DEPLOYMENT TESTS OF A 36-ELEMENT TETRAHEDRAL TRUSS MODULE

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DEPLOYABLE PLATFORM

OBJECTIVE:

DEVELOP BASIC STRUCTURAL TECHNOLOGY & TEST TECHNIQUES FOR LARGE DEPLOYABLE PLATFORMS

OUTLINE:

- o GROUND DEPLOYMENT TEST METHODS FOR LARGE SPACE STRUCTURE
- o SINGLE ELEMENT & 36 ELEMENT MODULE EXPERIMENTAL/ANALYTICAL RESULTS
- o APPROX. ANALYSIS TO DETERMINE MAX. SIZE PLATFORM THAT CAN BE DEPLOYED IN GROUND TESTS

Figure 1.

36-ELEMENT DEPLOYABLE TRUSS

Photographs of the truss used in the deployment experiments are shown in figure 2. The upper surface is composed of twelve thin wall graphite-epoxy tubular elements foldable at their midpoints and hinged to a cluster joint at each end to form a hexagon. The nine element lower surface forms a triangle and is connected to the upper surface through thirteen non-folding inter-surface elements pinned at each end to a cluster joint. All elements were 38 mm in diameter by 2.134 m in length node to node and had a wall thickness of .6 mm. Surface elements were designed to fold outward forming a package 4.3 m in length by .3 m in diameter. Deployment energy was provided through the first half of the deployment cycle by a linear spring in each of the 21 surface elements. Surface elements were locked in the deployed position by a conventional spring loaded catch mechanism located on each knee-joint. Fifty-six percent of the 14.5 kg total truss mass was in the graphite-epoxy and the remainder in the aluminum joints and fittings. Several strain-gage bridges and accelerometers were installed on the truss to measure deployment loads.

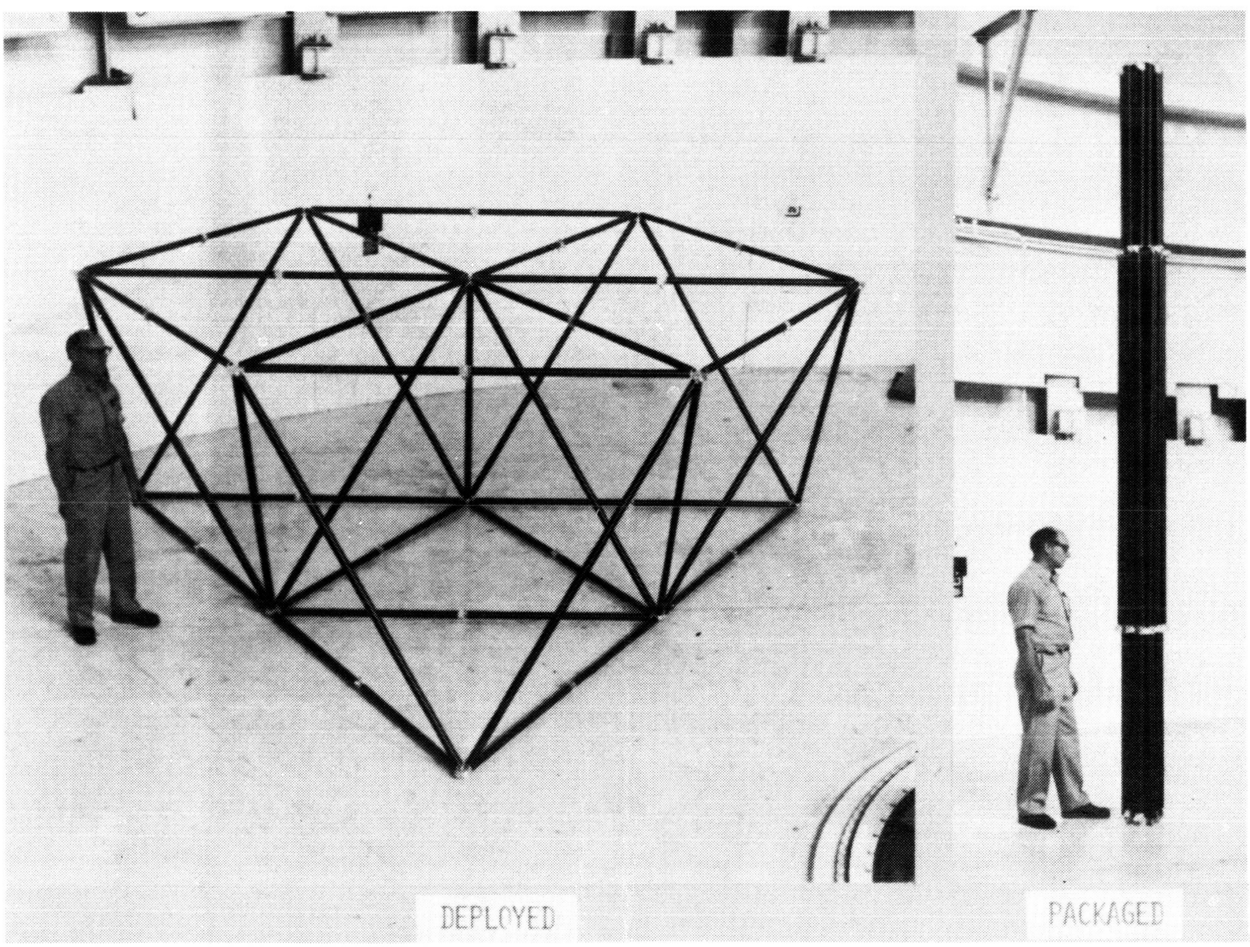

Figure 2.

MAXIMUM BENDING STRESS OF GRAPHITE-EPOXY ELEMENT

For a truss of the size shown in the previous figure, the principal deployment load (bending of a pinned-pinned beam) can be simulated without the use of deployment springs by testing a single surface element as indicated in figure 3. In this technique, a mass which is large relative to the mass of the element is fixed to each end of a foldable element and allowed to swing outward in pendulum fashion on long cables. The kinetic energy of the element at lockup can be accurately controlled by the separation at the upper end of the support cables. The maximum experimental bending stresses at lockup measured adjacent to the element knee-joint (open symbols) shows excellent agreement with stress predicted by the simple analytical expression given over a wide range of deployment energies. In the analytical expression d is the element diameter, E the modulus of elasticity, U_0 the deployment energy, I the area moment-of-inertia, ℓ the element length, m the mass of the graphite/epoxy tube, and m_k the mass of the knee-joint.

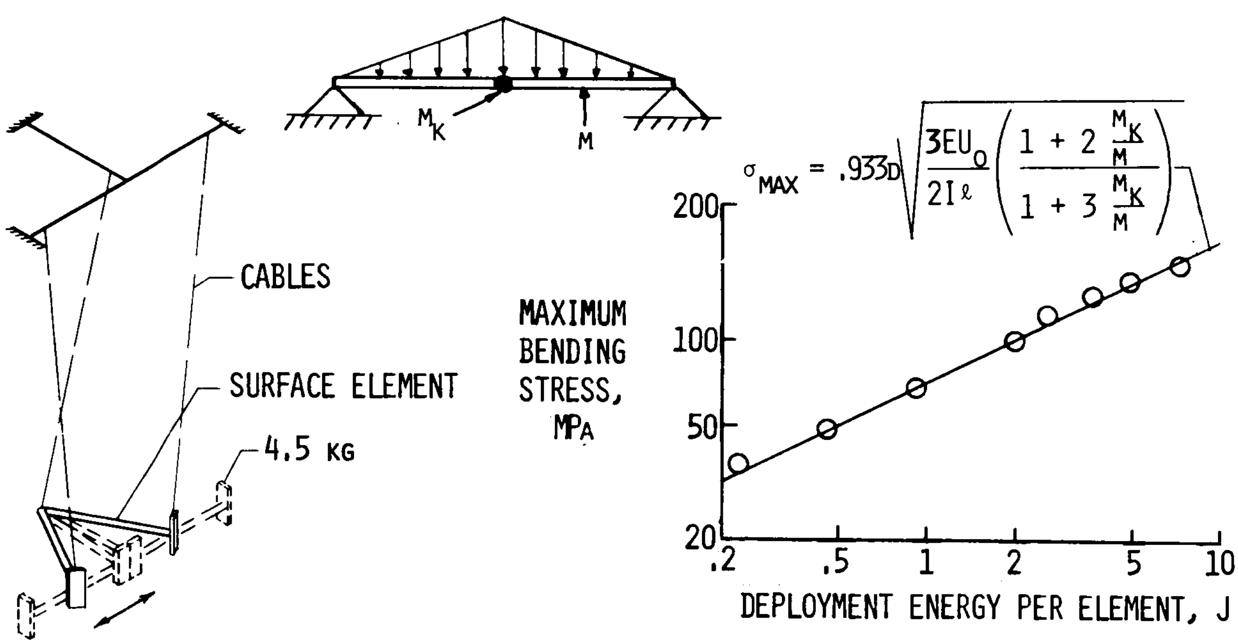

Figure 3.

TEST METHODS

In the past, models of deployable structures have been limited largely to small scale models which could be readily deployed by suspending the model on several soft shock cords. The scale of the deployable truss used in the present investigation precluded the use of this test technique as the gravity forces and moments are of the same order of magnitude as the deployment forces and moments. For these tests, the truss was deployed during free-fall in the LaRC 55' vacuum facility. Appreciably larger trusses could be deployed by lofting the packaged truss upward from the floor of the facility and allowing it to deploy during the upward as well as the downward portion of its trajectory, thus doubling the available test time. It must be realized, of course, that the mechanisms required to loft and decelerate such a large truss would be much more complex than those required for a straight drop.

- SOFT SUSPENSION
- STRAIGHT DROP
- LOFT AND DROP

Figure 4.

36-ELEMENT TRUSS IN LaRC 55' VACUUM CYLINDER

Deployment tests of the 36-element truss were conducted in the LaRC 55' vacuum facility as illustrated in figure 5. This facility is approximately 17 m in diameter and 18 m in height. The packaged truss was secured by a small diameter cable about its girth midway along its length. A pyrotechnic cable cutter was installed to sever the cable on command. Prior to a test, the 21 deployment springs were cocked and the packaged truss hoisted to the top of the facility by means of a 1.6 mm cable attached to the central cluster joint of the hexagonal surface. The support cable passed through a pulley at the top of the facility and was attached to a wall by means of a short loop of cable containing a pyrotechnic cable cutter. 8.2 m of slack cable was provided for free-fall as illustrated. Both pyrotechnic devices were actuated simultaneously, allowing the truss to deploy while in free-fall. After 1.3 seconds of free-fall, the 8.2 m of slack cable was used up and a wire energy absorbing device installed in the support cable just above the truss brought the deployed truss to a gentle halt. Signals from strain gage bridges and accelerometers were recorded on tape during deployment for later analysis.

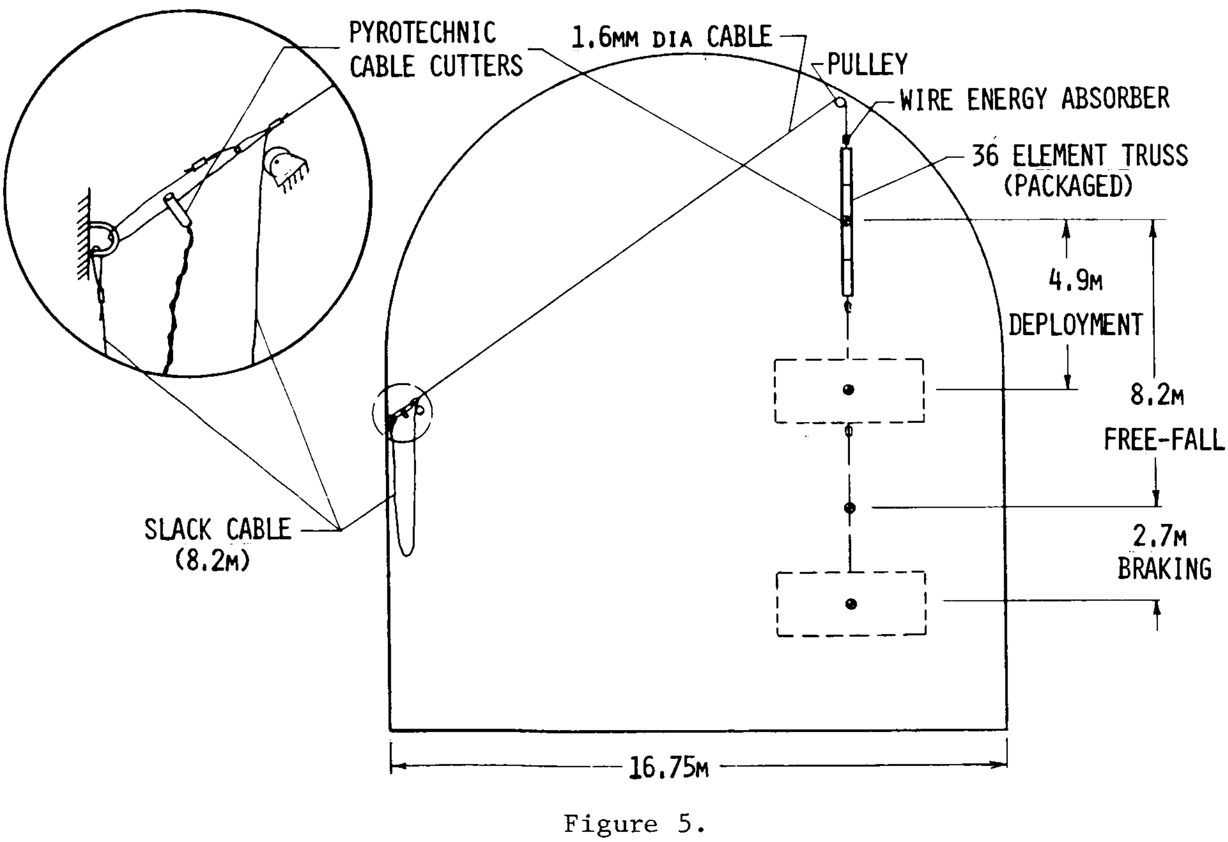

Figure 5.

WIRE ENERGY ABSORBER

After the free-fall test period, the deployed truss was brought to a gentle halt by means of the wire energy absorber depicted in figure 6. In this device a mild steel wire is pulled over a series of three pulleys yielding the wire in bending six times. The braking force is dependent upon the number and diameter of the pulleys and the diameter and yield strength of the wire. The energy absorber was designed for a drag force of 534 N thus limiting the load felt by the deployed truss to 3.75 g's.

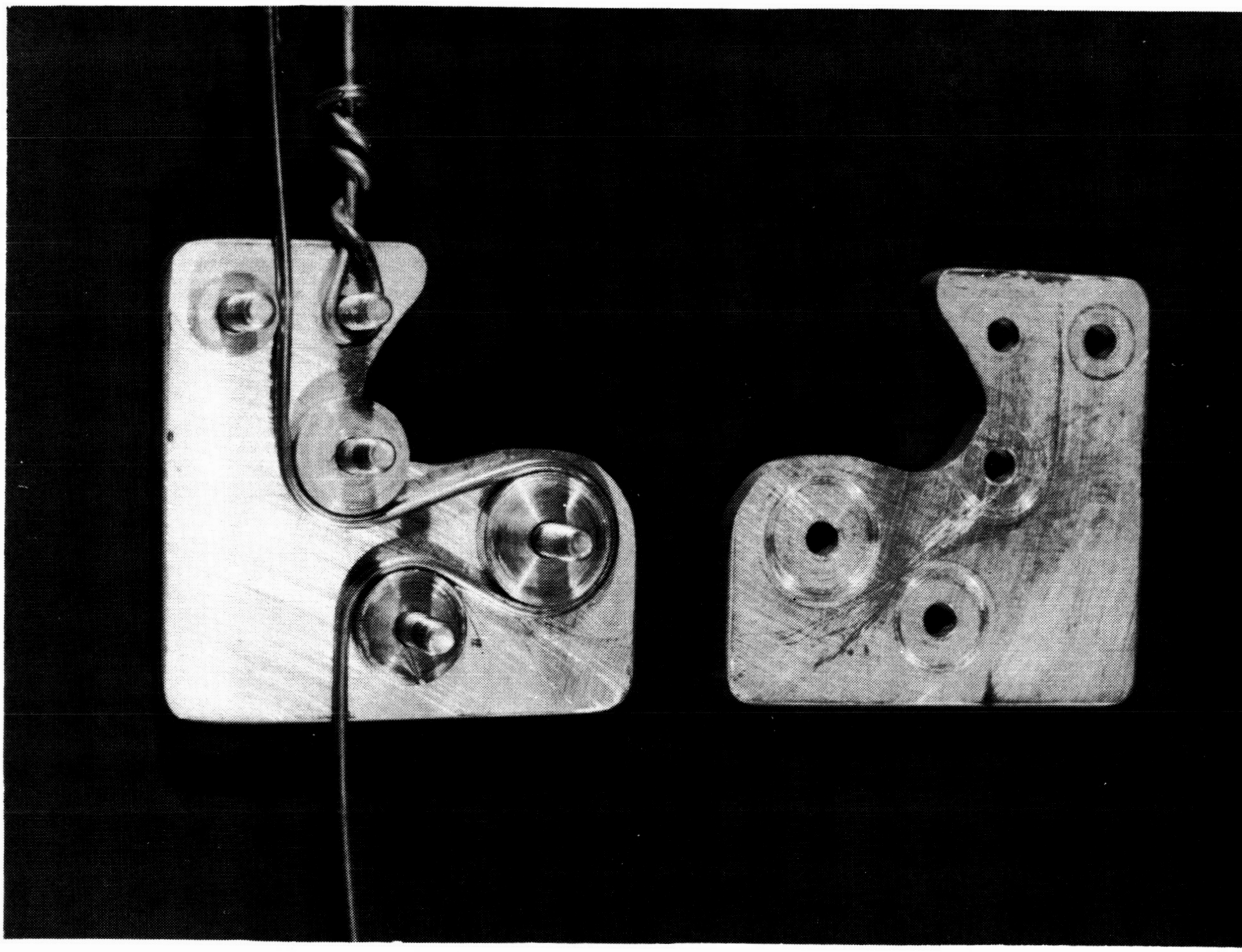

Figure 6.

EFFECT OF ATMOSPHERE ON VERTICAL ACCELERATION

A servo accelerometer mounted on one of the lower surfae cluster joints was oriented to measure the vertical acceleration. Figures 7(a) and 7(b) show time histories from this accelerometer during deployment tests conducted at atmospheric pressure and at 1/10th atmosphere, respectively. At atmospheric pressure, release occurs at time zero; lock-up at 1.1 seconds; braking from 1.4 to 2.0 seconds and bouncing on support cable from 2 seconds on. At 1/10th atmosphere, lockup and braking occurs .1 second earlier. The kinematic analysis indicated a deployment time of 1.05 seconds. For the tests at atmospheric pressure, the vertical acceleration is seen to drop initially to zero-g but increases (due to aerodynamic drag) to approximately .8g by the time the brake is applied. At 1/10th atmosphere, the acceleration between lockup and braking remains in the vicinity of zero-g.

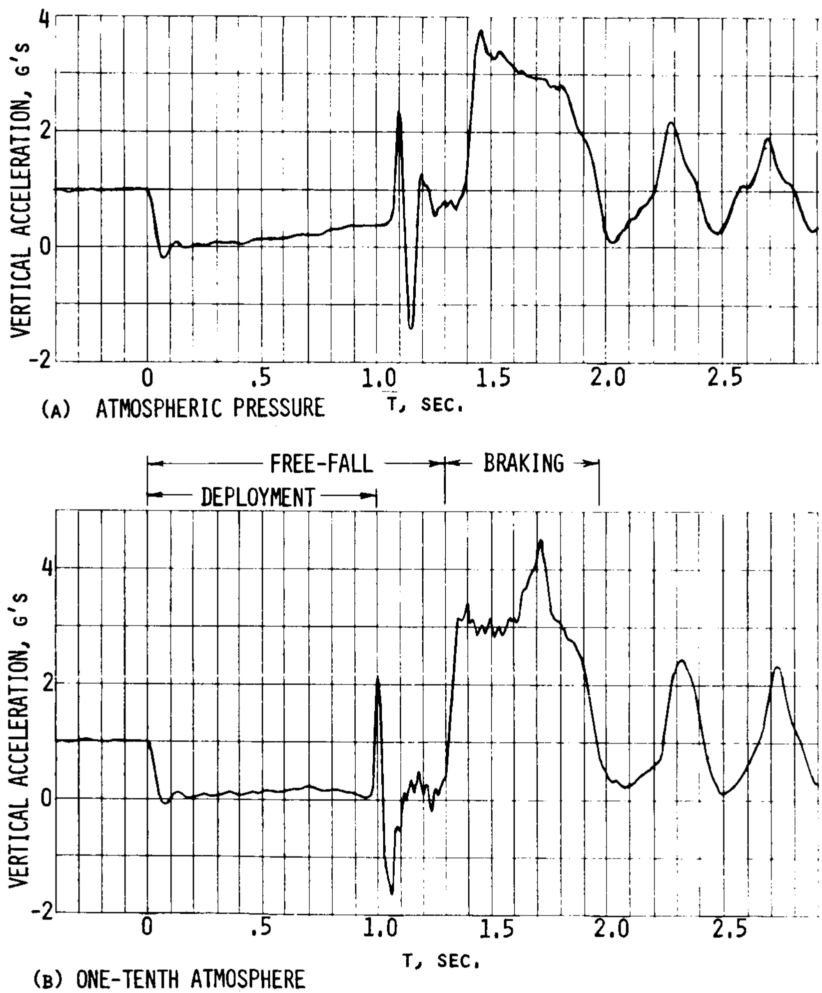

Figure 7.

RATIO OF MEASURED TO CALCULATED BENDING STRESS AT LOCKUP

Although the atmosphere had but a minor effect on deployment time, it was found to have a major effect on deployment loads. Strain gage bridges were located adjacent to the knee-joint of four surface elements (two on upper surface and two on the lower) to measure the bending stresses at lockup. In figure 8 the average of the stress measured on these four gages relative to the calculated stress of 107 MPa is tabulated for three deployment tests; two at atmospheric pressure and one at one-tenth atmosphere. For the tests conducted at atmospheric pressure, the average of the measured bending stresses was only 56% of calculated while at one-tenth atmosphere, the average of the measured bending stresses was the same as the calculated stress.

(CALCULATED STRESS = 107 MPa)

TEST NO.	TEST PRESSURE	STRESS EXP/CALC
1	1 ATMOS	.57
2	1 ATMOS	.55
3	1/10 ATMOS	1.00

Figure 8.

DIMENSIONLESS DEPLOYMENT TIME AS FUNCTION OF PLATFORM SIZE

The results of a simplified kinematic analysis are shown in figure 9 where the dimensionless deployment time is plotted as a function of the number of radial bays in the truss. In the dimensionless parameter, t represents the deployment time, U_o the deployment energy per element, ℓ the element length, and m_c the effective mass associated with each cluster joint. For values of N>4, the curves are essentially straight lines with a slope of 45°, indicating that the deployment time is proportional to N. The separation of the various curves show that deployment time is not only a function of the deployment energy but also how quickly that energy is delivered to the truss. It may be observed that the deployment time for a constant moment input is more than double that for an impulsive energy input. Since drop height for free-fall deployment tests varies as the square of the deployment time, the rapidity with which the deployment energy is put into the truss can become critical. The angle Θ represents half the included angle formed by the two halves of the foldable elements.

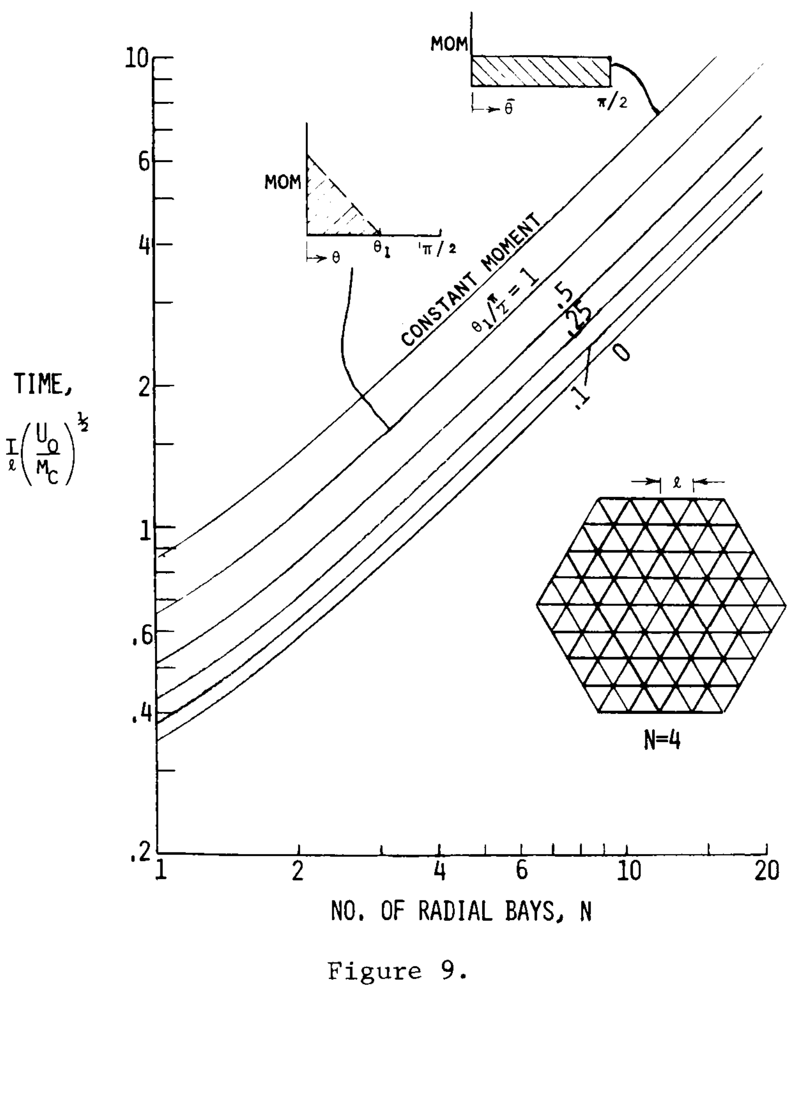

Figure 9.

FACILITY HEIGHT REQUIRED AS FUNCTION OF DEPLOYMENT ENERGY AND TRUSS SIZE

Utilizing the same truss elements as were used in the present deployment tests, figure 10 indicates the facility height required for deployment tests as a function of the deployment energy and the number of radial bays. The 18m working height of the LaRC 55' vacuum facility is indicated by the horizontal broken line. It is seen that in order to deploy a truss with two radial bays in this facility, the deployment energy of 2.3 J per element used in the present tests would have to be doubled and doubled again for N=3. Although the resulting bending stresses at these energy levels are not excessive, the design of the deployment spring and cocking mechanism may present some problems. An alternative test method which hypothetically doubles the test time is to loft the packaged truss upward from the floor of the facility and allow it to deploy during the upward as well as the downward portion of its trajectory. For a given height, this has the effect of cutting the energy requirements by a factor of four as indicated in the abcissa. Thus a truss having three radial bays could be deployed in the LaRC 55' vacuum cylinder using the same springs as were used in the present one bay test. The mechanism to loft and decelerate such a large truss would, of course, be much more complex.

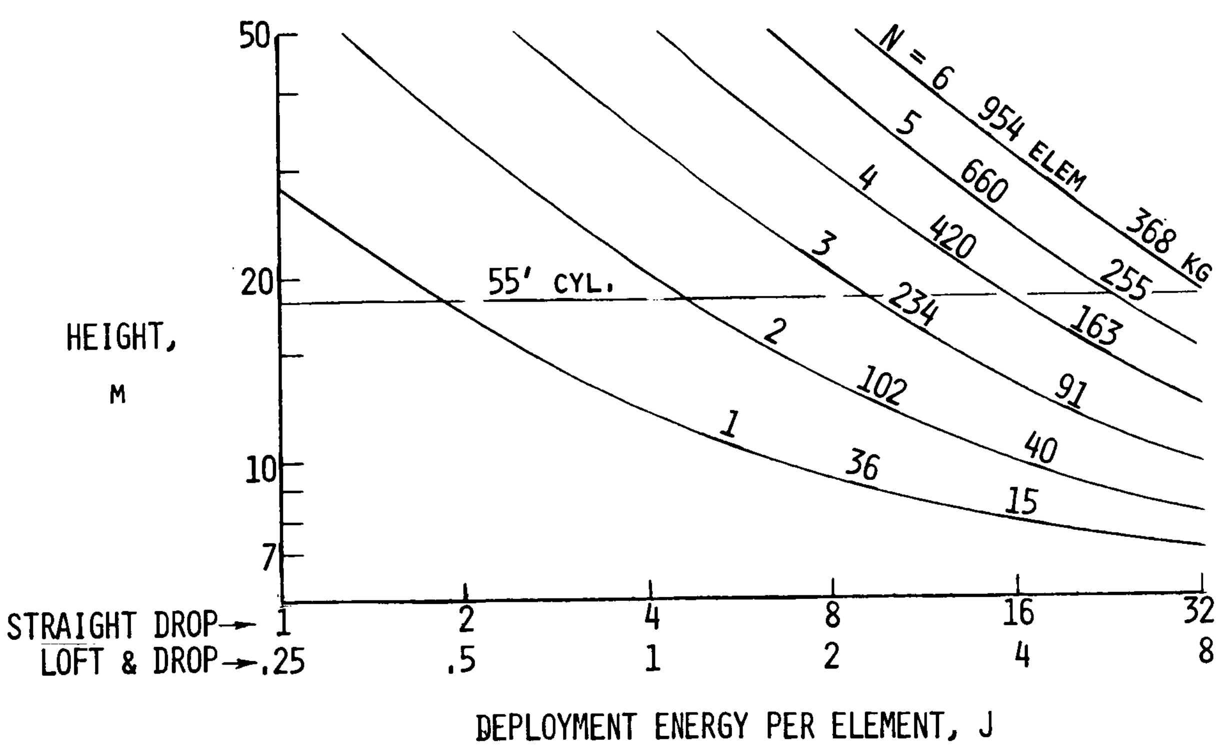

Figure 10.