr.,
and J. E. Walz
Langley Research Center
Hampton, Virginia

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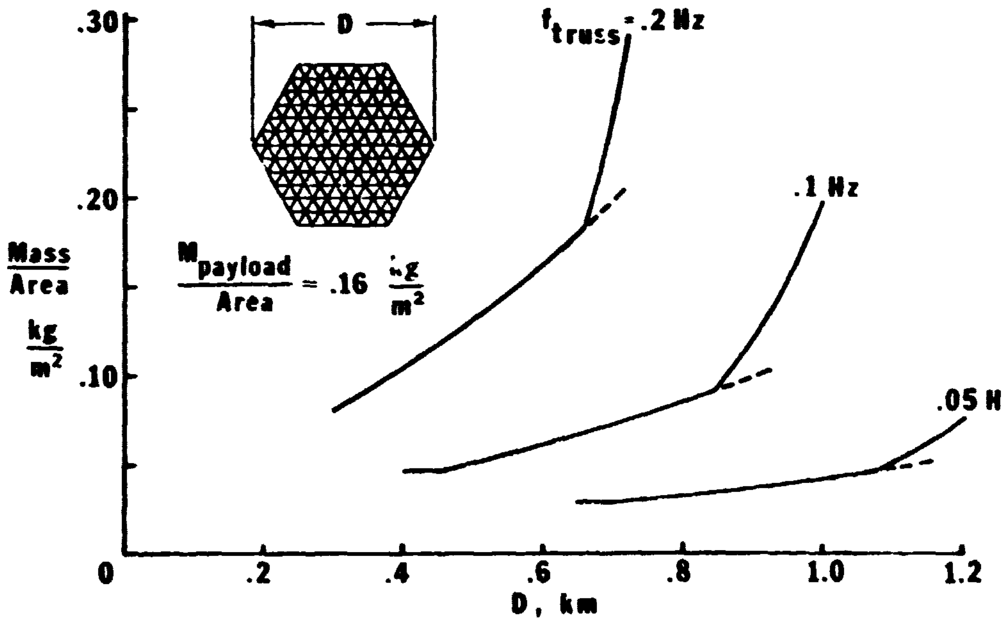
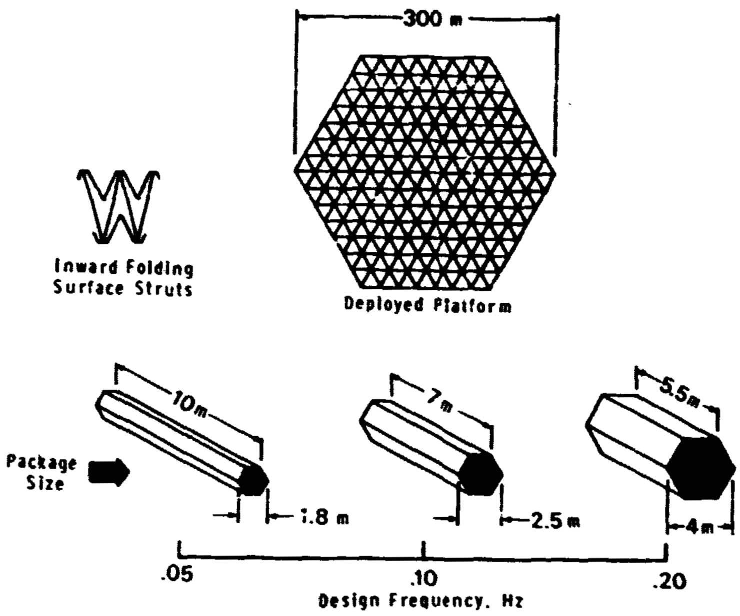
The cost of transporting spacecraft to low earth orbit, even using Shuttle, is extremely high. It is imperative that the most efficient use be made of the transportation system. In order to minimize the amount of mass which must be orbited, and to determine spacecraft designs which meet the multiplicity of design conditions and system constraints, it is necessary to employ an optimization approach. A preliminary analysis and design code for sizing hexagonal planform spacecraft is currently being developed at LaRC. The minimized structural mass/area for reflector class spacecraft of various spans (D) is shown in figure 1 (F-1) for several design values of platform fundamental frequency. The results are for tetrahedral truss platforms with inward folding surface members. The truss depths of the results shown were constrained to 18m - the length of the Shuttle cargo bay. In F-2, the sensitivity of package size dimensions for a 300m platform are illustrated as a function of platform fundamental frequency. The results show that package size changes from long and slim for low frequencies to short and fat for higher frequencies. The impact of this dimensional change on transportation requirements is shown in F-3 for two different spacecraft classes. The results show that below a critical stiffness value (frequency) the spacecraft can be transported in a mass critical mode, indicated by the horizontal lines. However, above the critical stiffness value, transportation requirements become dominated by package geometry and increase rapidly as indicated by the near vertical lines. Thus, a deployable spacecraft for any mission would appear to have a limiting stiffness value above which it becomes impractical to transport, even in segments.

OPTIMIZATION



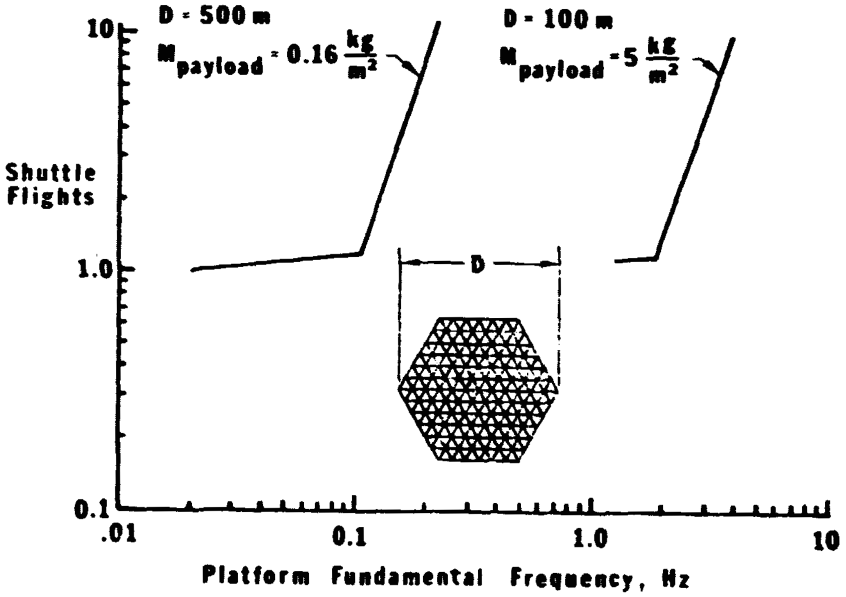
F-1

PACKAGING



F-2

TRANSPORTATION



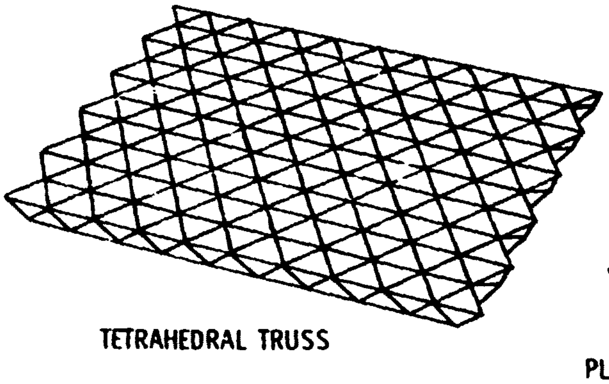
F-3

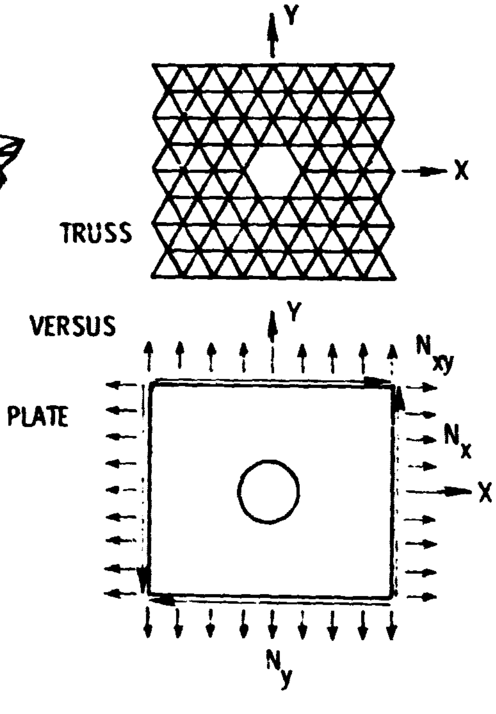
ANALYSIS AND DESIGN - PLATFORMS AND REFLECTORS

The spacecraft sizing activity requires an analysis for each design requirement considered. As appropriate design requirements are identified, analyses are developed and included in the sizing code for simultaneous consideration with all constraints. Results from one such analytical study (reference 1) are shown in F-4 where load concentrations resulting from missing members in truss plates were examined. The table shows that using a "classical approach" to estimate load concentration effects would result in concentration factors which are over a factor of 2 higher than those predicted by a discrete analysis.

Results from a preliminary analysis for sizing curved reflectors (reference 2) are shown in F-5. This figure shows the approximate dimension (L) of a triangular facet arrangement which is used to approximate a curved reflector surface for a specified surface error (δ_{rms}) and focal length (F). The triangular apices are assumed to coincide with supporting truss hard points (nodes). Therefore, L becomes the required strut length for the truss and must be considered in the design process.

MISSING MEMBER EFFECTS

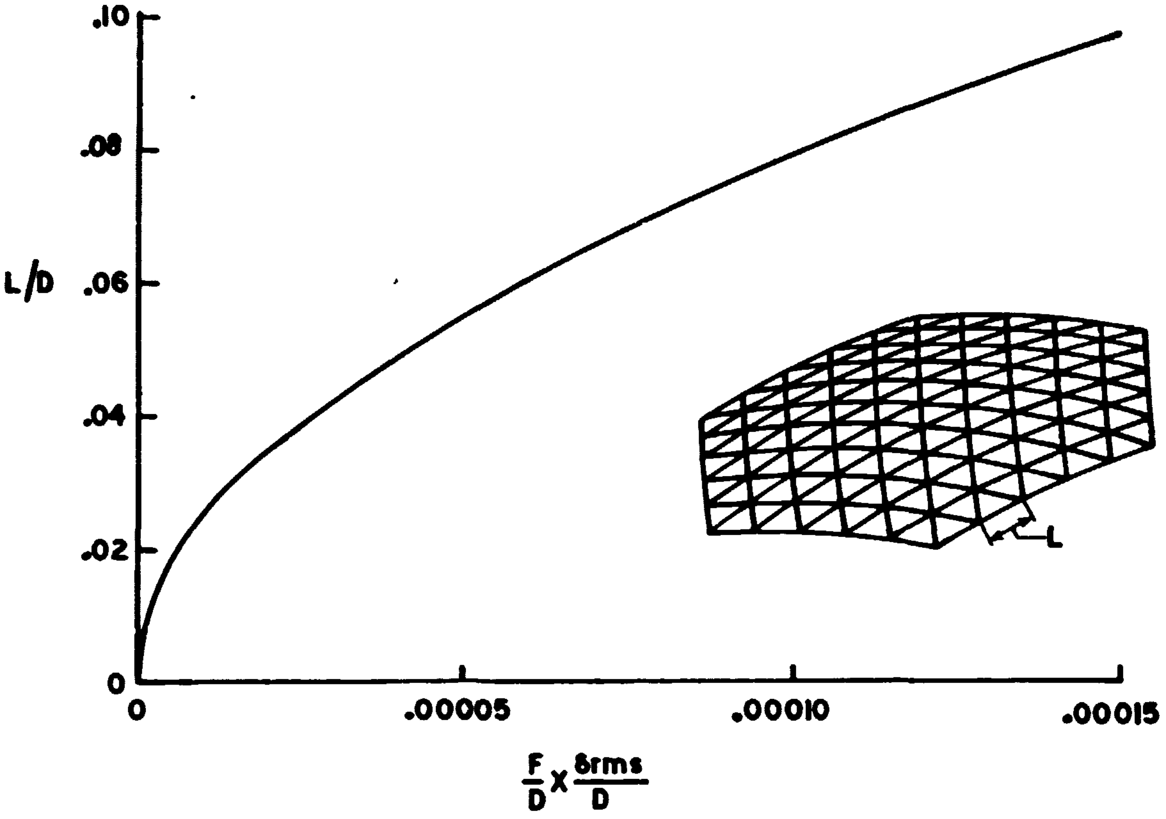




	TRUSS	PLATE
LOADING	LOAD CONCENTRATION FACTOR	STRESS CONCENTRATION FACTOR
N_x	1.30	3.00
N_y	' 48	3.00
N_{xy}	· 56	4.00

F-4

FACETED ANTENNA DESIGN

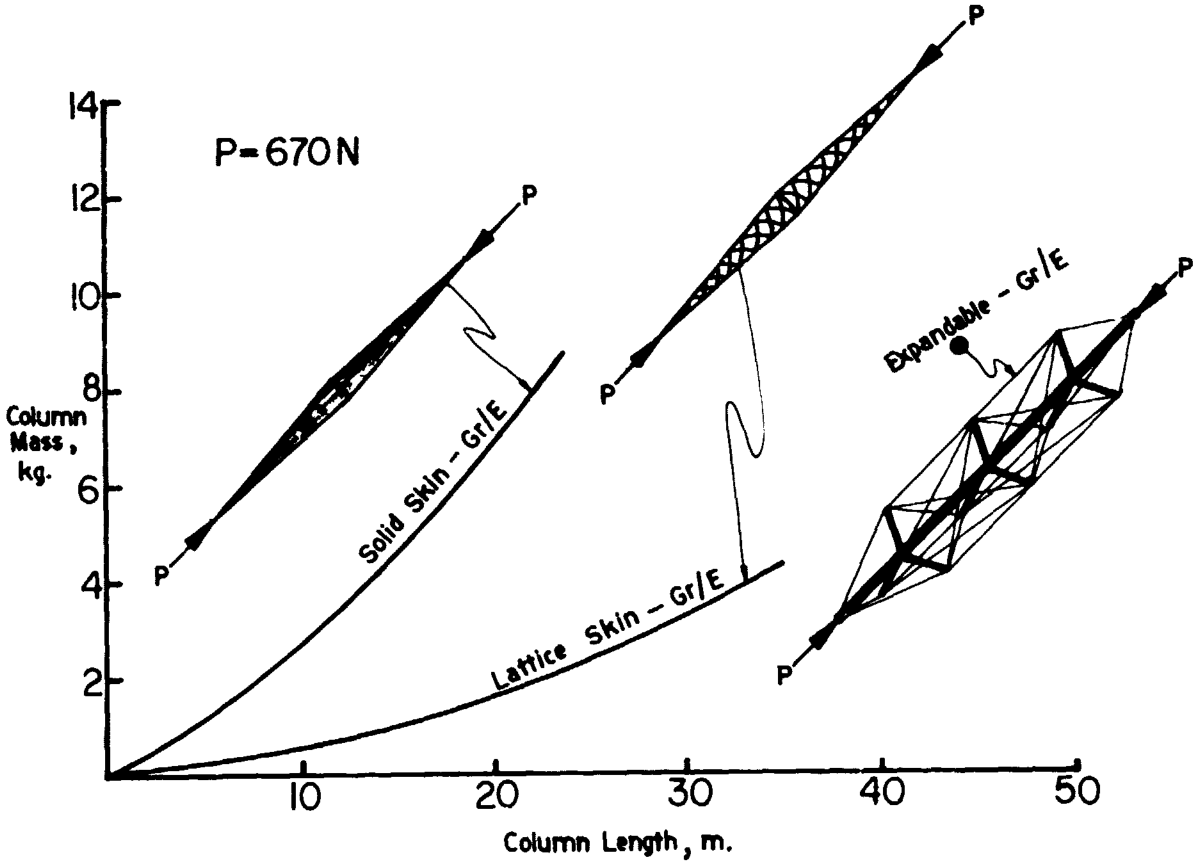


F-5

ANALYSIS AND DESIGN - BASIC ELEMENTS

A comprehensive characterization of various structural configurations for long columns was presented in reference 3, which compared structural efficiencies to identify preferred minimum mass concepts. Transportability of the structural configurations to orbit was not examined. In reference 4, a derivative of the cylindrical column which can be stacked for transporting is identified and is illustrated in F-6. This element-denoted the nestable column - is being studied and developed (reference 5) as a basic building block applicable to many types of built-up spacecraft structure. However, for extremely lightly loaded or long length applications, the solid skin nestable columns are minimum gage thickness constrained. Preliminary design calculations, based on analyses similar to reference 3, indicate that open or lattice skin configurations would offer significant mass savings as shown in F-6. In order to analyze and design this type of reticulated structure more accurately, a new buckling theory has been developed (reference 6). Some typical analytical results are shown in F-7 for a three longeron column which show that the discrete analysis predicts buckling, for some column proportions, at a lower load than is predicted by conventional methods.

BASIC ELEMENTS

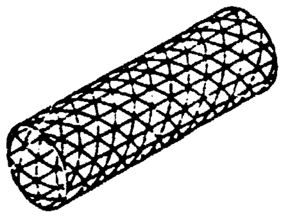


F-6

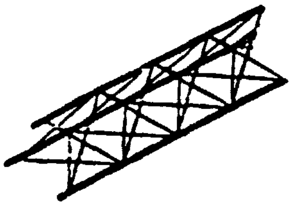
NEW BUCKLING THEORY PREDICTS DISCRETE EFFECTS IN LATTICES

TYPICAL CONFIGURATIONS

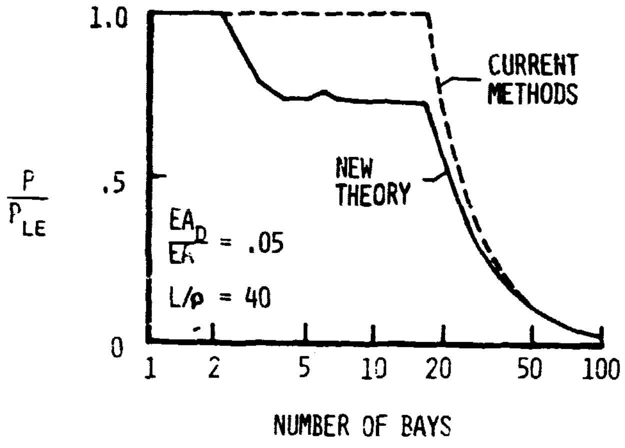
REPEATING GRID COLUMN



THREE ELEMENT BOOM



BUCKLING OF THREE ELEMENT BOOM



FEATURES OF THEORY

- CONFIGURATIONS WITH EACH NODE HAVING SIMILAR GEOMETRY
- FINITE ELEMENT BASED ON BEAM-COLUMN THEORY
- PERIODIC MODE SHAPE
- 6x6 DETERMINANT FOR BUCKLING OR VIBRATION

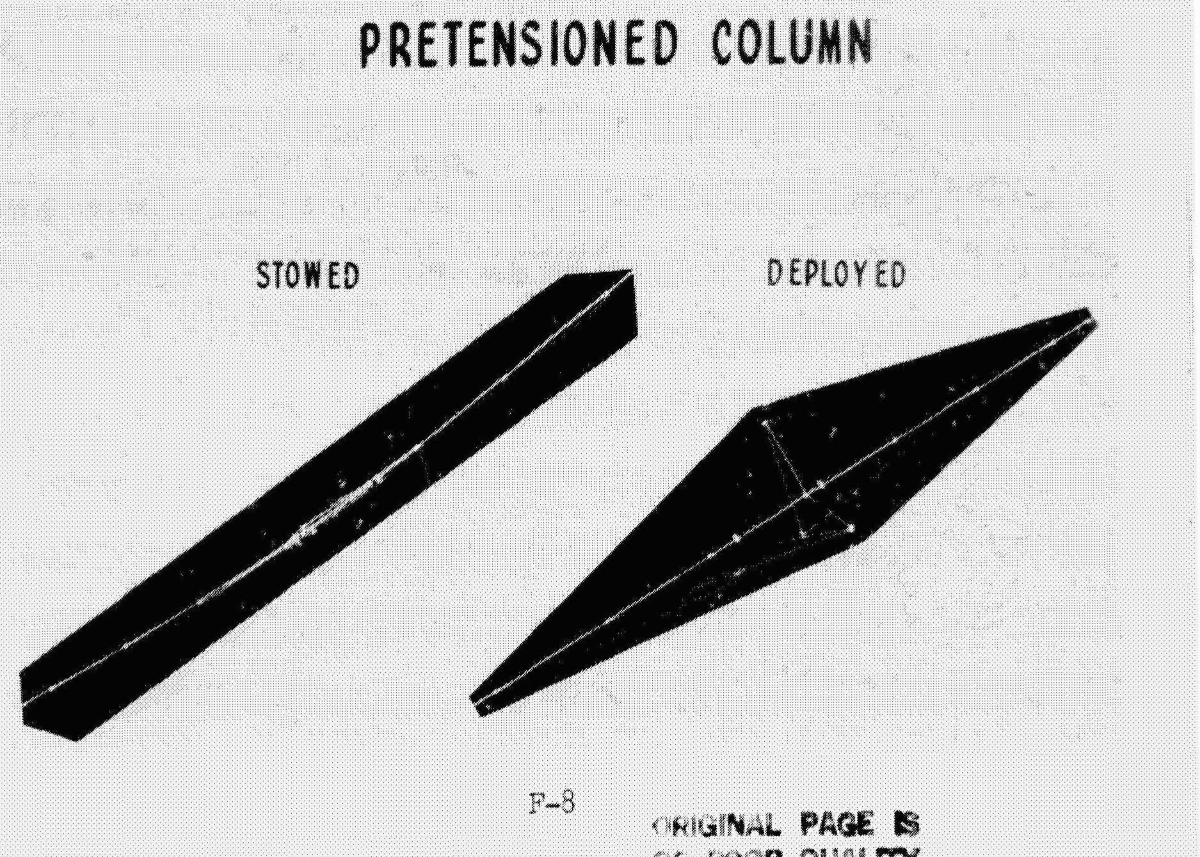
CONCEPT DEVELOPMENT

Pretensioned Column

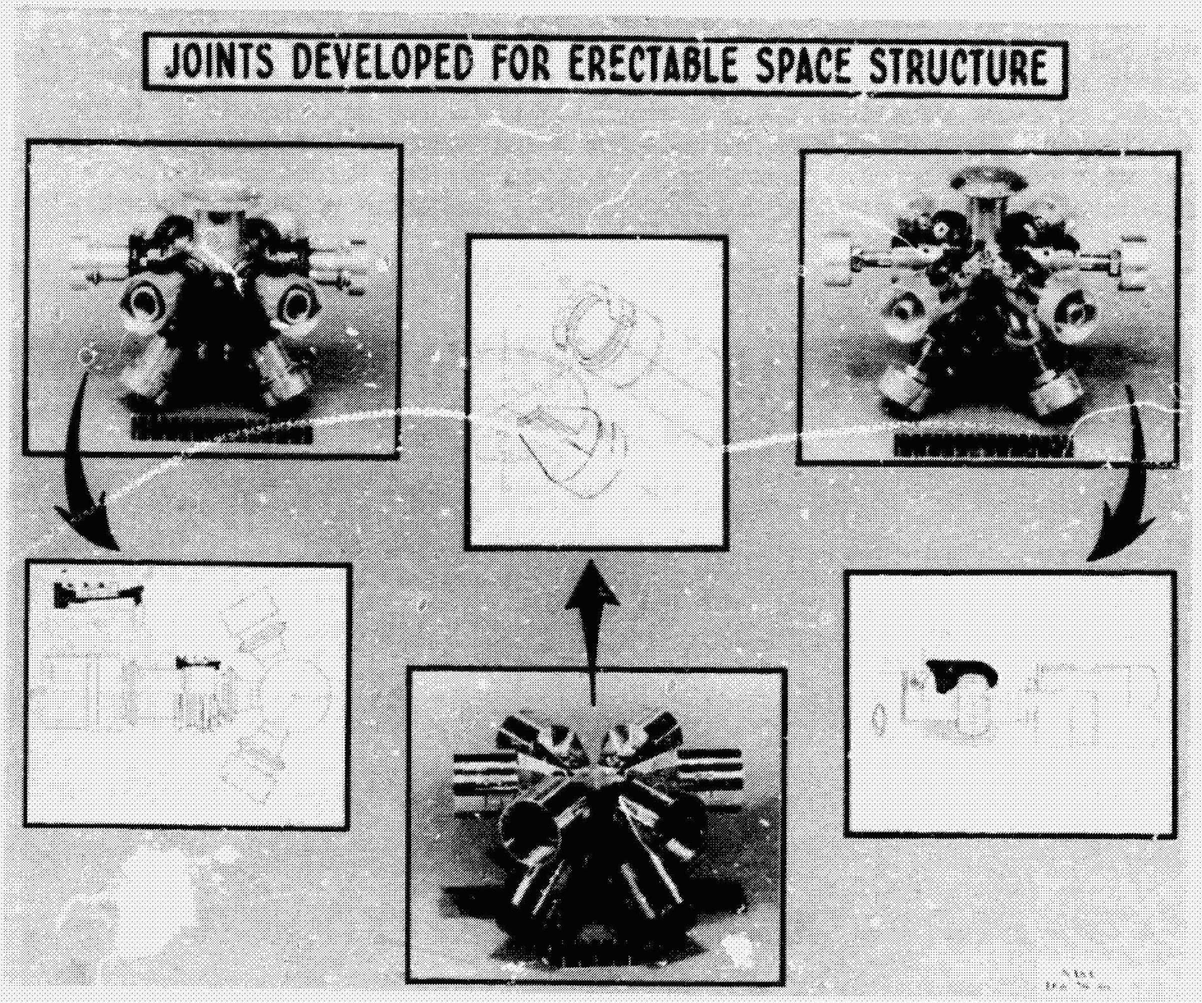
One potential way in which the mass and volume of a compression strut may be reduced, is through the use of pretensioned elements which stabilize a central compression carrying member. The efficiency of one such column is shown in F-7 (previous page). Another example of this type of structure is shown in F-8, where a deployable pretensioned column is illustrated in the stowed and deployed position. This column is 5m in length, weighs approximately 0.4kg and was designed to buckle at 220 N. Preliminary testing indicated that it would carry approximately 260 N before buckling.

Joint Concepts

Along with the development of basic elements, ways to join erectable components are being studied. Several joint concepts which have been fabricated are shown in F-9. All models exhibit side entry and can be manually removed from, or inserted into, existing structure. However, disassembly of two joint models requires special tools. Also, all models are designed to be compatible with automated assembly of erectable structures. The joints were designed to represent actual flight quality components so that meaningful evaluations of each model's operational, structural and dynamic characteristics may be made.



F-8



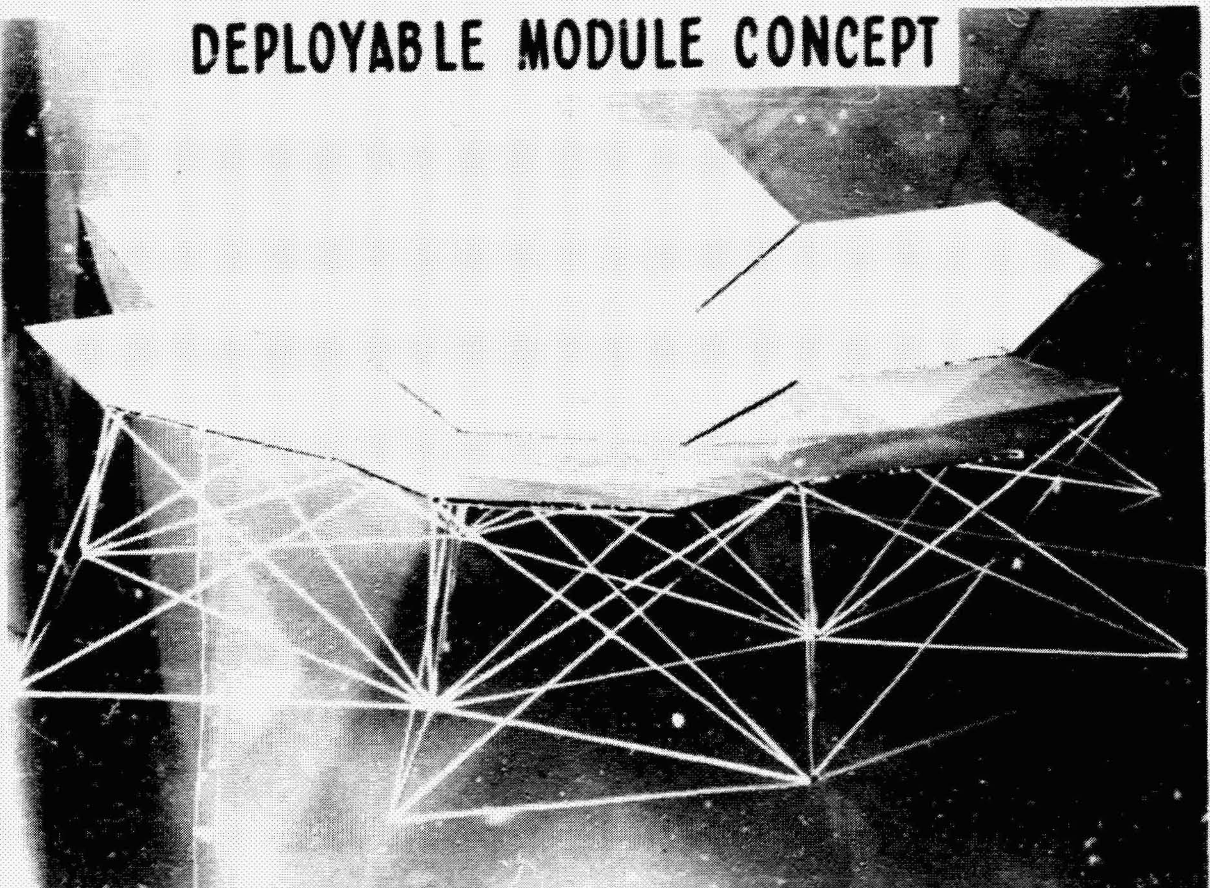
JOINTS DEVELOPED FOR ERECTABLE SPACE STRUCTURE

F-9

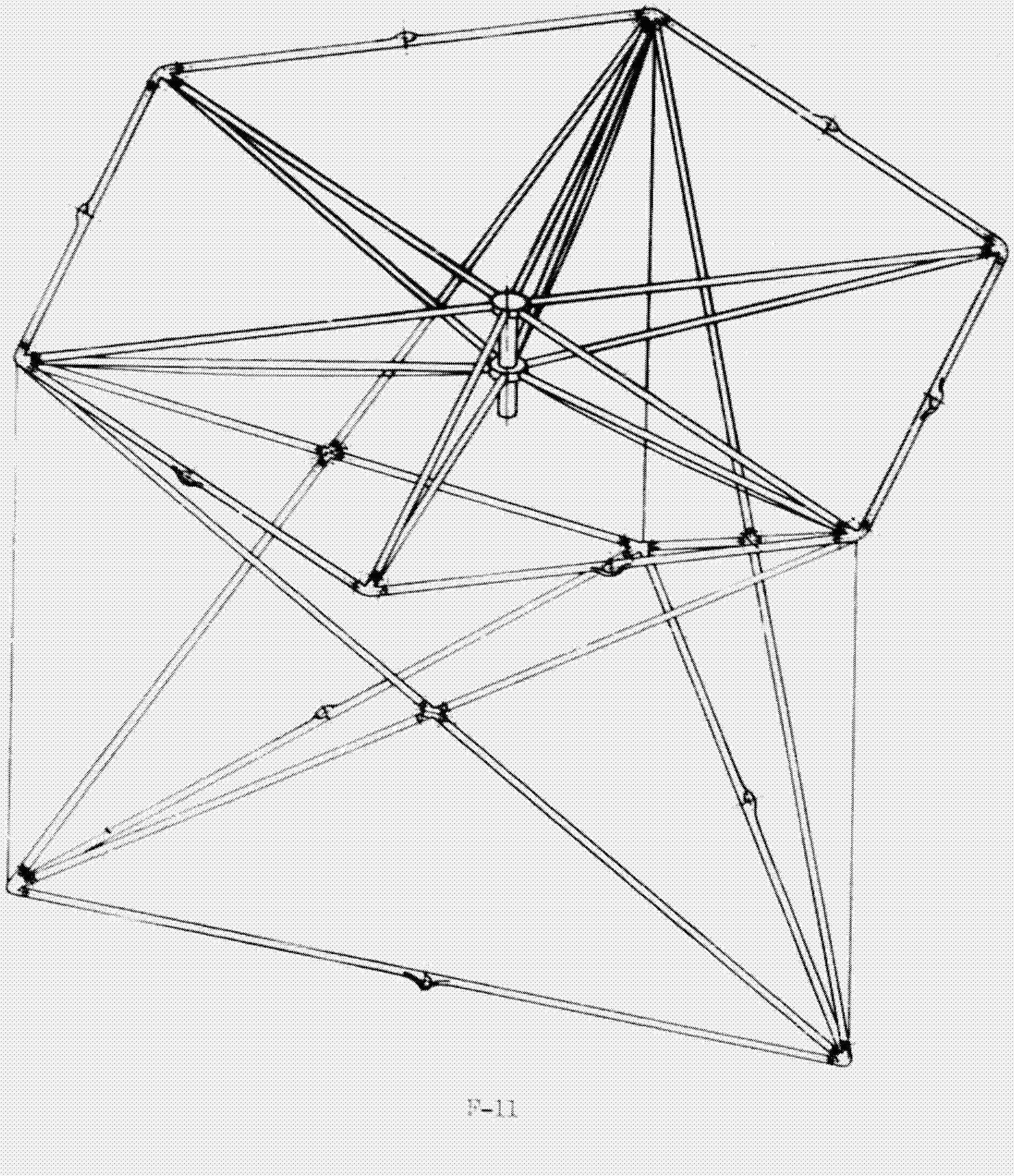
CONCEPT DEVELOPMENT

Deployable Module

A modular concept for constructing reflectors is shown in F-10 and F-11. The modules are connected together at three points in each surface. When assembled, the hexagonal planform of one side forms the closed reflector surface as shown in F-10. This concept incorporates a flat triangular facet approximation to a doubly curved reflector surface. Each module, shown in F-11, can be folded with all members stowed parallel for transport to orbit where it would be deployed and assembled. Currently, the necessary joint hardware is being developed and a deployment method for each module is being investigated. Mesh attachment methods are being examined and an engineering model will be fabricated. Packaging techniques for the folded modules are being investigated along with on-orbit assembly scenarios which are compatible with use of the Shuttle.



F-10



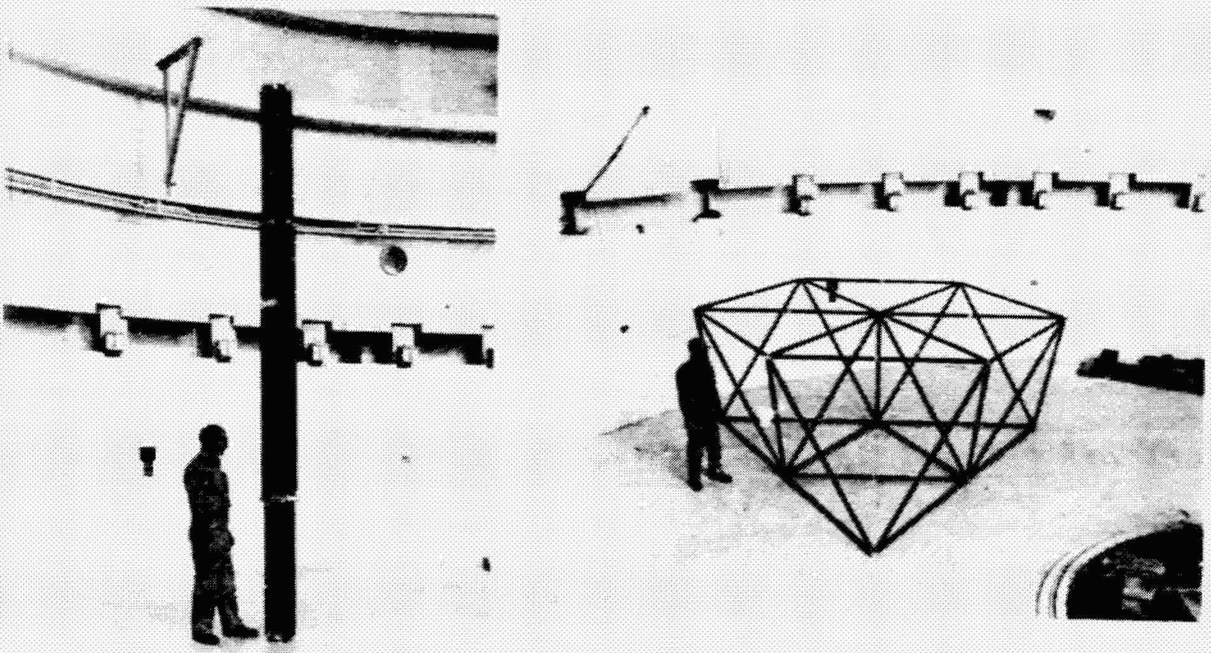
F-11

CONCEPT DEVELOPMENT

Deployable Truss Test

Deployable trusses are an important class of spacecraft structure. The ability to fabricate and package an entire spacecraft on earth for transfer to orbit where it is deployed into a functional status is a desirable goal. Foldable trusses, however, exhibit several features which can limit their utility unless overcome. Deployment kinematics of many folding truss members pose a challenge to designers to eliminate potential mechanical anomalies. To investigate this feature, and to determine member loads during an unrestrained deployment, the tetrahedral truss model shown in F-12 was fabricated and successfully deployed in zero-g. The truss was deployed using springs at the joints to provide deployment energy during the freefall experiment. Strains recorded during member lockup compared favorably with pretest analytical predictions.

DYNAMIC QUALIFICATION MODEL

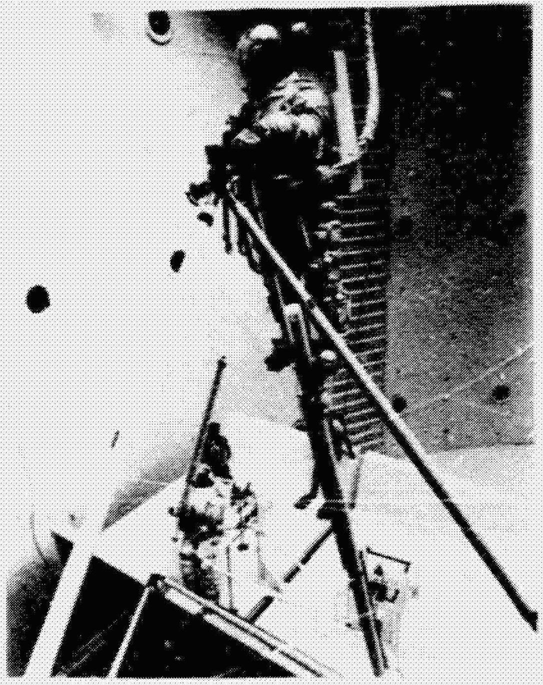


F-12

ASTRONAUT ASSEMBLY STUDIES

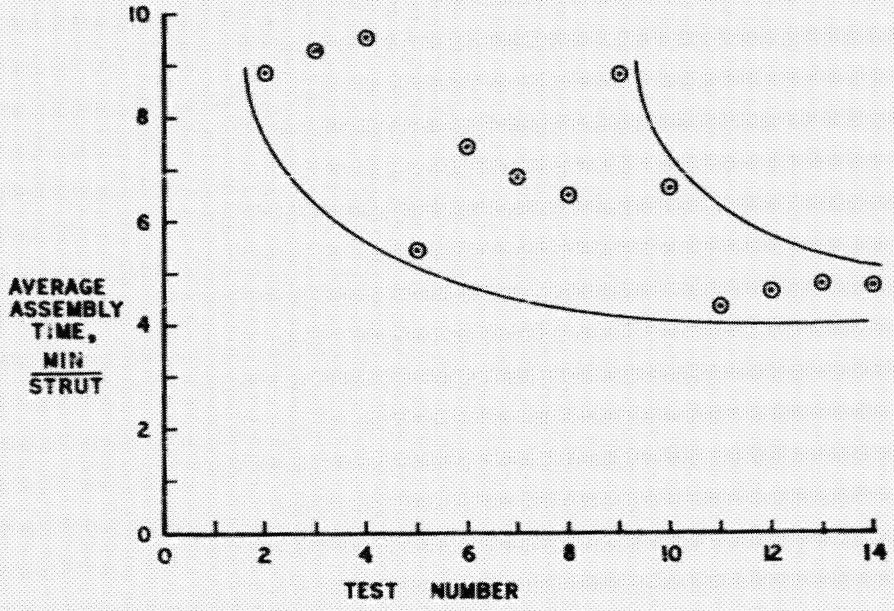
Man's capability for assembling structural components in a weightless environment has been investigated in the MSFC Neutral Buoyancy Facility. The test purposes were to develop preliminary timelines for various construction scenarios using Astronaut subjects and to obtain information on the types of hardware and assembly aids required by pressure suited workmen. A six strut tetrahedral cell, shown in F-13, was assembled by two pressure suited Astronaut subjects. The average assembly times (min/strut) for various pairs of subjects are shown in F-14. The bounding lines around the data indicate the general learning curve trend. As more tests were conducted, experience was gained and the assembly times decreased, appearing to plateau at about 5 min/strut for the tests shown. Using this preliminary labor rate, an estimate may be made of the size spacecraft which could be assembled during one Shuttle flight. Such an estimate is shown in F-15 where the Shuttle is assumed to have an operational on-orbit limit of seven days. The calculations are based on the crew being able to assemble 96,20 m struts/day. The figure shows that approximately a 200 m span spacecraft can be assembled. This result should not be considered in a quantitative sense but rather in a qualitative sense of whether man can make a significant contribution participating in the assembly process. The results to date, from a productivity viewpoint, indicate that man's capability should be further considered, particularly for proposed nearer term activities.

NEUTRAL BUOYANCY FACILITY TESTS



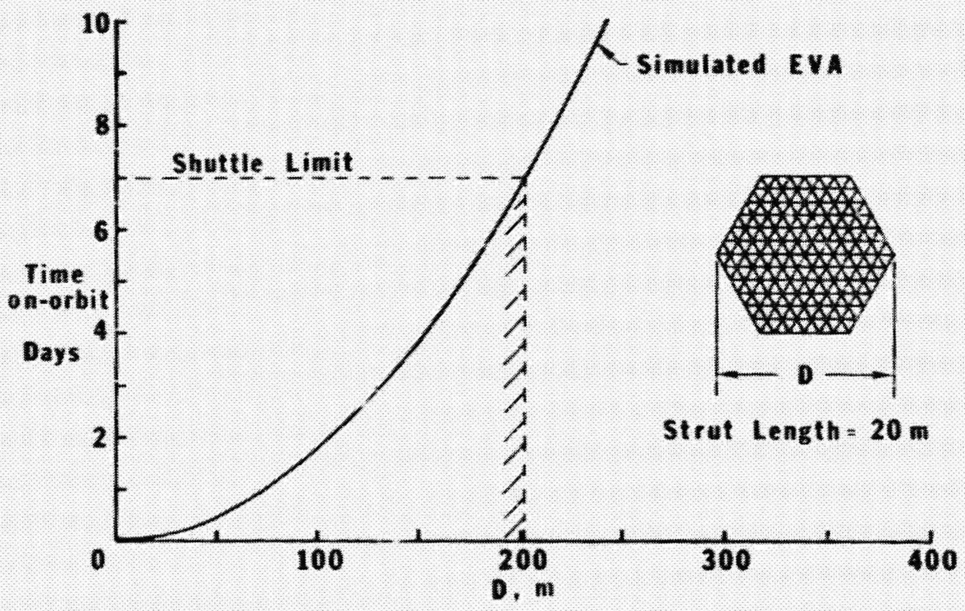
F-13

ASTRONAUT ASSEMBLY - NBF SIMULATION



F-14

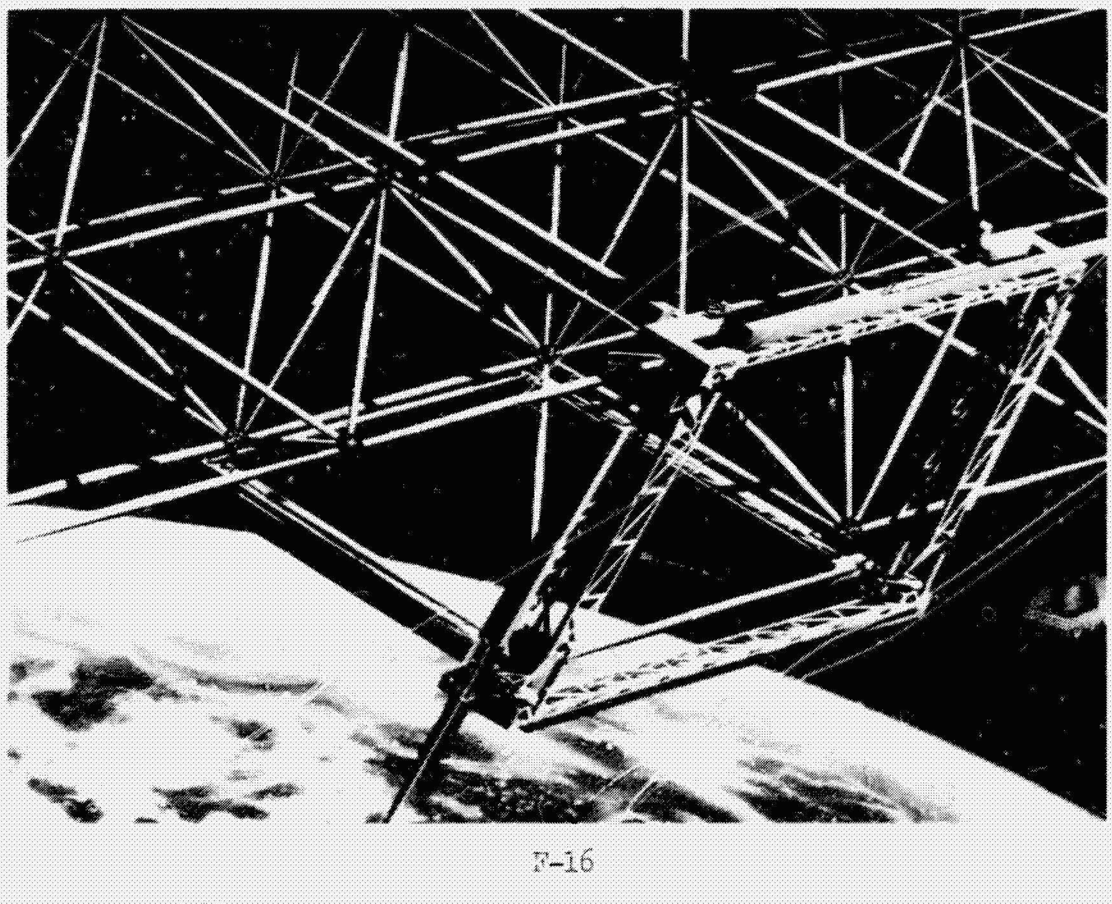
ESTIMATED CONSTRUCTION TIME



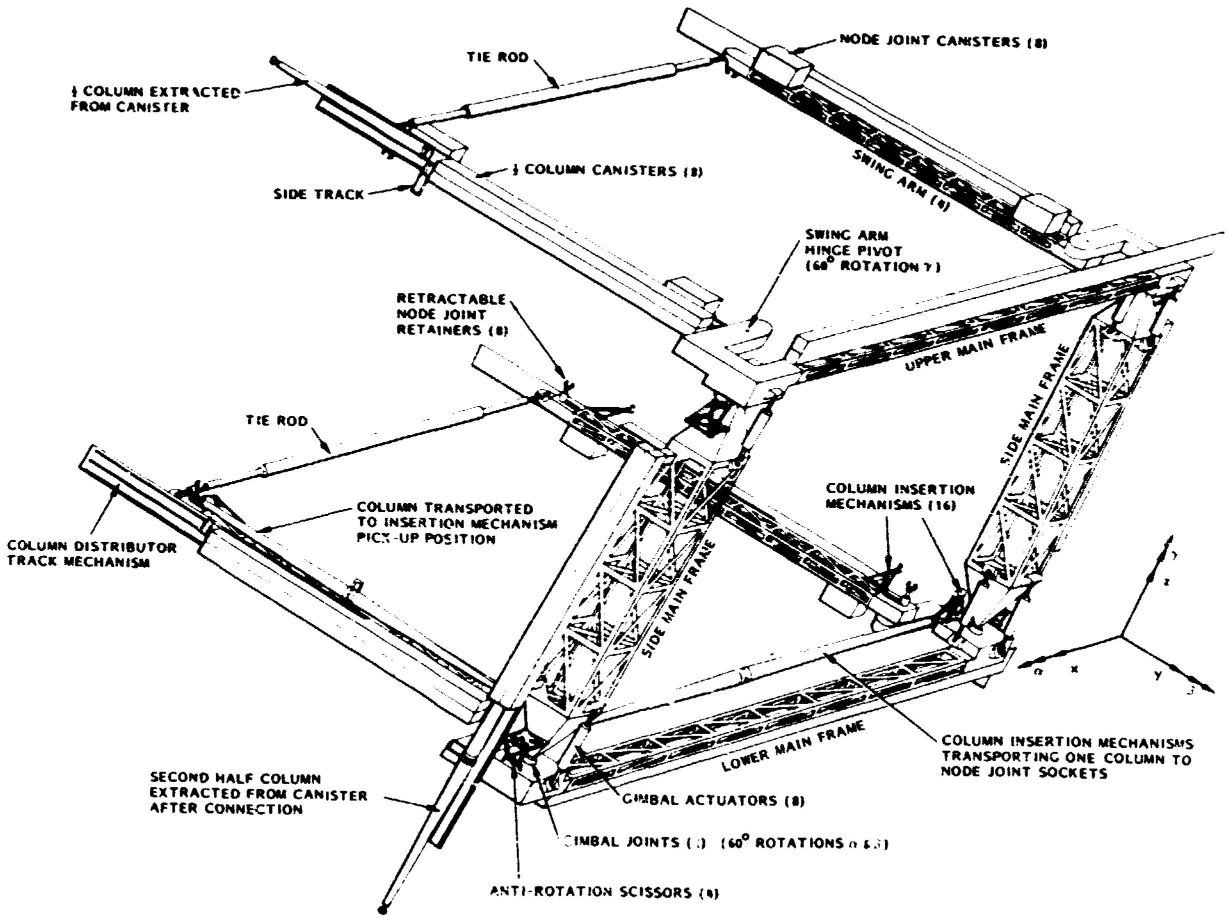
F-15

AUTOMATED ASSEMBLY STUDIES

Some proposed missions require structures sufficiently large that they are impractical to deploy or assemble by Astronauts. For such structures, it would be desirable to automate the assembly process as much as possible. Several automated concepts have been studied over the past year. An artist's illustration of preferred concept is presented in F-16, where the automated assembler is shown constructing a truss platform. A detailed sketch of the machine is shown in F-17. Conceptually, the machine is envisioned to be an assemblage of simple mechanisms which perform specific, sequential, repetitive operations to construct a repetitive truss structure using nestable struts. The machine consists of two pairs of swing arms, each pair connected by a tie rod (F-17), and a gimballed four-sided main frame. Cannisters, containing nested half-struts and/or nodal joints are attached to the arm and frame members. The machine operates by alternately swinging the upper and lower arms to walk from node to node (hardpoints) along the platform edge inserting struts and nodes which are dispensed from the cannisters as it progresses. Strut halves are snapped together as the machine steps using a strut assembly mechanism, an example of which is shown in the figure. Theoretically, in two days of operation this machine could assemble all of the 20 m nestable struts which Shuttle could transport to orbit in a mass critical mode (approximately 2600). The assembled structure would have an area of approximately 0.1 km^2.



F-16


NODE JOINT CANISTERS (8)
TIE ROD
½ COLUMN EXTRACTED FROM CANISTER
½ COLUMN CANISTERS (8)
SIDE TRACK
SWING ARM (4)
SWING ARM HINGE PIVOT (60° ROTATION γ)
RETRACTABLE NODE JOINT RETAINERS (8)
UPPER MAIN FRAME
SIDE MAIN FRAME
TIE ROD
COLUMN INSERTION MECHANISMS (16)
COLUMN TRANSPORTED TO INSERTION MECHANISM PICK-UP POSITION
COLUMN DISTRIBUTOR TRACK MECHANISM
SIDE MAIN FRAME
γ
z
α
x
y
β
LOWER MAIN FRAME
COLUMN INSERTION MECHANISMS TRANSPORTING ONE COLUMN TO NODE JOINT SOCKETS
SECOND HALF COLUMN EXTRACTED FROM CANISTER AFTER CONNECTION
GIMBAL ACTUATORS (8)
GIMBAL JOINTS (4) (60° ROTATIONS α & β)
ANTI-ROTATION SCISSORS (4)

F-17

REFERENCES

1. Walz, Joseph E.: Load Concentration Due to Missing Members in Planar Faces of a Large Space Truss. NASA TP-1522, 1979.

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4. Bush, Harold G.; Mikulas, Martin M., Jr.; and Heard, Walter L., Jr.: Some Design Considerations for Large Space Structures. AIAA J., vol. 16, no. 4, Apr. 1978, pp. 352-359.

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