NASA Technical Memorandum 87673

NASA-TM-87673 19860014152

ANALYSIS OF A SINGLE-FOLD DEPLOYABLE TRUSS BEAM PRELOADED BY EXTENSION OF SELECTED FACE DIAGONAL MEMBERS

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APRIL 1986

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Space Administration

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INTRODUCTION

A major concern in the design of large space structures is the loss of structural predictability due to non-linear joint stiffnesses. A primary cause of non-linear behavior in deployable truss joints is free play in pin connections. In this study, one technique for removing joint free play and improving truss performance is analyzed for an existing deployable truss concept.

Box trusses which deploy in one direction (single-fold), much like an accordion, are being considered for future space structure applications. One single-fold truss concept is described in reference 1. This concept has fixed batten frames, folding longerons, and telescoping face diagonals (see figure 1a). A method proposed for reducing possible non-linear behavior in this design is to induce a preload in the truss by adjusting the length of one face diagonal in each bay. This preload is designed to eliminate joint free play and uniformly load the joints into a linearly elastic region where their behavior is more predictable. To enhance predictability and avoid stress concentration areas within the structure, it is necessary to insure that all joints are preloaded uniformly.

In this study, four preload cases were analyzed using linear finite element techniques to determine the force distribution in the members and truss deformations resulting from the applied preload. Each case involved the lengthening of a different pattern of face diagonal struts. Results from these analyses were compared to determine if a pattern existed that would induce a uniform distribution of forces in the members while causing minimum truss deformations.

MODEL DESCRIPTION

Four bays of the aforementioned truss configuration are diagrammed in figure 1(a). A finite element model was developed for a 21 bay truss beam of this configuration. The truss members are represented by axial stiffness elements having properties of two inch diameter graphite/epoxy tubes with a cross sectional area of 0.3657 in^2, a Young's modulus of $40x10^6 lb_f/in^2$, and a coefficient of thermal expansion of $0.5x10^{-6} in/in^oF$ (reference 2). All truss joints are assumed to behave linearly. This assumption is based on the design criterion that the preload must load the joints into a linear stress-strain region. Also, the joints are assumed to have the same linear stiffness as the struts.

A statically determinant set of constraints are applied to three nodes at one end of the truss beam to restrain rigid body motion without interfering with the deformation of the truss members. The other end of the truss beam is left free. Effects of the preload are studied in three typical regions of the truss beam (figure 1(b)): 1) the region near a fixed end, 2) the region near a free end, and 3) the region away from any end conditions where the structural behavior approaches that of an infinite truss beam. Note that due to the choice of constraints at the fixed or "cantilevered" end, the member forces and local deformations in this region should be the same as those for the free end.

To mathematically represent an extension, or a strain, in the face diagonal members, a unit thermal load was applied. The unit load chosen was a temperature differential that would cause a 1 lb_f compressive force in a diagonal if its ends were fixed (i.e. fully constrained). The equation which relates the member force (P) to the applied thermal loading (ΔT) is

$$P = -EA\alpha\Delta T$$

where E is the Young's modulus, A is the cross sectional area, and α is the coefficient of thermal expansion.

Using this equation, the thermal load required to generate a 1.0 lb_f compressive force in a fully constrained diagonal may be computed. This thermal load is 0.1367^{o}F. Since the face diagonals in the truss are not fully constrained, the actual compressive force in these members will be less than 1.0 lb_f.

STATIC ANALYSIS OF FOUR PRELOAD CASES

Four preload cases are analyzed and compared in this study; each involves loading a different pattern of face diagonal members (figure 2). For each case, the unit thermal load is applied to one diagonal in each bay of the truss, and the resulting member forces and static deformations in the truss are calculated.

Member Force Distribution

For each of the preload cases described, the resulting member forces were calculated and the ranges (maximums and minimums) of these forces were noted for each member type (i.e. longerons, face diagonals, batten diagonals, and battens). Despite the differences in the preload patterns all patterns give essentially the same ranges of forces for each member type although the distributions may differ slightly. Table 1 lists these ranges within the three characteristic regions of the truss beam (i.e. near a fixed end, near a free end, and away from any end constraints).

In the region away from end constraints all of the members of a given type are loaded approximately the same, as indicated by maximums and minimums that are about equal. This result implies that the truss joints in this region would be loaded uniformly, a condition which was described as a necessity. For the model being studied, this region starts four bays in from each end of the beam (see figure 1(b)).

There is, however, a spread in the forces for each member type in the end regions as indicated by maximums and minimums that are not equal. Therefore, the joints in the end regions are not loaded uniformly with the present preload scheme. Further, it should be noted that as a result of this preload scheme the maximum forces that exist in an end region are greater than the corresponding member forces in the uniform load region of the beam.

Truss Deformations

Although the four preload patterns considered all resulted in the same maximum and minimum member forces, the static deformations of the truss are different in each case. Figures 3 through 6 are plots of the truss deformations resulting from preload cases 1 through 4, respectively. These plots are each scaled to their own maximum deflection and can, therefore, only be compared qualitatively.

Two types of deformation result from preloading. The first is a shearing deformation where adjacent batten frames move relative to each other in the y-z plane. The second is a twisting deformation where adjacent batten frames rotate relative to one another about the x axis. As seen in figures 4 and 5, preload cases 2 and 3 result in similar twisting deformations of the truss beam, whereas preload cases 1 and 4 result in predominantly shearing deformations (figures 3 and 6). However, the type of shearing present in preload case 1 is different than that of preload case 4. In preload case 1 (see figure 3a) adjacent bays are shearing in opposite directions as viewed in the x-z plane. In preload case 4 (figure 6a) all bays shear in the same direction. This result is justified by considering the preload patterns in figure 2 and noting that in both cases 1 and 4 all of the preload members are parallel to the x-z plane, lining up in the same direction in case 4 and in a "zig-zag" arrangement in case 1.

To quantitatively compare the truss deformations, the deflections at the free end of the truss are summarized in Table 2. These deflections represent the average of the deflections at the four joints of the end batten frame. It should be noted that the y-z plane of the coordinate system is fixed to the three nodes constrained in the fixed end of the beam and therefore, warping of the fixed end batten frame will result in a rigid body rotation of the beam in the y or the z direction.

For all four preload cases the average x deflection (Δx) is essentially the same. In all preload patterns only one diagonal per bay is being loaded and thus, the average longitudinal stretching (Δx) should be the same. Also, the average y deflection (Δy) is the same for all load cases. This is understood by recalling the constraint condition imposed on the fixed end and noting that the same diagonal has been preloaded in the first bay (near the fixed end) for all load cases. This first preload diagonal causes warping in the fixed end batten frame which, consequently, causes a rigid body rotation of the beam due to the constraints on three of the four joints in that frame. The z deflection (Δz) is also approximately the same for cases 1-3, due to this rigid body rotation, but is nearly 5 times larger for preload case 4 due to the fact that all preloaded diagonals in case 4 have the same oriention (see figure 2). As noted previously, in cases 2 and 3 the preloaded diagonals form spiral patterns causing the truss to undergo a comparatively large twist, as shown by the large θ_x rotation in Table 2.

CONCLUSIONS

A technique for preloading a deployable box truss beam to improve truss predictability was studied to determine if its application would result in uniform loading of the truss joints without causing excessive deformations in the truss. The technique presented allows only one face diagonal per bay of the truss beam to be preloaded. In this analysis four patterns of preloaded face diagonals were compared.

The results of the analysis indicate that all preload patterns considered give similar distributions of forces in the truss members. In the region of the truss beam away from any boundary constraints, the member forces are uniform within two percent, and thus, the joints in this region are loaded uniformly. In the regions near the boundary constraints (ends of the beam) the member forces become very non-uniform and maximum member forces are greater than the corresponding member forces in the uniform load region. Finally, the type of resulting deformation in the truss depends on the pattern of preloaded diagonals.

REFERENCES

1. Greenberg, H. S.: Development of Deployable Structures for Large Space Platform Systems. NASA CR-170914, October 1983.

2. Mikulas, Martin M., Jr., et. al.: Space Station Truss Structures and Construction Considerations. NASA TM-86338, January 1985.

	$P_{max}(lb_f)/P_{min}(lb_f)$		
MEMBER TYPE	NEAR FIXED END	AWAY FROM END CONSTRAINTS	NEAR FREE END
longerons	.1150/.0000	.0754/.0741	.1150/.0000
face diagonals	-.1245/-.0813	-.1064/-.1057	-.1245/-.0813
batten diagonals	.2237/.0813	.2140/.2120	.2237/.0813
battens	.0000/.0000	.0000/.0000	.0000/.0000

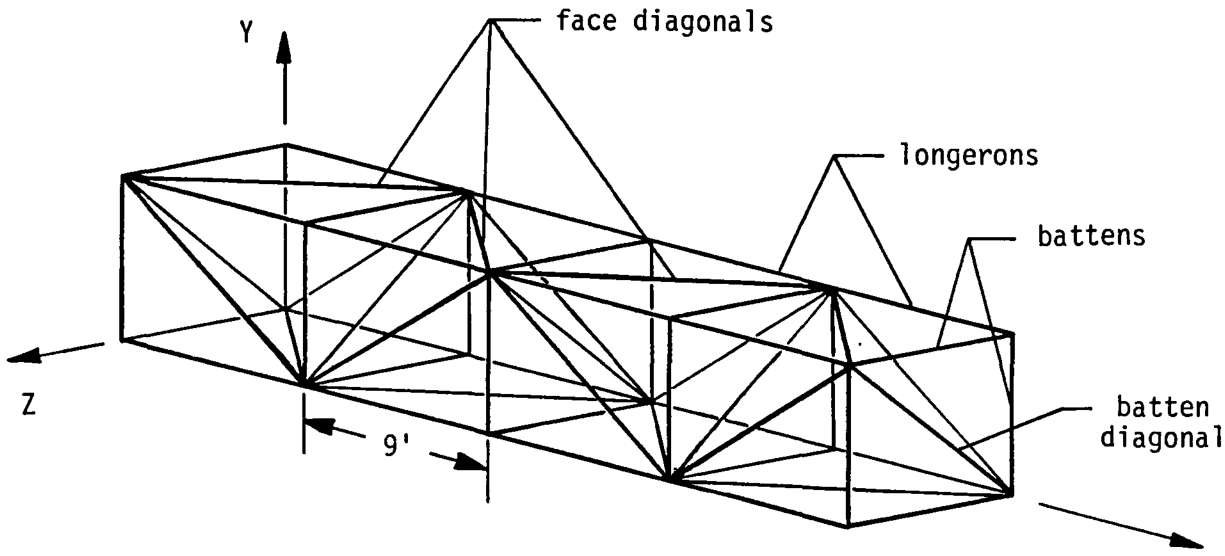
(Negative force is compression, positive force is tension)

Table 1.- Maximum and Minimum Member Forces in Three Beam Regions for All Preload Cases.

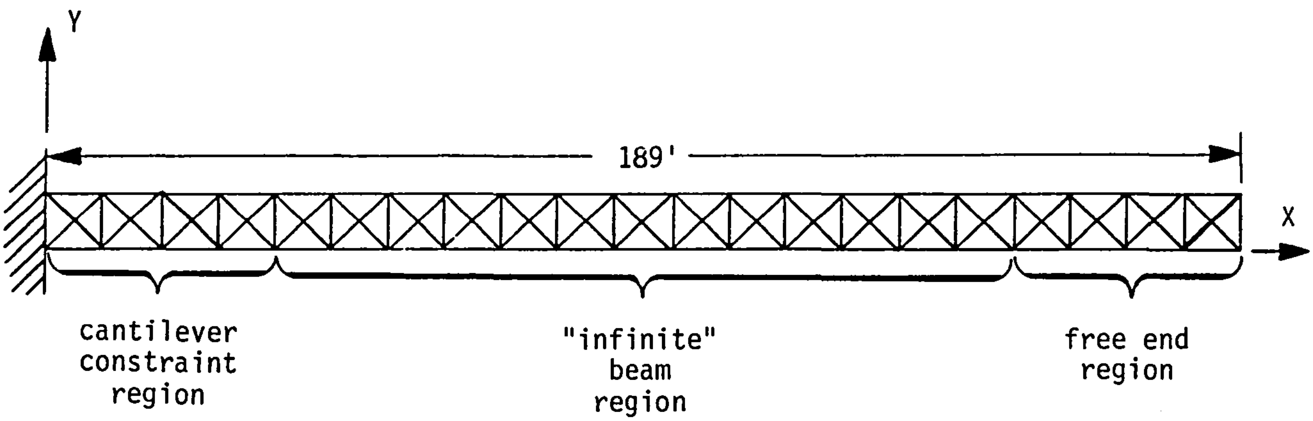
	PRELOAD CASE			
Average Free End Deflections*	1	2	3	4
Δx (in x 10^{-5})	1.223	1.223	1.223	1.223
Δy (in x 10^{-5})	3.065	3.055	3.055	3.065
Δz (in x 10^{-5})	-3.740	-3.765	-3.765	-18.500
θx (degrees x 10^{-6})	-4.218	-82.650	-82.650	-4.059

*These numbers represent the average of the deflections at each of the four joints of the free end batten frame.

Table 2.- Average Free End Deflections for Four Preload Cases.



(a) reference truss configuration



(b) 21-bay truss beam

Figure 1. - Finite Element Model Configuration

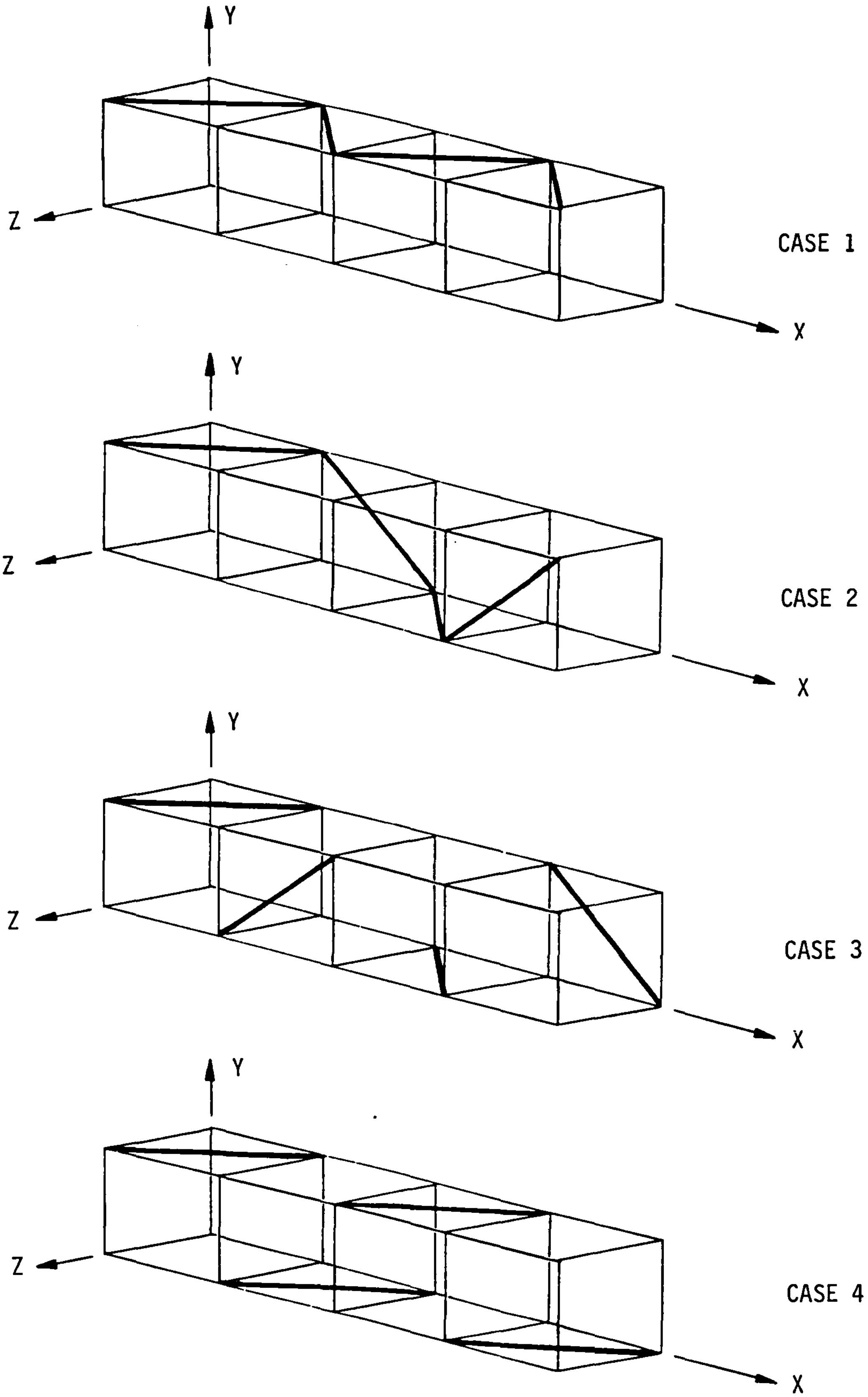
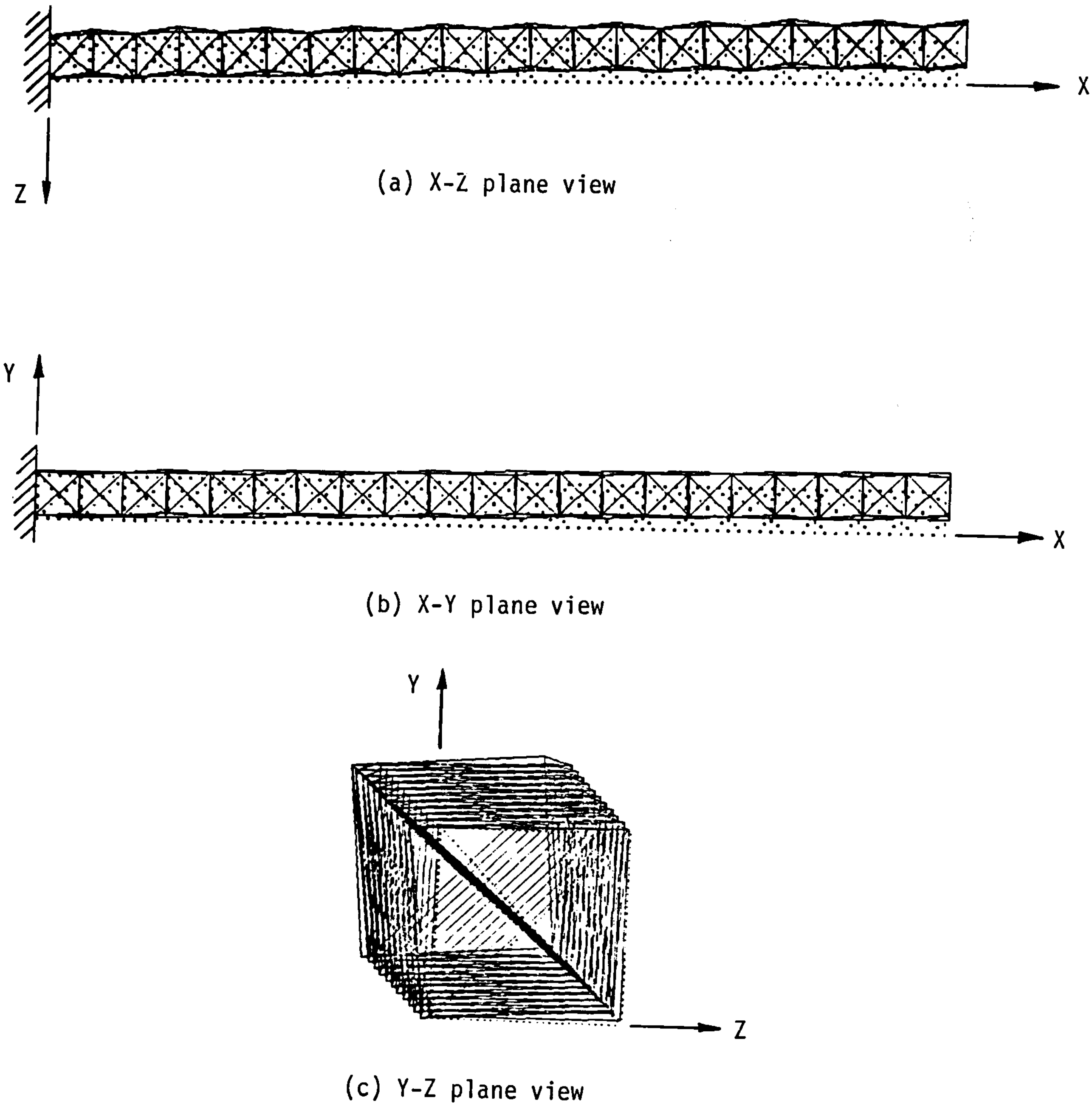


Figure 2. - Preload Diagonal Patterns

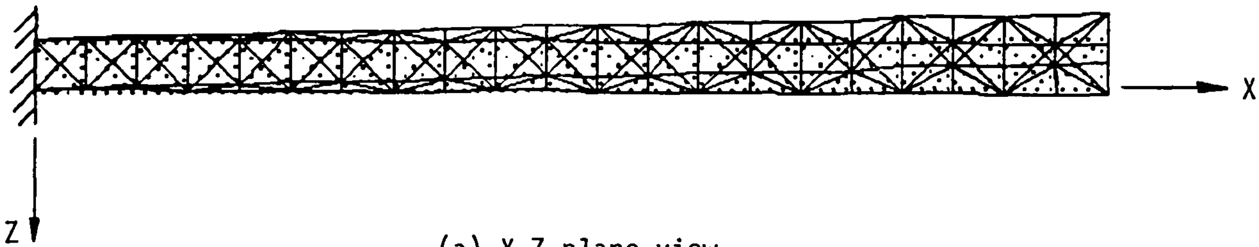


(a) X-Z plane view

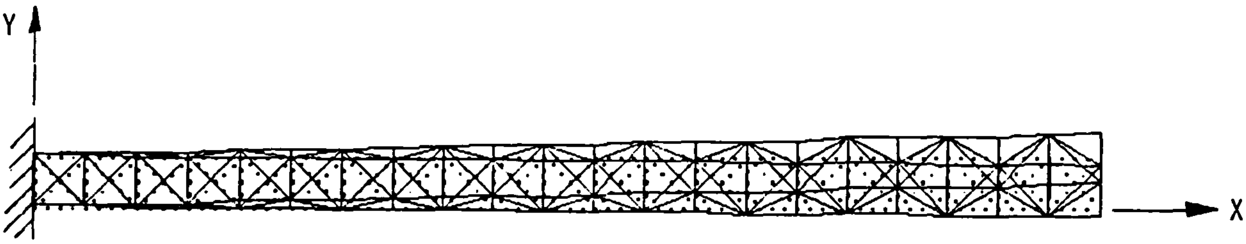
(b) X-Y plane view

(c) Y-Z plane view

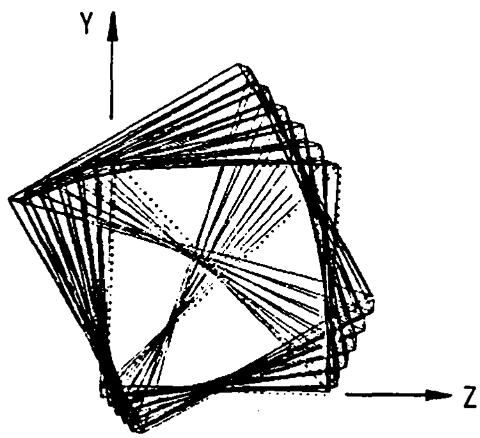
Figure 3. - Truss Deformation From Preload Case 1



(a) X-Z plane view



(b) X-Y plane view



(c) Y-Z plane view

Figure 4. - Truss Deformation From Preload Case 2

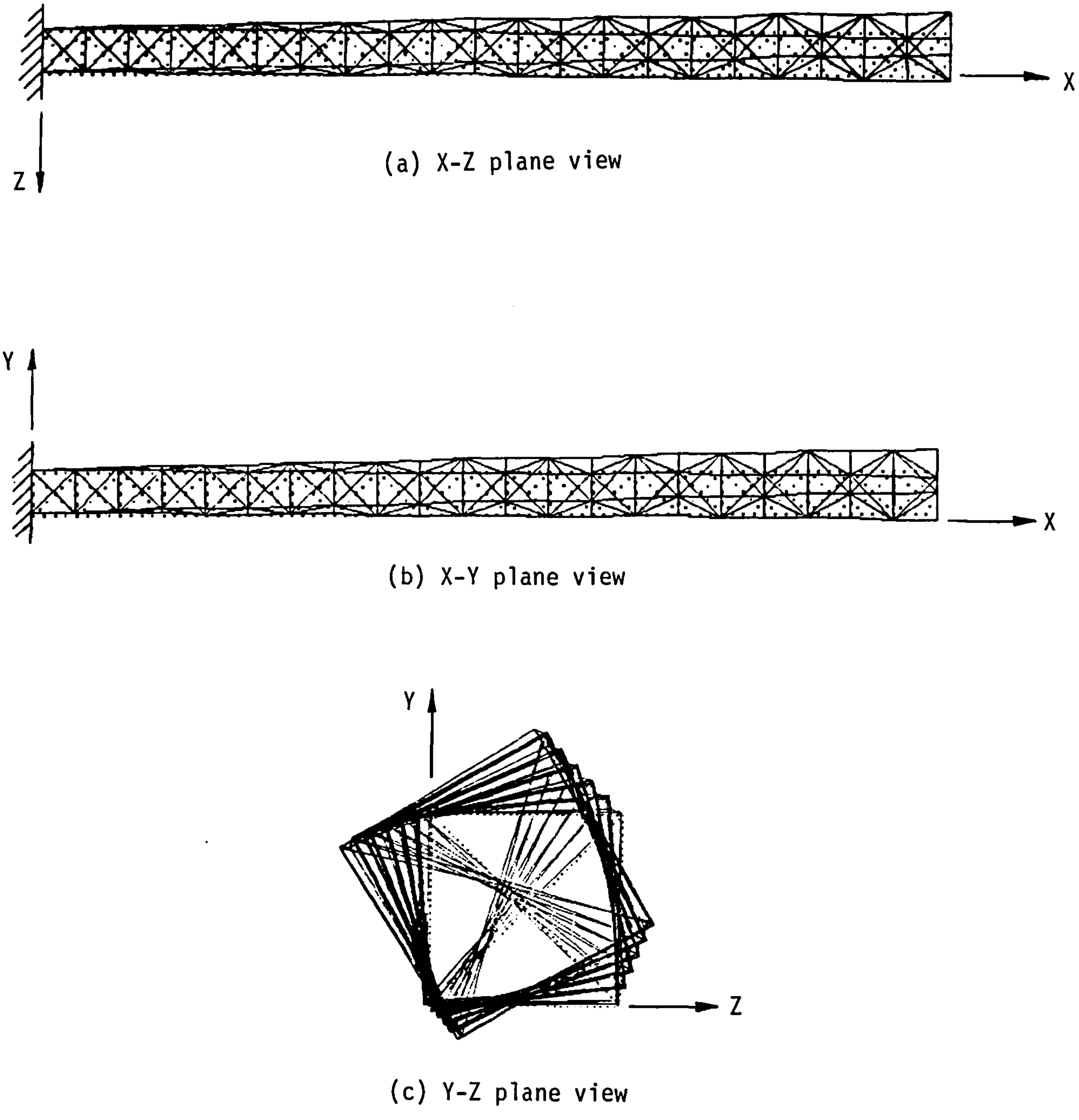
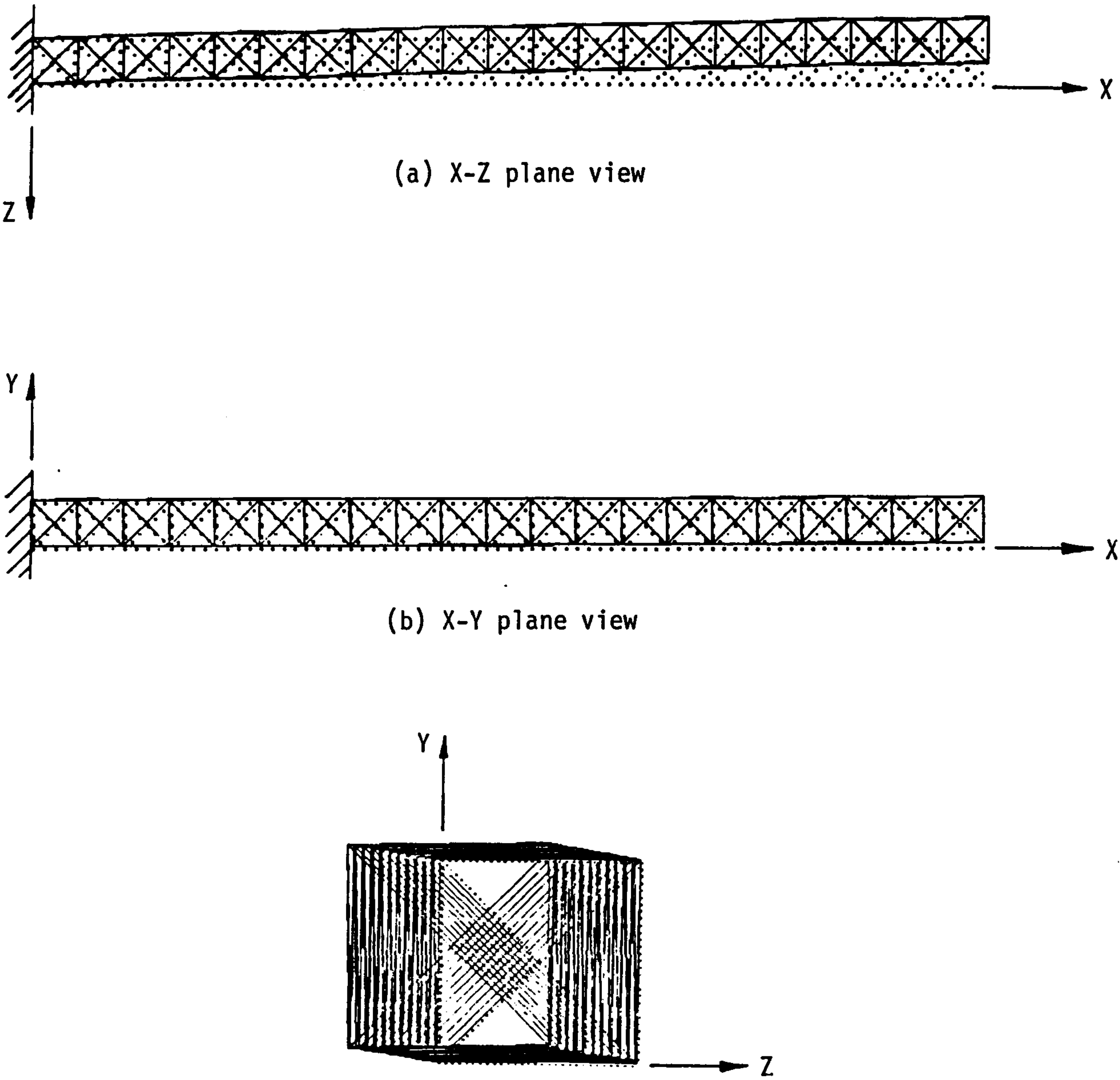


Figure 5. - Truss Deformation From Preload Case 3



(a) X-Z plane view

(b) X-Y plane view

(c) Y-Z plane view

Figure 6. - Truss Deformation From Preload Case 4

1. Report No. NASA TM-87673	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Analysis of a Single-Fold Deployable Truss Beam Preloaded by Extension of Selected Face Diagonal Members		5. Report Date April 1986
		6. Performing Organization Code 506-43-41-02
7. Author(s) K. Chauncey Wu and Mark S. Lake		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address NASA Langley Research Center Hampton, VA 23665		11. Contract or Grant No.
		13. Type of Report and Period Covered Technical Memorandum
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

A technique for preloading a deployable box truss beam by extension of one face diagonal per bay was studied to determine if it would result in uniform loading of truss joints without causing excessive truss deformations. Results indicate that it is possible to accomplish uniform loading in the beam region away from beam boundaries, whereas in the regions near boundaries the member loading becomes non-uniform with magnitudes greater than those in the uniform load region. Also, the type of deformation which results in the beam depends on the pattern of preloaded members.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Preload Deployable truss Member loads Truss deformations	Unclassified - Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	16	A02

For sale by the National Technical Information Service, Springfield, Virginia 22161

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