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# Structural Design Feasibility Study of Space Station Long Spacer Truss

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## SUMMARY

The structural design and configuration feasibility of the long spacer truss assembly that will be used as part of the Space Station Freedom is the focus of this study. The structural analysis discussed herein is derived from the transient loading events presented in the Space Transportation System Interface Control Document (STS ICD). The transient loading events are liftoff, landing, and emergency landing loads. Quasi-static loading events were neglected in this study since the magnitude of the quasi-static acceleration factors is lower than that of the transient acceleration factors. Structural analysis of the proposed configuration of the long spacer truss with four longerons indicated that negative safety margins are possible. As a result, configuration changes were proposed. The primary configuration change suggested was to increase the number of truss longerons to six. The six-longeron truss appears to be a more promising structure than the four-longeron truss because it offers a positive margin of safety and more volume in its second bay (BAY2). This additional volume can be used for resupply of some of the orbital replacement units (such as a battery box). Note that the design effort on the long spacer truss has not fully begun and that calculations and reports of the negative safety margins are, to date, based on concept only.

## INTRODUCTION

Space Station Freedom (fig. 1(a)) is a low-Earth-orbit (220-nmi) manned spacecraft that is currently being designed and developed by the United States, Japan, Europe, and Canada. NASA Lewis Research Center will develop the two solar power modules (SPM's) of Space Station Freedom: one with two photovoltaic power modules (PVM's) and the other with one PVM. The SPM which is composed of two PVM's includes two spacer truss assemblies, one long and one short. Each PVM is made up of an integrated structure of two photovoltaic solar array assemblies, two beta gimbal assemblies, and an integrated equipment assembly (IEA). Structural design and configuration feasibility of the long spacer truss is the focus of this paper.

It will take 17 shuttle flights to assemble Space Station Freedom. The three PVM's will be launched on the 1st, 10th, and 14th flights. The short spacer is planned for launch on the 11th shuttle flight. One PVM (scheduled for launch on the 14th shuttle flight) will be integrated with the long spacer truss assembly. The SPM, which consists of two PVM's (scheduled for launch on the 1st and 14th shuttle flights), is shown in figure 1(b). These two PVM's are connected through two rectangular cross-section spacer trusses. The distance between the centers of the two PVM's (which make up the total SPM) when assembled is 590 in. This corresponds to the distance necessary to minimize the shadowing effect of one solar array on the other. Since the maximum allowable length of any cargo element in the STS cargo bay is 540 in., the 590-in. dimension must be accommodated by splitting the components into multiple shuttle cargo elements. The long spacer truss is shown in figure 2.

## FINITE-ELEMENT ANALYSIS

The finite-element model generated for the structural and normal mode analyses is a three-dimensional model of the long spacer that contains 3900 degrees of freedom (fig. 3). This finite-element model primarily contains linear isoparametric beam elements known as BAR elements (ref. 1). (The BAR element is a two-noded beam element with a capability of predicting axial, bending, and torsional stresses.) Concentrated mass elements have also been used to account for some of the nonstructural masses such as truss interconnects. To account for the mass of the components, whose locations and exact magnitudes have not yet been determined, a 1.5 uncertainty factor was applied to the loads specified by the Space Transportation System Interface Control Document (STS ICD). The finite-element model of the integrated equipment assembly (IEA) was obtained from the hardware contractor, Rockwell International Corp., Rocketdyne Division, and contains nearly 50 000 degrees of freedom.

The components of the truss assembly are identified in figure 2. The material and sizes of the longeron and keel trunnions are discussed in reference 2. The trunnions were all modeled using the BAR elements. The tubes making up the longerons, battens, and diagonals were made from Aluminum, 6061-T6. Although tubes of four different outer diameters (1.0, 2.0, 2.5, and 3.0 in.) were considered in the overall analysis, all had a common wall thickness of 0.2 in. In each analysis all tube sizes were the same. The reasons for varying the outer diameters of the members in this structural analysis were: (1) to examine the resulting stresses as they affect the margins of safety and (2) to examine the displacements.

## DESIGN CRITERIA

In this initial study, the sizes of the structural members of the long spacer were selected to meet the allowable stress and minimum circular frequency requirements.

The failure criteria considered in this study are based on a comparison of the stresses and displacements (deformation) obtained from the structural analysis and the circular frequencies obtained from the normal mode analysis to the allowables shown in references 2 and 3. The displacements of payloads are of particular concern since they are required to stay within the dynamic envelope of the shuttle cargo bay. However, since the drawings of the long spacer truss assembly have not yet been developed, the clearances between it and the cargo bay internal envelope are unknown. Thus, no displacement failure criterion was established. However, the maximum displacements at the corner points (joints) of the long spacer truss (fig. 2) have been calculated in support of future design development. The corners of the long spacer truss will be the points closest to the cargo bay envelope, and any interferences are expected to occur at those points.

The circular frequencies obtained from the normal mode analysis were compared to minimum allowable frequencies as shown in reference 2. For the combined weight of the long spacer truss and the IEA (less than 30 000 lb), the minimum frequency is specified as 6.0 Hz. A cargo element will not necessarily fail if the minimum frequency is not met, but a frequency of less than 6.0 Hz does indicate a potential need for a control-structure interaction study. This study is done primarily to analyze the effect of the cargo element frequency on the control of the space shuttle during flight. If an element fails to meet the frequency requirement, but does not interact with control of the shuttle, the design may be acceptable. However, to avoid a control-structure interaction study at this early stage of the design work, we decided to consider the minimum frequency requirement as a failure criterion.

Another possible failure criterion is the buckling of the long spacer under the launch loads. However, since the outer diameter and thickness of all members are the same, we determined that any possible local buckling could be avoided easily by adding local stiffeners, and that any system buckling could be avoided by adding more truss bays or shear panels. Therefore, because of the preliminary nature of this feasibility study, no buckling analysis was performed.

## TEST CRITERIA

The strength margins of safety calculated in this study are influenced by the option selected for conducting a static test. NASA Lewis Research Center used the second option of the three given in reference 4:

> ". . . static test the payload to 1.2 times the design limit load. This test shall verify the static analytical math model such that the design can be verified for ultimate load capability by a detailed and formal stress analysis. The ultimate design factor of safety for the analysis shall be 1.4 or greater."

The requirements in reference 4 were developed to ensure that no damage will result to the STS, regardless of whether its payload can or cannot function after launch. Because the truss spacers serve functions, such as supporting the mobile transporter rail which may have small tolerances, no yielding can be tolerated. An additional safety factor of 1.1 was assumed on the yield strength of the material to eliminate the possibility of any yielding. Therefore, the margin of safety will have to be calculated from the lower of the value derived by dividing the ultimate strength of the material by 1.4 or that derived by dividing the yield strength of the material by 1.1.

## STRUCTURAL ANALYSIS

During launch, loading in the shuttle cargo bay occurs through gravitational accelerations imposed on the structure in six directions. For this analysis, the acceleration loads were obtained from reference 5 (see table I). To ensure that the maximum stresses and displacements could be determined, the loads in all six directions had to be combined in all possible combinations. NASTRAN (ref. 1) was used for the structural analysis. The method chosen was a static analysis solution with superelement and substructure capability.

## NORMAL MODE ANALYSIS

Prior to the normal mode analysis, one of the modeling checks done on the finite-element model was recovering and checking the rigid body modes to ensure that there was no artificial grounding in the finite-element model. The finite-element model of the long spacer truss was isolated from the IEA finite-element model, and freed, that is, all the shuttle constraints at trunnions were removed from the finite-element model of the long spacer truss. For the purpose of normal mode analysis, NASTRAN was again used. The method chosen was a normal mode analysis solution with superelement and substructure capability.

## DISCUSSION OF ANALYSES

The structural analysis of the long spacer truss combined with the IEA began with an analysis of the baseline design shown in figure 3. The baseline design of the long spacer truss contains four longerons and will be referred to as the four-longeron truss. The assembly of the long spacer truss and the PVM is referred to as the 14th Mission Build (MB14) cargo element. The load boundary condition applied to the structural model consisted of 136 independent transient load events. The magnitude of these transient load events was increased by 50 percent to account for model uncertainties. Displacement boundary conditions applied to the structural model are: (1) constraining the IEA's and the spacer's keel trunnions in the shuttle's lateral direction, (2) constraining the IEA's longeron trunnions in the shuttle's longitudinal and vertical directions, and (3) constraining the long spacer's longeron trunnions in the shuttle's vertical direction (fig. 4).

In an effort to determine if the load and displacement boundary conditions were applied to the MB14 cargo element finite-element model correctly, six additional load cases were applied to the structural model. These loads consisted of 1.0 g in three translational directions and 1.0 rad/sec$^2$ in three rotational directions. The data recovered for this portion of the analysis were the loads at constraint points and the deformation plots. The deformation plots, figures 5(a) to (f), indicated that the MB14 structure deformed in the direction of loading.

To find out whether there was any artificial grounding in the structural model of the long spacer truss, this portion of the model was separated from the MB14 cargo element, and a normal mode analysis was performed with all the trunnions freed. Six rigid body frequencies and modes were extracted from this analysis. All rigid body frequencies were near zero and had an order of magnitude of $10^{-5}$ to $10^{-6}$ Hz. This analysis showed that no artificial grounding was present in the model.

The first structural analysis resulted in negative margins of safety, as defined in this study, under liftoff and landing loads in the forward bulkhead area. To determine how to strengthen these areas, the stress and deformation plots for one of the most severe liftoff load cases were extracted and examined (figs. 6(a) and (b)). A severe load case is defined here as a case in which the maximum stresses occur. The stress plots indicated a significant concentration of high stresses around the forward bulkhead. The red areas in figure 6(a) possess the maximum positive stress, and the blue areas possess the maximum negative stress. As an example, the maximum stress in a four-longeron truss is approximately 40 000 psi. Comparing this stress to an allowable stress of 30 000 psi results in a negative margin of safety of –0.25. The deformation plots indicated a large slope of deformation at the interface of the IEA and the long spacer truss. The stress and deformation plots indicated that two areas of the long spacer truss needed to be modified, namely, the forward bulkhead and the interface of the IEA and the long spacer truss.

In order to increase the overall stiffness and strength of the long spacer truss, and thus to decrease the stresses, we first increased the outer diameters of the structural members from 2.5 in. to 3.0 in. But the stresses of the long spacer truss increased. This increase in the stress was because the additional material increased not only the strength, but also increased the mass in a more severe manner. The next step that could have been taken was to decrease, one by one, the stresses in the finite elements with negative margins. However, this type of approach would have been time consuming, and would have caused the structural members and the joints to be different, and this was not desirable. In order to save cost and manufacturing time, the joints and the structural members should have a common design. Therefore, we decided it was more convenient to conceptually redesign or remodel the forward bulkhead, eliminating all the high stress areas and elements at the same time. In order to reconfigure change in the forward bulkhead, the deformation plot in the forward bulkhead (fig. 6(b)) was examined first. It revealed an independence between the two halves of the bulkhead. This meant that the two halves of the bulkhead were not sharing the loads. A stiffer bulkhead was required.

As previously mentioned, the deformation plots of the MB14 cargo element revealed a relatively large slope of deformation at the IEA-long spacer truss interface. The large slope of deformation in the long spacer truss members is not desirable structurally, and indicates that the IEA-long spacer truss interface loads are not transmitted in an efficient manner. In fact, when the loads at this interface were calculated, the moments were on the order of 40 000 in.-lb. This can be considered high and could be detrimental to a 2.5-in. hollow tube insofar as buckling is concerned. In order to decrease the loads at the IEA-long spacer truss interface, a transition structure, BAY1 (fig. 2), needed to be designed.

Prior to redesign of the long spacer truss, the following ground rules were devised:

(1) Keep a positive margin of safety at the forward bulkhead.
(2) Maintain efficient load transfer at the IEA-long spacer truss interface.
(3) Don't allow the weight of the long spacer truss to exceed that of the four-longeron truss.

(4) Ensure that the design of the short spacer truss and the long spacer truss are similar (the commonality with the short spacer truss will reduce the cost of manufacturing and the learning curve).

(5) Make the loads of the MB14 configuration of the IEA similar (±15 %) to the loads of the MB01 (1st Mission Build cargo element) configuration of the IEA (adherence this ground rule will make redesign of the IEA less necessary).

Using these ground rules, the bay closest to the IEA, BAY1 (fig. 2), was modeled as a transition structure similar to the design of the MB01 cargo element. This transition structure would redistribute the loads and eliminate the relatively large deformation at the IEA-long spacer truss interface. The structure of BAY1 would consist of 10 structural members of adjustable lengths. The members should have either universal joints or ball joints at one of their ends for assembly purposes. Such joints combined with the adjustable length of the structural members would allow preloading of BAY1 and thereby eliminate any mechanical play in the structural members of BAY1. Mechanical play in structures under dynamic loading is not desirable since it introduces nonlinearities in the load path and the structures may come loose during test or flight. The combination of the adjustable lengths and the flexible joints of the structural members of BAY1 would also eliminate the need to match drill the long spacer truss interface to the IEA during assembly, which would be beneficial. In addition, the following steps were taken:

(1) All six attachment points at the IEA-long spacer truss interface were used in order to redistribute and reduce the loads at the interface. All six attachment points were used for the MB01 configuration of the IEA, but only four of them had been planned to be used for the MB14 configuration of the IEA.

(2) Two longerons were added to the long spacer truss at BAY2 to make this bay hexagonal and to make the transition to BAY2 more convenient since all six of the IEA's attachment points were used to combine the long spacer truss and the IEA.

(3) BAY2 was deepened in the STS vertical direction to increase its effective moment of inertia and thus its bending and torsional stiffness. The addition of the stiffness reduces the deformation.

(4) The two added longerons of BAY2 and BAY3 were connected directly to the longeron trunnions of the forward bulkhead to reduce loads in the bulkhead. BAY3 was modeled as a transition structure to transfer the launch loads to the forward bulkhead in the most efficient manner.

(5) BAY3 was deepened in the STS vertical direction (similar to BAY2) to make it compatible with BAY2 and to increase its effective moment of inertia and thus its bending and torsional stiffness.

(6) The forward bulkhead was completely redesigned to eliminate the independence between its two halves. As mentioned before, this independence does not allow load sharing, and lack of load sharing causes relative overloading of one side of the bulkhead. The forward bulkhead was replaced with a stiffer bulkhead (fig. 7) consisting mainly of I-beams. The dimensions of the I-beams have not been structurally optimized, so there is room for increased structural efficiency and weight reduction in the bulkhead.

The long spacer truss with these modifications is referred to as the six-longeron truss (fig. 8).

## RESULTS

Both the four-longeron and the six-longeron trusses were varied by selecting different diameters for the members. Structural and normal mode analyses of both configurations were performed. In each structural or normal mode analysis, the outer diameter and the thickness of all structural members were kept the same.

The normal mode analyses for both configurations of the MB14 cargo element (four-longeron truss and six-longeron truss) showed first natural frequencies greater than 6 Hz (see table II). Therefore, the natural frequency requirement was met. Figures 9 to 13 show the first 5 typical mode-shape plots of the four-longeron truss combined with the IEA. Figures 14 to 18 show analogous plots for the six-longeron truss combined with the IEA. The first 2 or 3 modes in each configuration of the MB14 cargo element represent the system level modes where the entire cargo element is in motion. Similar to the MB01 cargo element, the 10.2-Hz frequency applies to the solar array assembly when this assembly is in motion. Table II shows the natural frequencies for different configurations of the long spacer truss with different member sizes.

The structural analyses of the six-longeron truss with 1.0- and 2.0-in. diameter members showed positive margins of safety. The smaller sized members are more desirable from the viewpoint of weight and stress, but at too small a certain diameter the deformation of the six-longeron truss should increase. Such an increase could cause interference with the dynamic envelope of the shuttle cargo bay. The deformations of the six-longeron truss with 1.0-in. members were higher in magnitude than of those with 2.0-in. members because of higher member flexibility. A typical stress plot and deformation plot for the six-longeron truss are shown in figure 19. Figure 19(a) shows that the magnitude of stresses for the six-longeron truss are substantially lower than the stresses for the four-longeron truss, and that there are no stress concentration areas. The margins of safety for the four-longeron truss concept appeared to be negative regardless of member sizes.

The loads at the IEA trunnions for various four- and six-longeron trusses are shown in table III. In general, the MB14 loads are higher than the MB01 loads. The MB01 loads may be lower because the MB01 truss is more rigid in both bending and torsional directions. Without determining the load limits for major interfaces of both the MB01 and MB14 configurations of the IEA, it would be impossible to judge clearly why one set of loads is higher than another set. The task of making this determination was beyond the scope of this study. The MB14's cargo element interface (the interface of the cargo element and the shuttle) loads are within ±15 percent of the MB01's cargo element interface loads. Therefore, the ground rule presented in the DISCUSSION OF ANALYSES section of this report is satisfied.

The weight summary of the four-longeron truss and the six-longeron truss is shown in table IV. The weight of the six-longeron truss, regardless of member size, is less than or equal to the baseline four-longeron truss. Although the weight of the six-longeron truss increased in BAY1, BAY2, and BAY3, the weight of the forward bulkhead decreased by an approximately equal amount.

## CONCLUDING REMARKS

The normal mode analysis indicates that, regardless of the configuration and member sizes of the long spacer truss, the minimum frequency requirement is always met.

The structural analysis indicates that the minimum margin of safety for the four-longeron truss concept appears to be negative in the forward bulkhead area.

The structural analysis indicates that the minimum margin of safety for the six-longeron truss is always positive but, as the member sizes decrease, the deformation of the entire structure may cause interference between the cargo element and the STS cargo bay. The IEA's trunnion loads are higher when the IEA is coupled with the six-longeron truss rather than the four-longeron truss. However, the additional IEA trunnion load should not cause a redesign of the IEA as long as the weight of the MB14 cargo element remains the same, since as the design matures the 1.5 model uncertainty factor can be reduced. A reduction in this factor will reduce the IEA trunnion load.

The six-longeron truss appears to be a more promising structure than the four-longeron truss since it offers a positive margin of safety and more volume in its BAY2, which can be used for resupply storage. It also meets all the self-imposed ground rules on commonality with the short spacer truss, and lower loads at the interface of the long spacer truss and IEA.

## REFERENCES


1. Joseph, J.A.: MSC/NASTRAN Application Manual. The MacNeal-Schwendler Corp., 1984.

2. National Space Transportation System. NSTS 20052, Vol. 8: Structural/Mechanical Interfaces and Requirements. NASA Johnson Space Center, 1988.

3. Military handbook. Metallic Materials and Elements for Aerospace Vehicle Structures. MiL-HDB-5, June 1987.

4. National Space Transportation System. NSTS 14046, Rev. B: Payload Verification Requirements. NASA Johnson Space Center, 1982.

5. National Space Transportation System. NSTS 07700, ICD-2-19001, Rev. K: Shuttle Orbiter/Cargo Standard Interfaces. NASA Johnson Space Center, 1991.


TABLE I.—CARGO LIMIT FOR PRELIMINARY DESIGN-LOAD FACTORS AND ANGULAR ACCELERATIONS IN TRANSIENT FLIGHT EVENTS
[See ref. 5.]

| Flight event | Load factor, L, g | | | Angular acceleration, A, rad/sec$^2$ | | | Cargo weight |
|---|---|---|---|---|---|---|---|
| | $L_x$ | $L_y$ | $L_x$ | $A_x$ | $A_y$ | $A_z$ | |
| Ascent: | | | | | | | |
| Liftoff | −0.2<br>to<br>−3.2 | ±1.4 | ±2.5 | ±3.7 | ±7.7 | ±3.1 | Up to 65 klb<br>(29 484 kg) |
| Descent: | | | | | | | |
| Landing | 1.5<br>to<br>−1.7 | ±1.0 | ±3.6 | ±4.8 | ±8.4 | ±3.2 | Up to 32 klb<br>(14 515 kg) |
| Emergency landing: | | | | | | | |
| Outside crew<br>Compartment | +4.5<br>−1.5 | +1.5<br>0 | +4.5<br>−2.0 | | | | |

TABLE II.—FREQUENCIES OF MB14 CARGO ELEMENT

| Number of longerons | Outer diameter, in. | Thickness, in. | Frequency, Hz | | | | |
|---|---|---|---|---|---|---|---|
| | | | $F_1$ | $F_2$ | $F_3$ | $F_4$ | $F_5$ |
| 6 | 1 | 0.25 | 6.27 | 6.41 | 7.83 | 10.20 | 10.43 |
| 6 | 2 | 0.25 | 6.33 | 8.20 | 10.20 | 10.50 | 11.43 |
| 4 | 2.5 | 0.25 | 7.29 | 9.55 | 10.21 | 10.50 | 11.75 |
| 4 | 2.5 | solid | 6.40 | 9.66 | 10.22 | 10.47 | 11.37 |

TABLE III.—IEA'S MAXIMUM ABSOLUTE VALUE TRUNNION LOADS

| Configuration | | | Load, klb | | |
|---|---|---|---|---|---|
| | | | Longeron trunnion direction | | Keel trunnion direction |
| Cargo element | Number of longerons | Outer diameters of members, in. | x | z | y |
| MB14 | 6 | 1 | 75 | 47.2 | 74 |
| MB14 | 6 | 2 | 76.4 | 49.0 | 76.2 |
| MB14 | 4 | 2.5 | 68.3 | 44.7 | 74.4 |
| MB01 | 6 | 2.5 | 63.2 | 43.8 | 82.2 |
| Maximum difference between MB14 and MB01 loads | | | 11.9% | 11.9% | 7.3% |

TABLE IV.—LONG SPACER TRUSS WEIGHT SUMMARY

| Configuration | | Weight, lb. |
|---|---|---|
| Number of longerons | Outer diameter of members, in. | |
| 6 | 1 | 2540 |
| 6 | 2 | 3102 |
| 4 | 2.5 | 3333 |

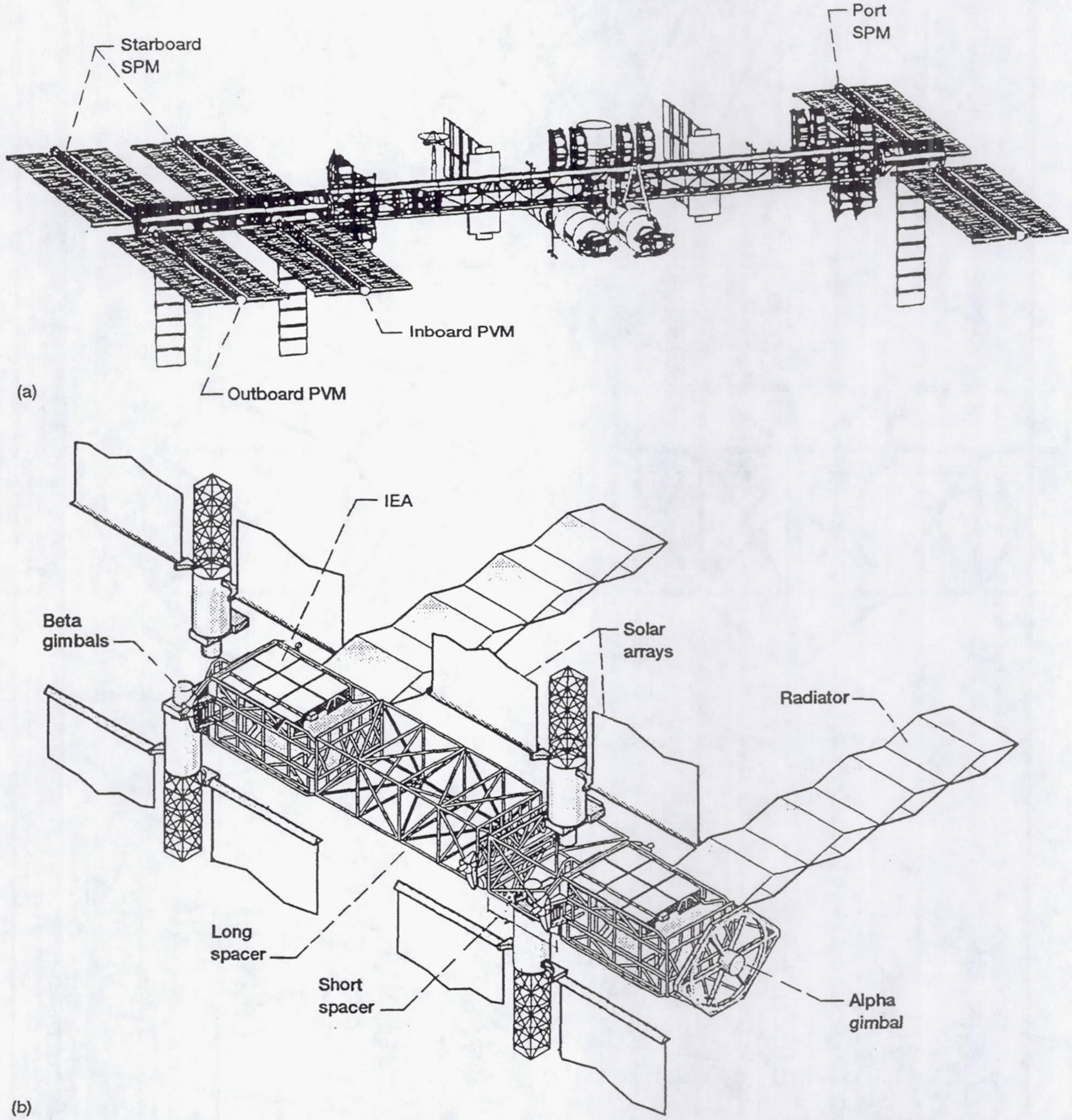



Figure 1.—Space Station Freedom. (a) Configuration for a permanently manned space station. (b) Starboard solar power module (SPM) configuration.

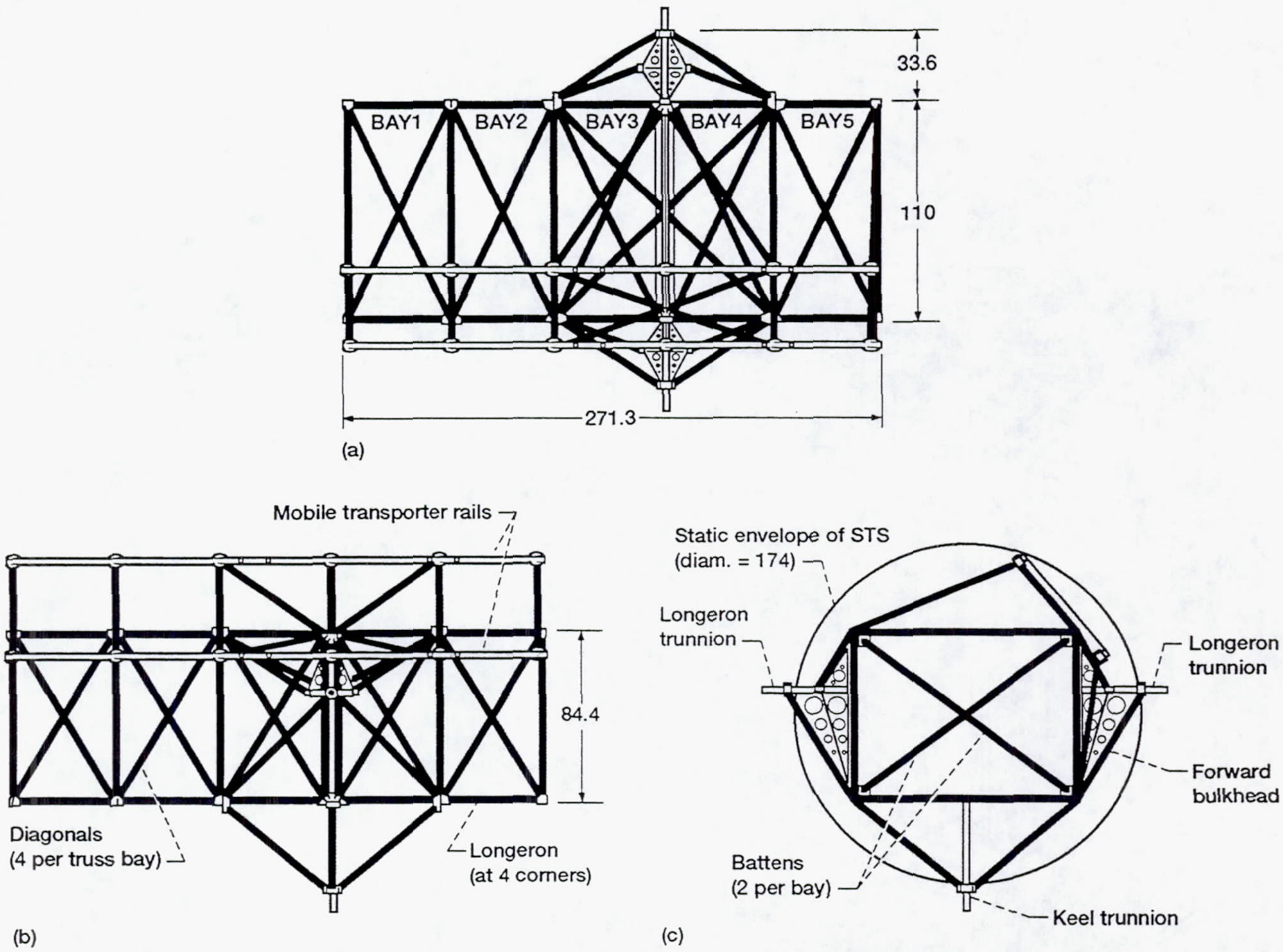



Figure 2.—Long spacer truss (dimensions are in inches). (a) Top view. (b) Plan view. (c) Side view.

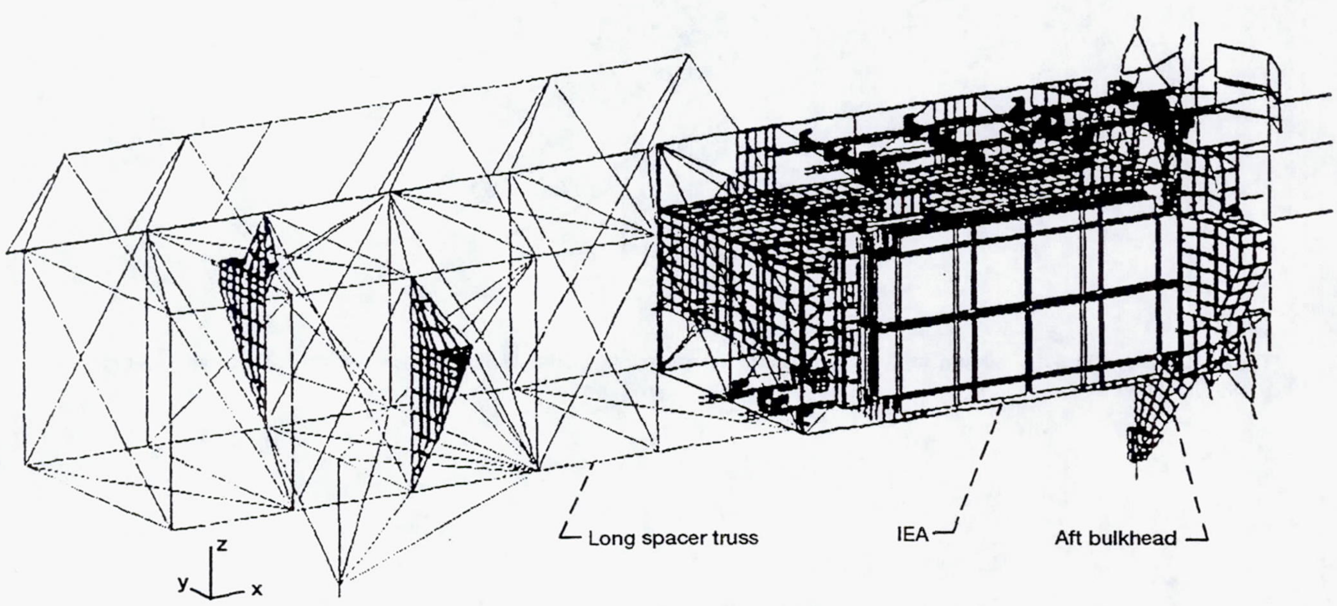



Figure 3.—Finite-element model of MB14 cargo element, long spacer truss coupled with IEA.

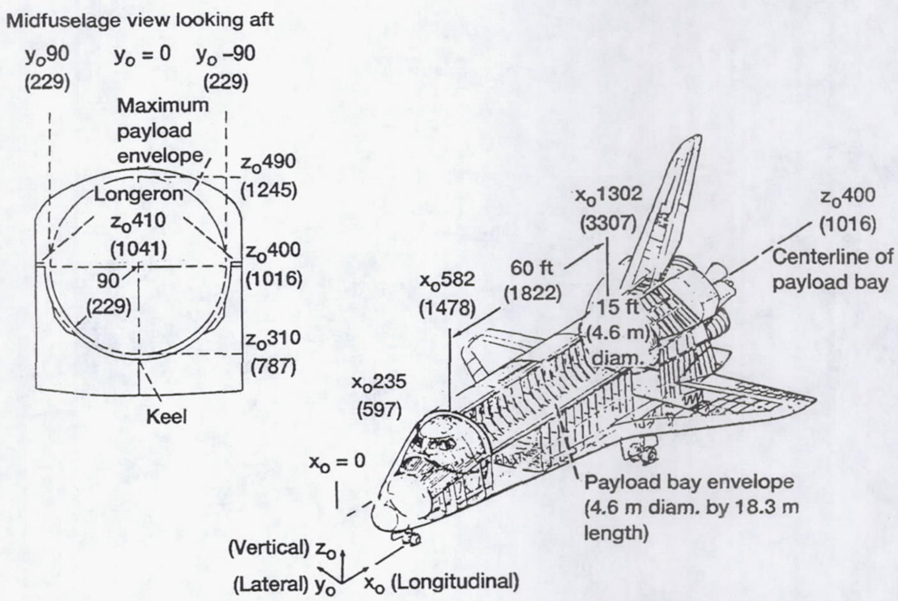



Figure 4.—Description of space transportation system (STS) axes (measurements given in inches (centimeters) unless otherwise indicated).

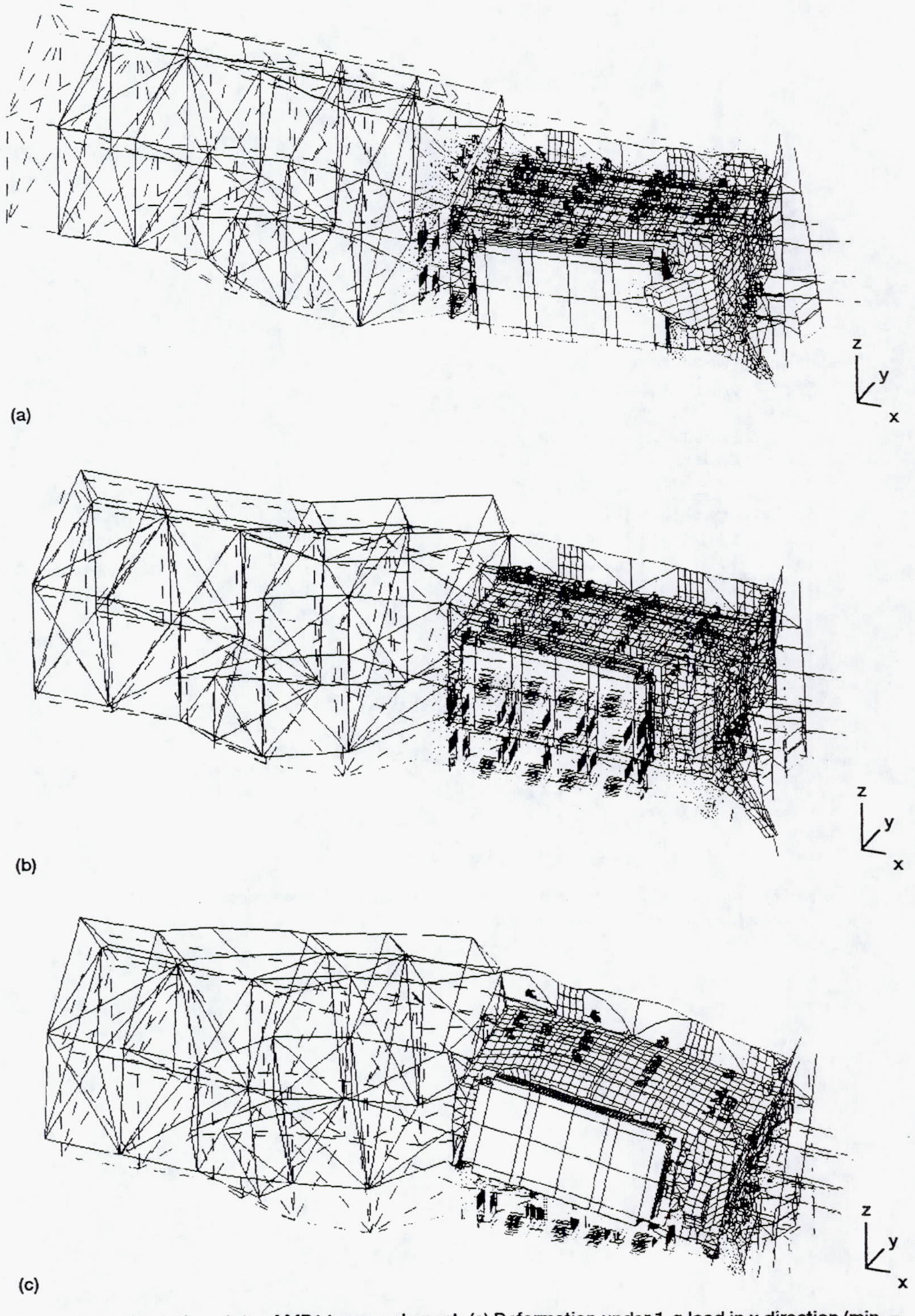



Figure 5.—Deformation plots of MB14 cargo element. (a) Deformation under 1-g load in x direction (min. = 0.000198 in.; max. = 0.10733 in.). (b) Deformation under 1-g load in y direction (min. = 0.001930 in.; max. = 0.38740 in.). (c) Deformation under 1-g load in z direction (min. = 0.002515 in.; max. = 0.138924 in.).

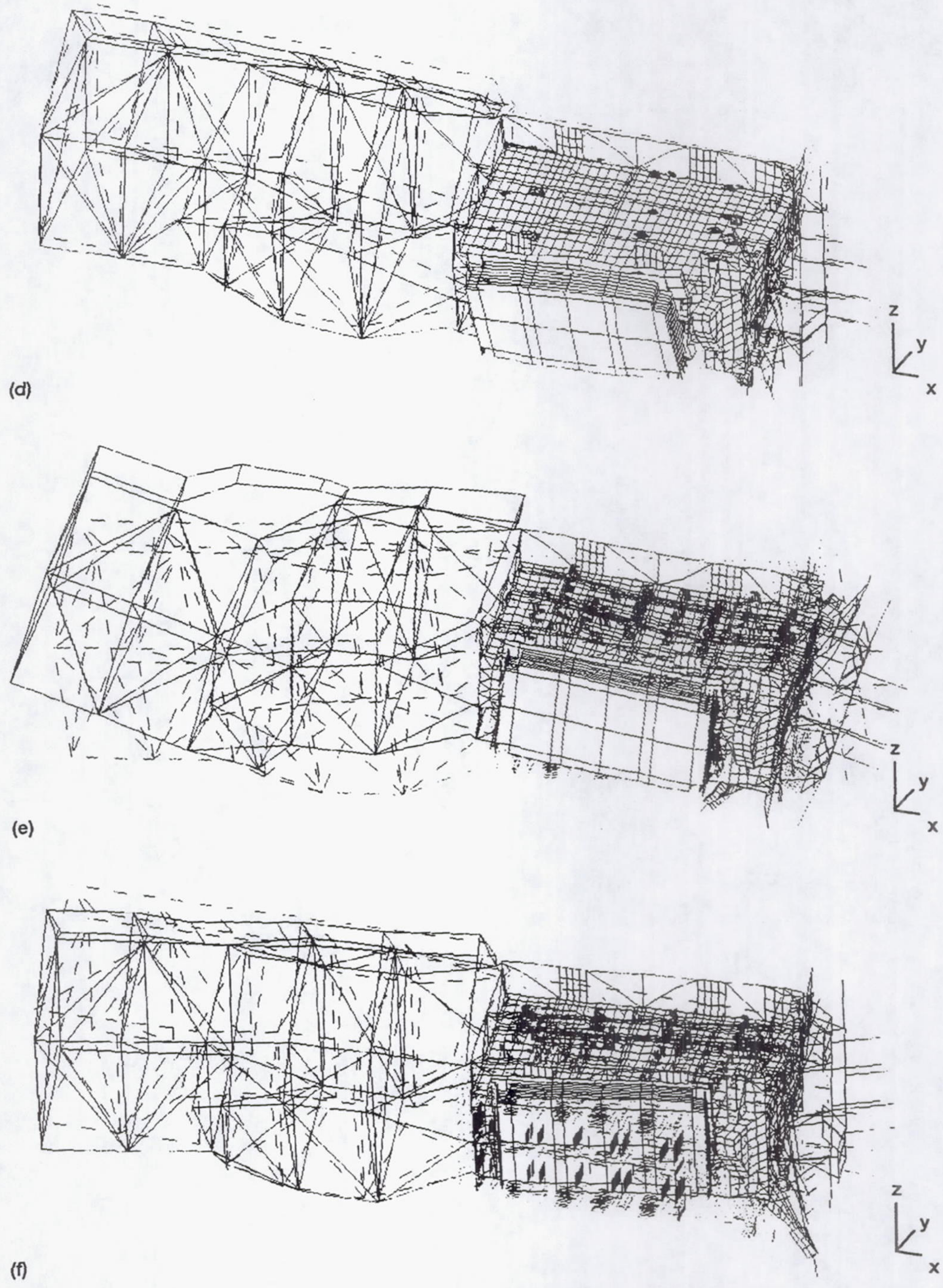
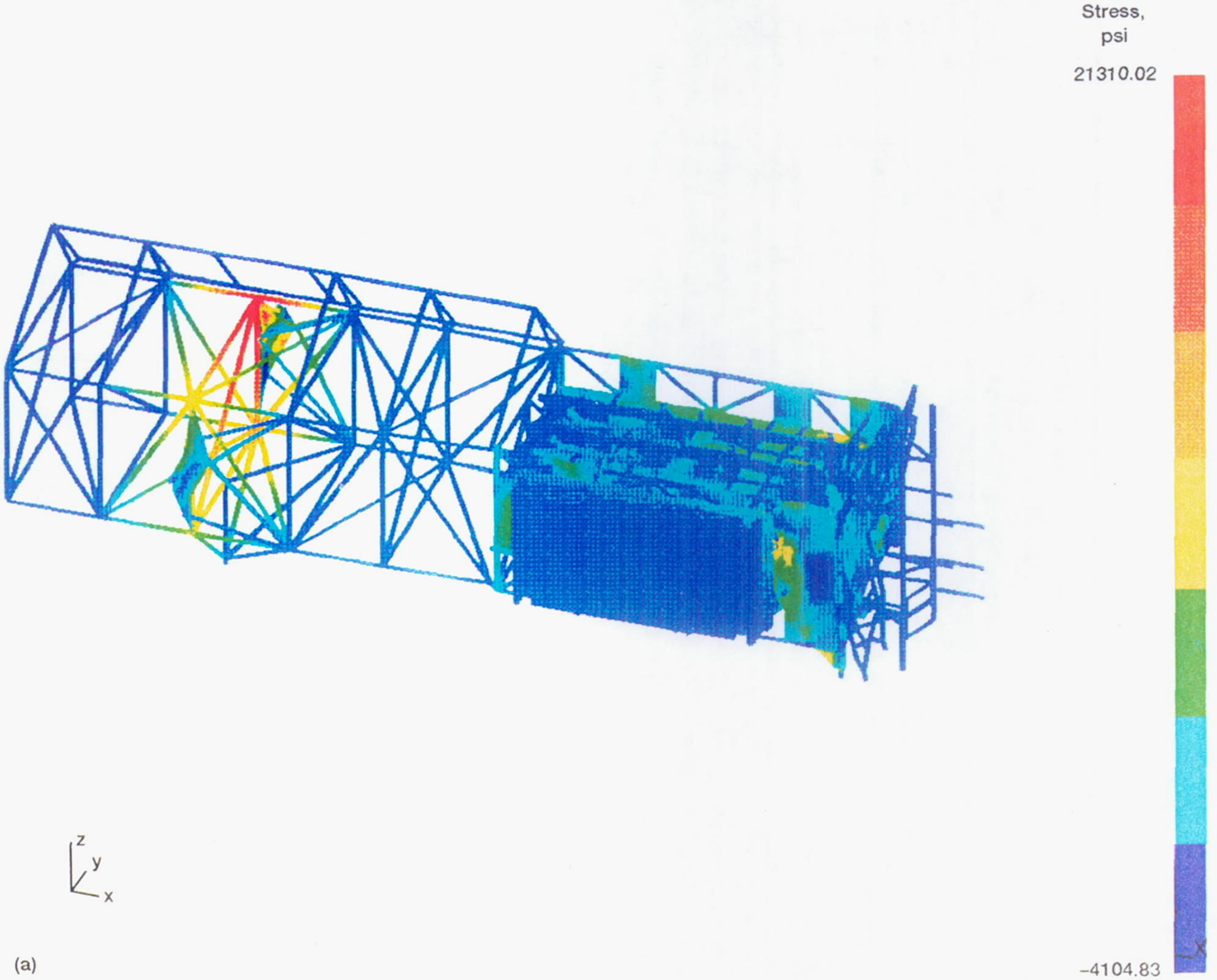
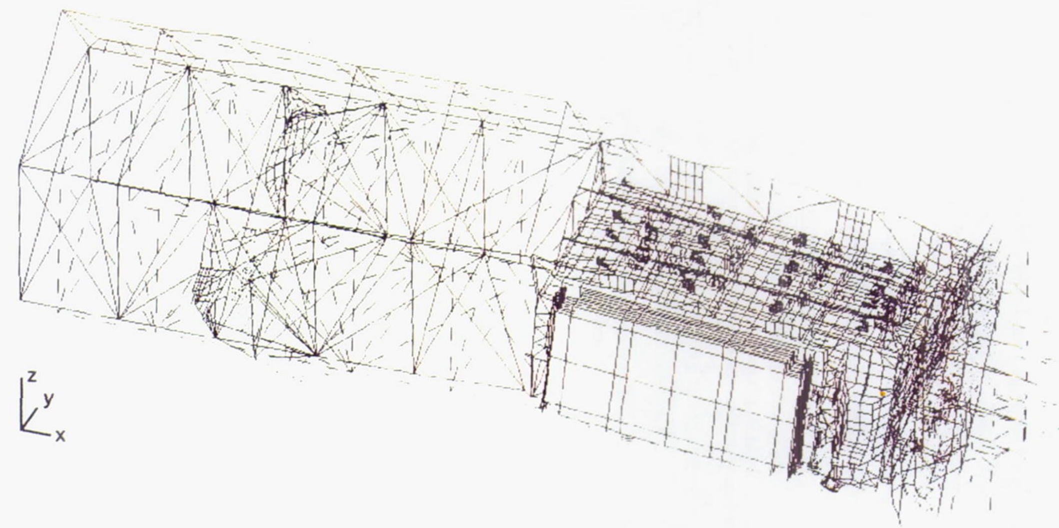



Figure 5.—Concluded. (d) Deformation under 1-rad/sec$^2$ load around x axis (min. = 0.0000728 in.; max. = 0.020833 in.). (e) Deformation under 1-rad/sec$^2$ load around y axis (min. = 0.000278 in.; max. = 0.027539 in.). (f) Deformation under 1-rad/sec$^2$ load around z axis (min. = 0.000418 in.; max. = 0.007398 in.).




(a)




(b)

Figure 6.—Most severe liftoff load case of MB14 cargo element with four-longeron truss. (a) Stress plot. (b) Deformation plot (min. = 0.200375 in.; max. = 1.51 in.).

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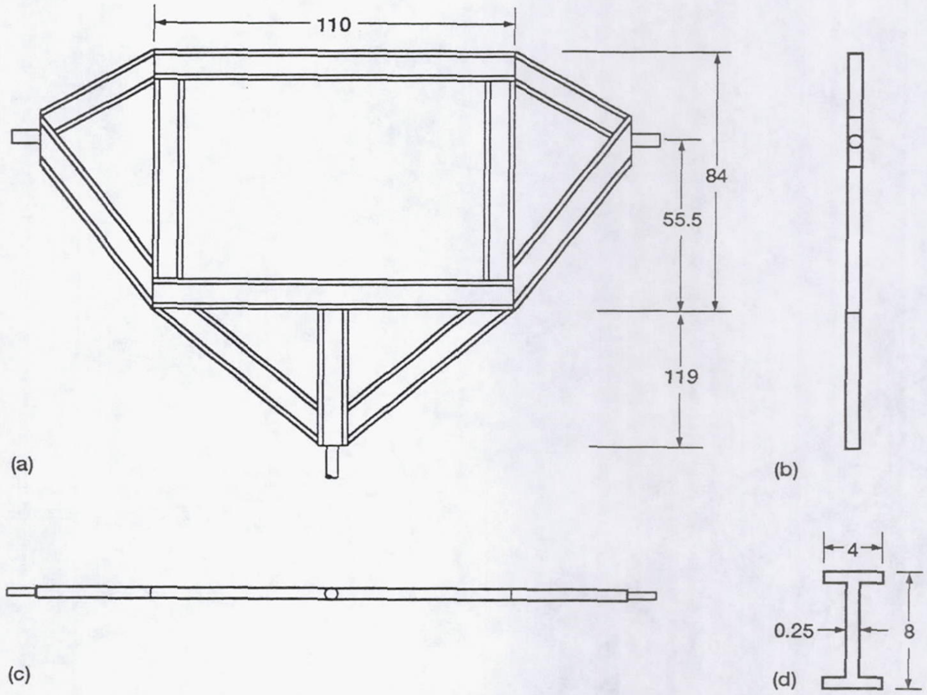


Figure 7.—Bulkhead of six-longeron truss (dimensions are in inches). (a) Front view. (b) Side view. (c) Top view. (d) Typical cross section of the bulkhead.

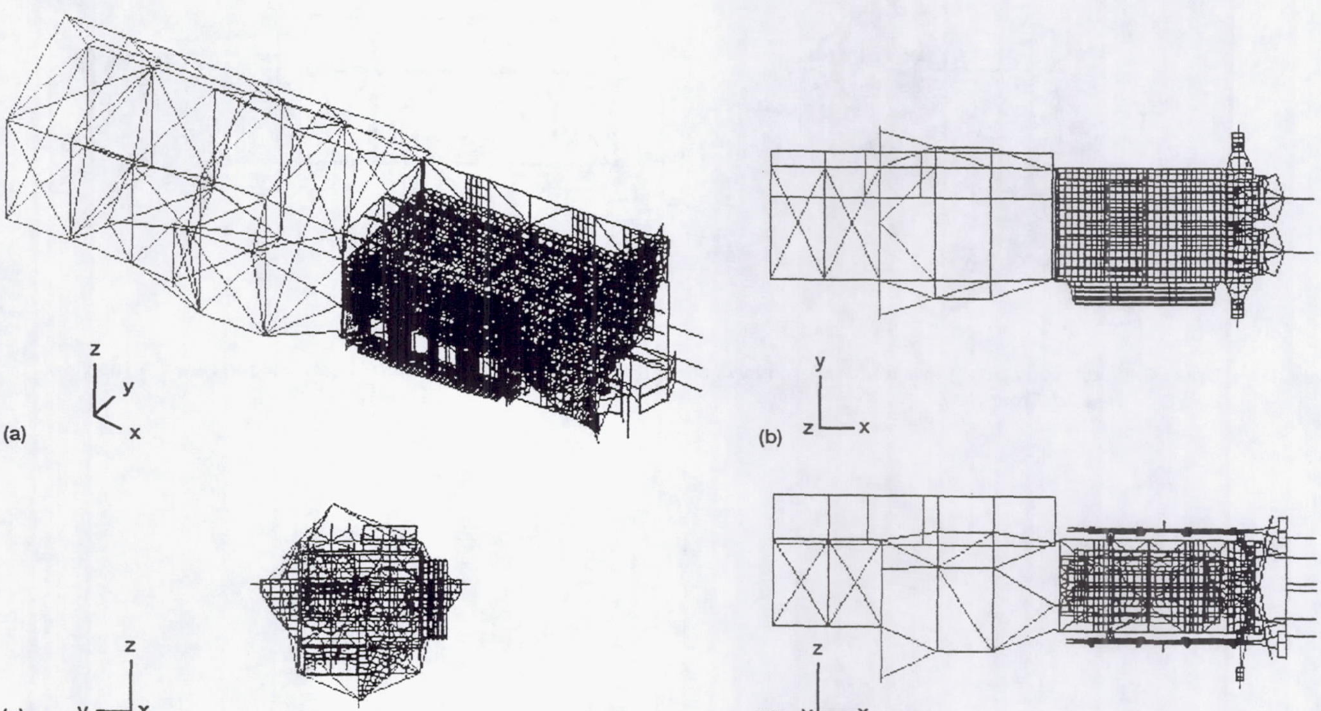


Figure 8.—Undeformed plot of six-longeron truss combined with the IEA. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

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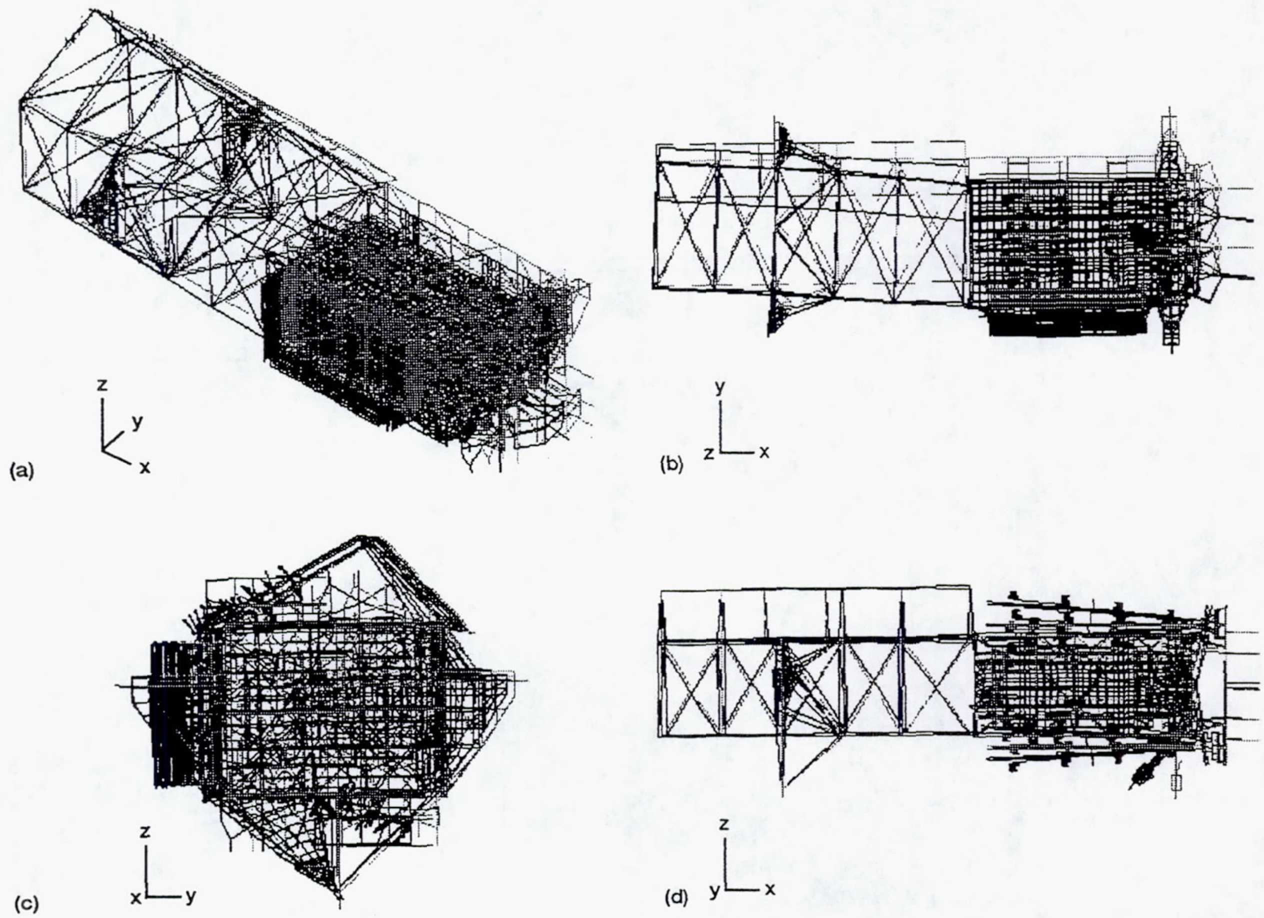



Figure 9.—First mode plot of five: four-longeron truss combined with the IEA at 7.2880301 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

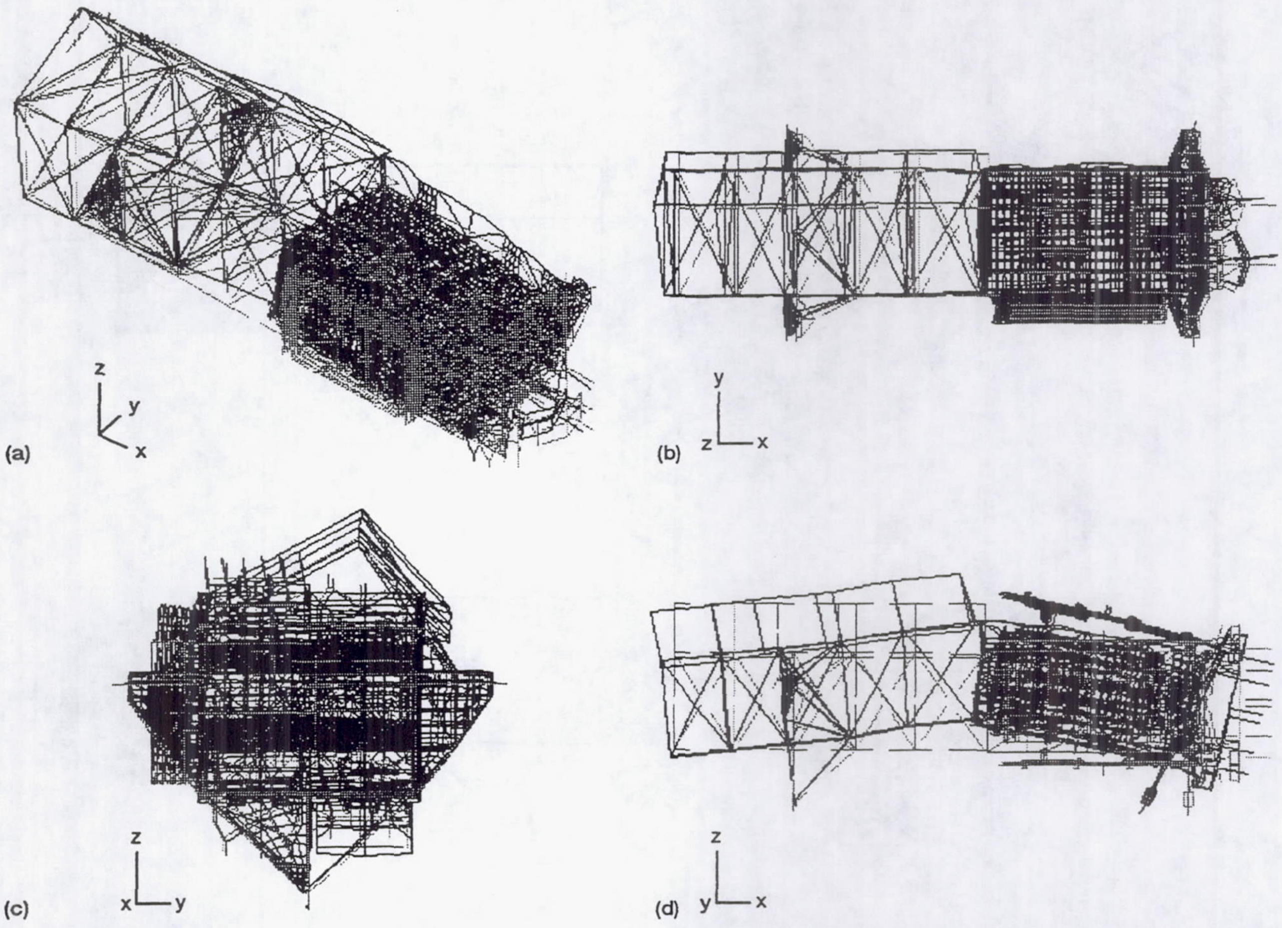


Figure 10.—Second mode plot of five: four-longeron truss combined with the IEA at 9.553970 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

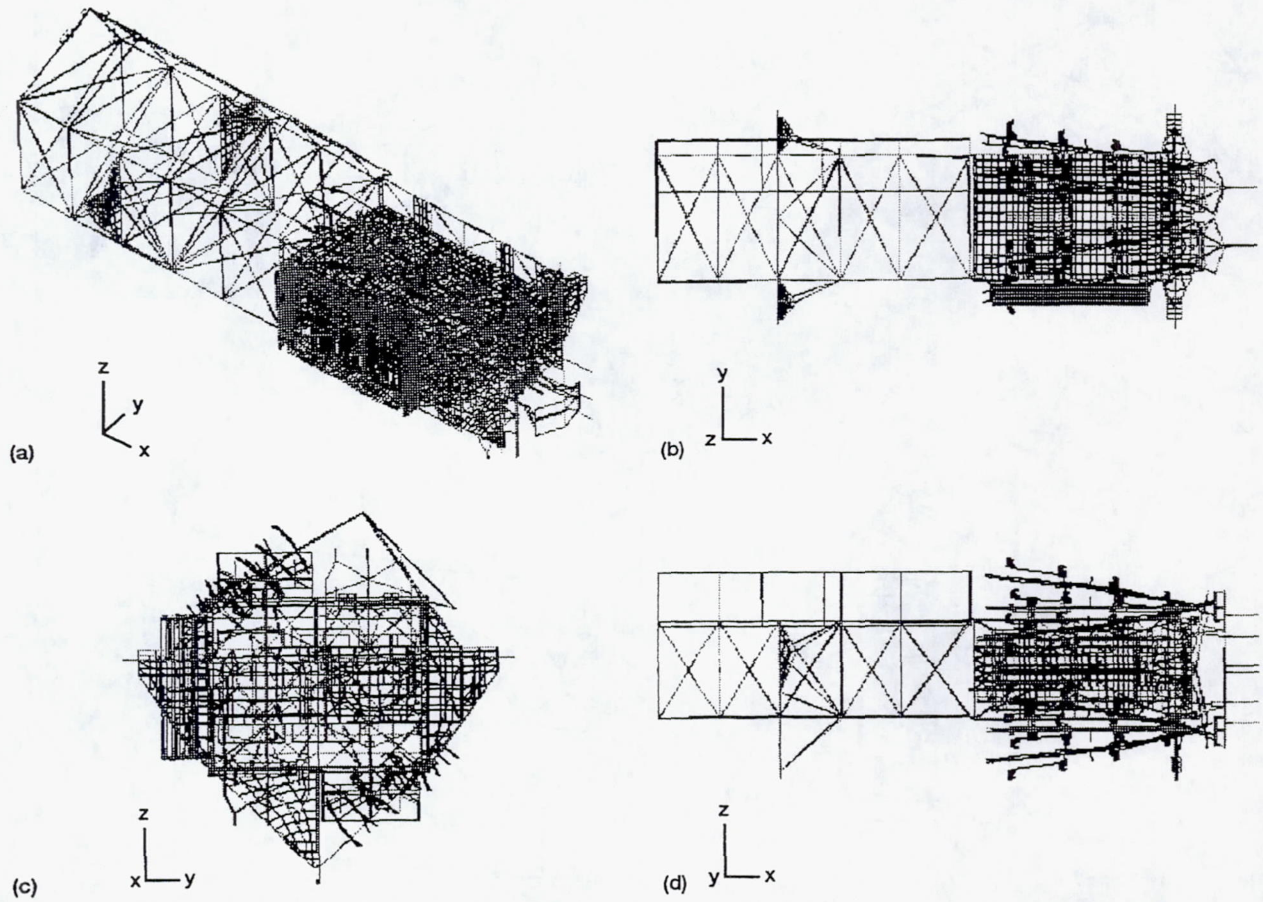



Figure 11.—Third mode plot of five: four-longeron truss combined with the IEA at 10.2146 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

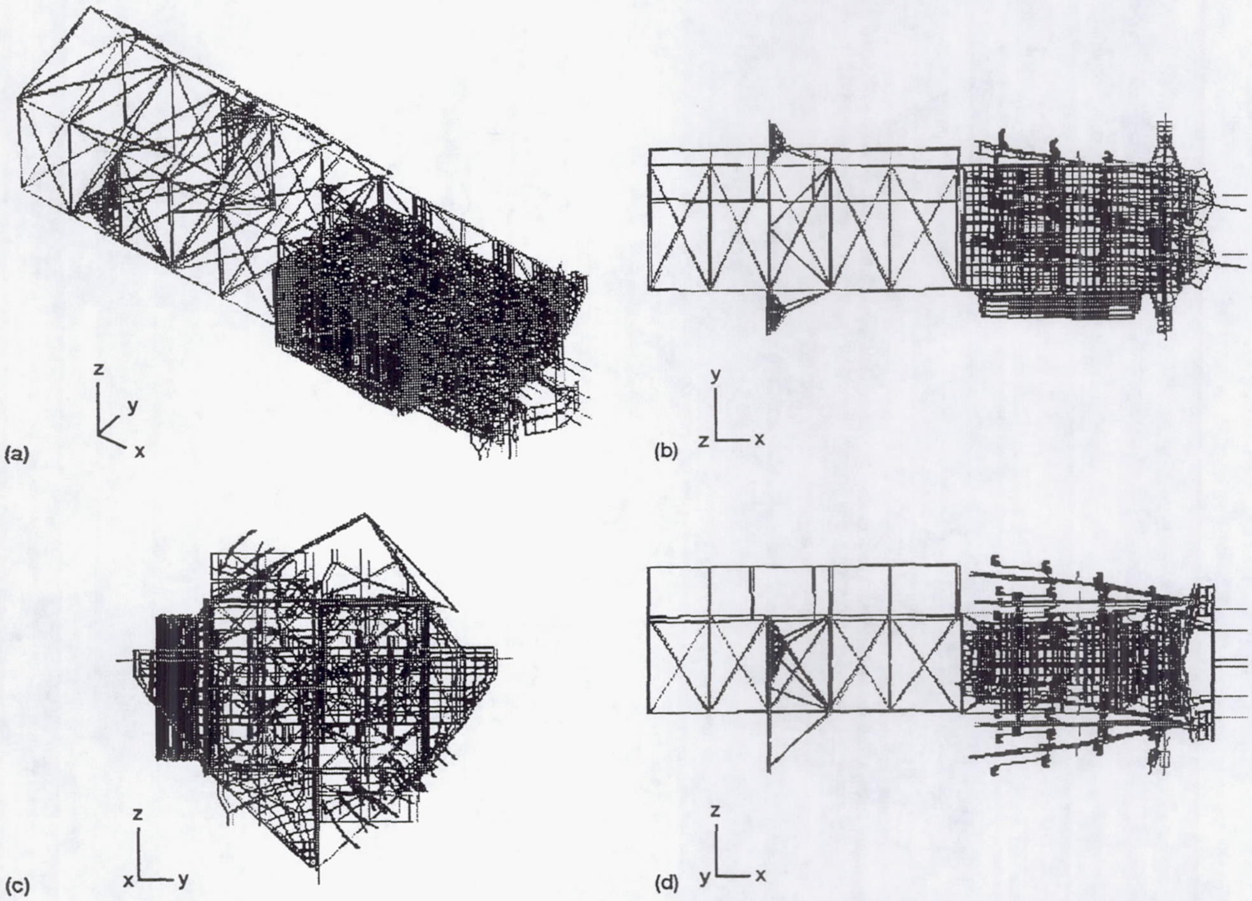



Figure 12.—Fourth mode plot of five: four-longeron truss combined with the IEA at 10.503100 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

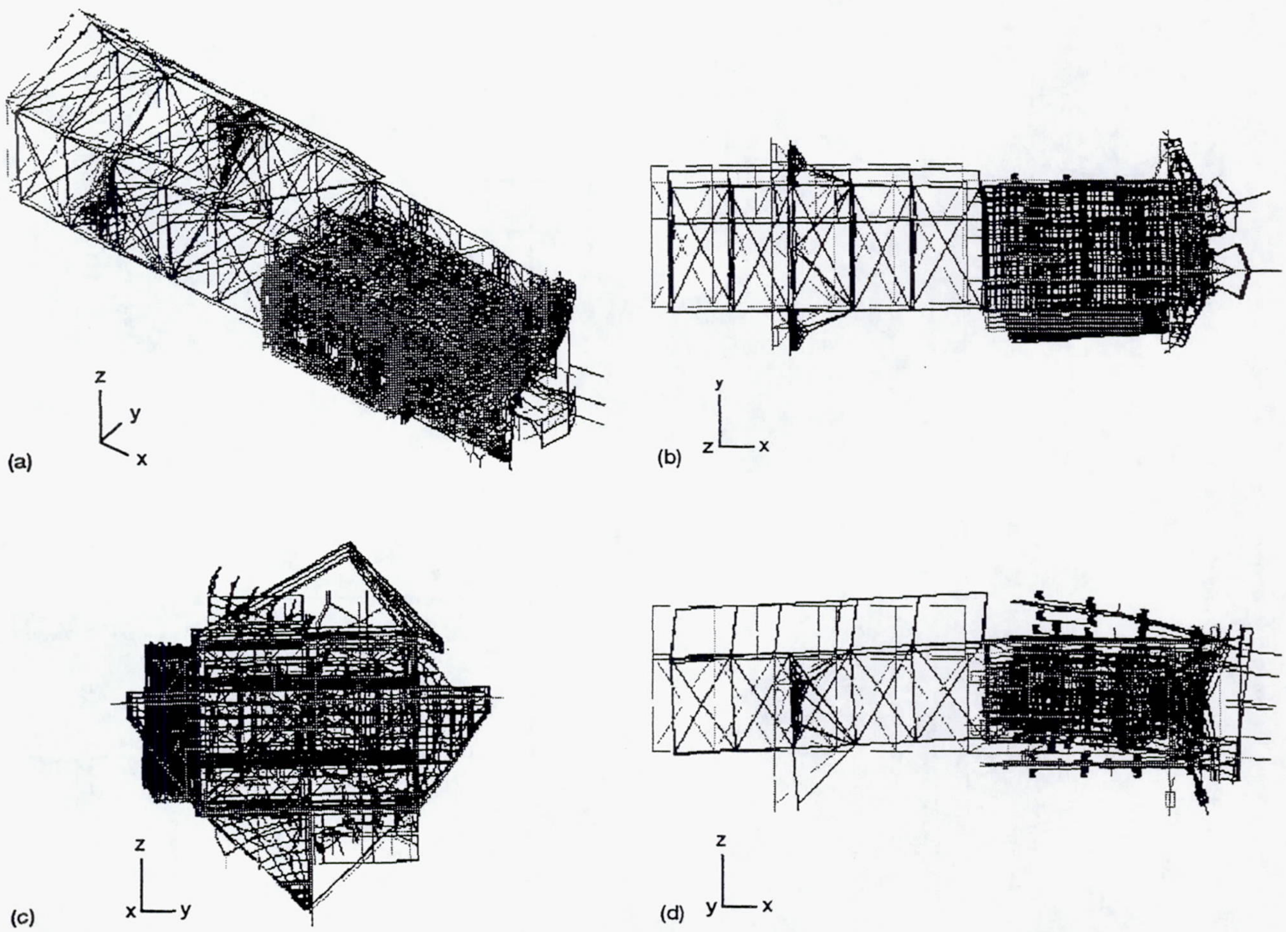



Figure 13.—Fifth mode plot of five: four-longeron truss combined with the IEA at 11.7483 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

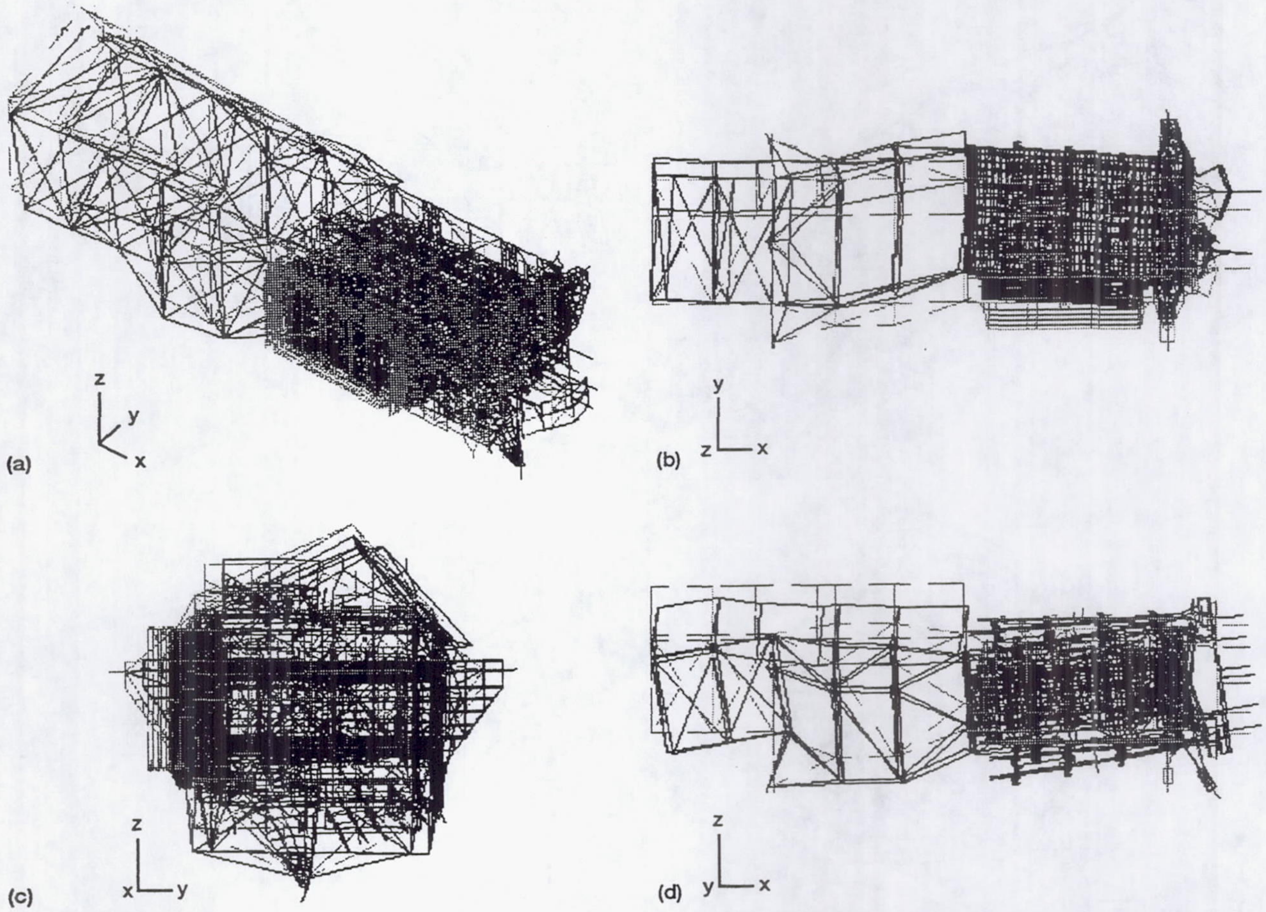



Figure 14.—First mode plot of five: six-longeron truss combined with the IEA at 0.27758 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

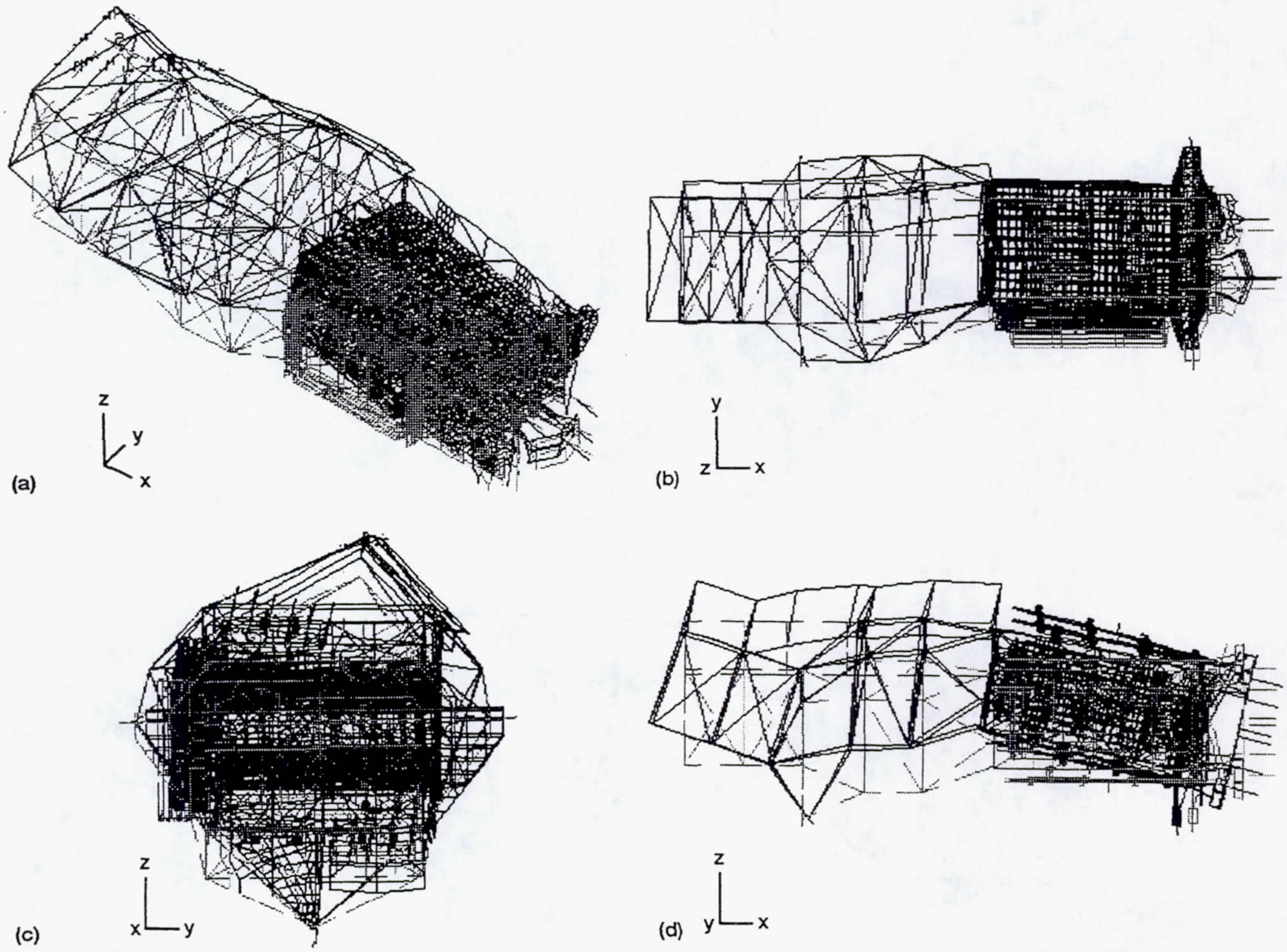



Figure 15.—Second mode plot of five: six-longeron truss combined with the IEA at 0.41207 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

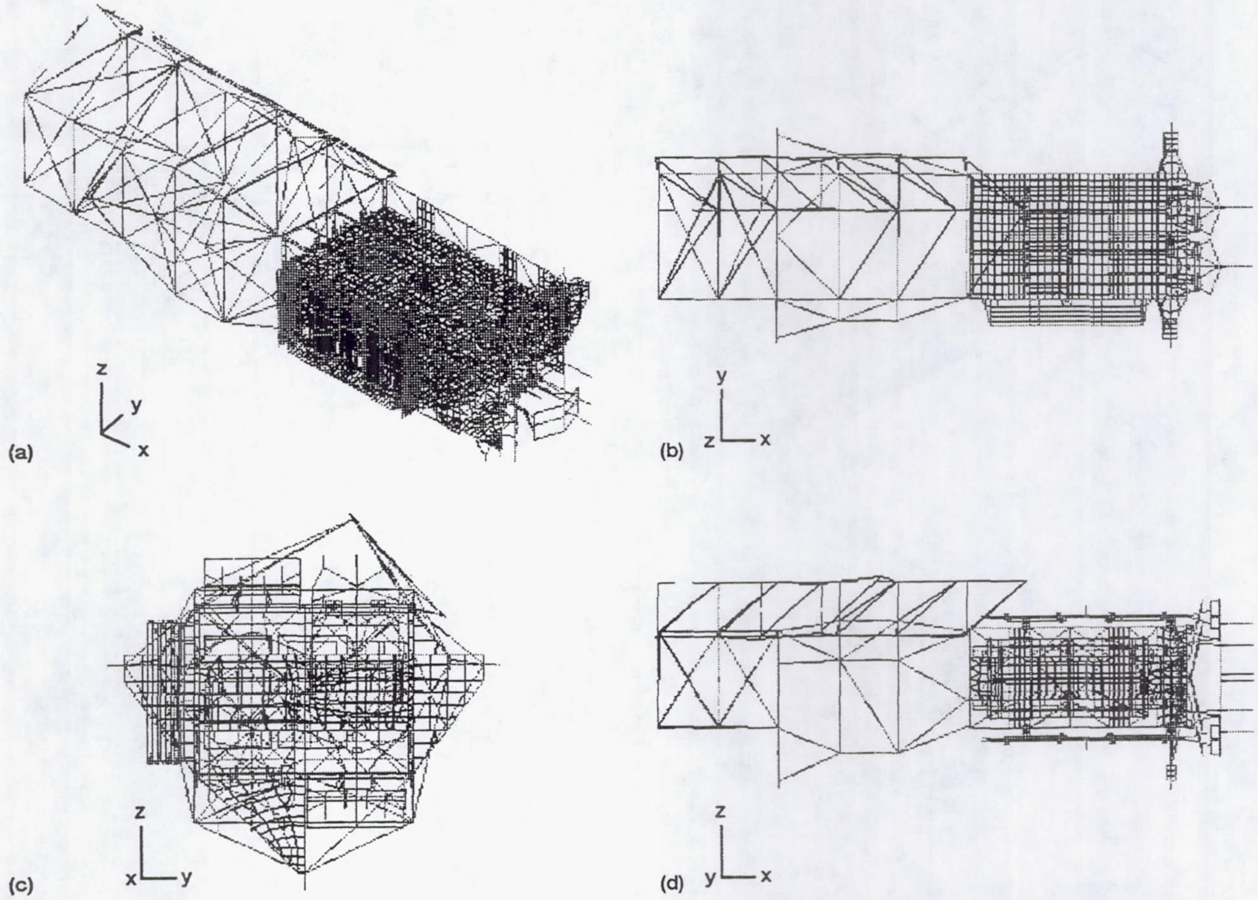



Figure 16.—Third mode plot of five: six-longeron truss combined with the IEA at 7.83105 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

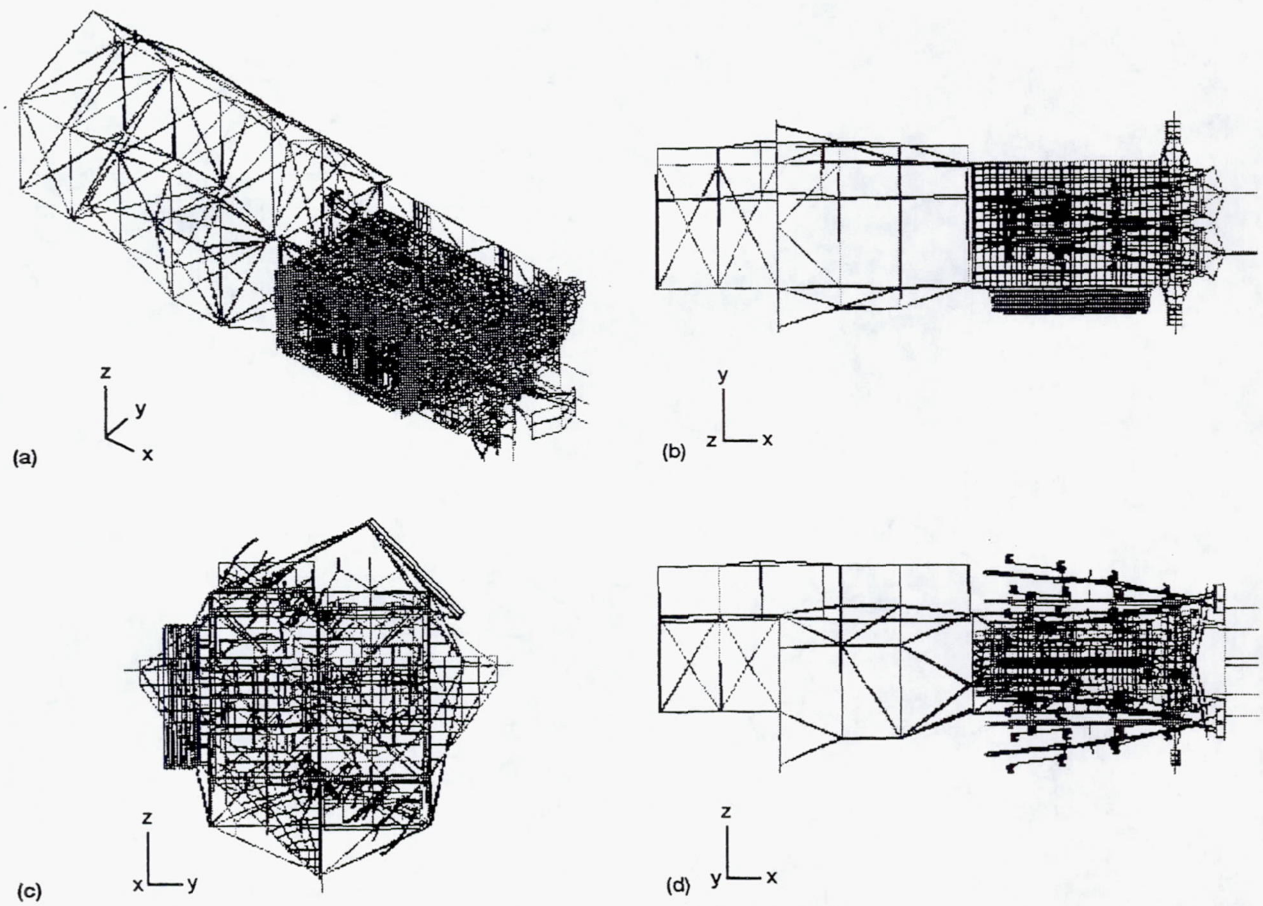



Figure 17.—Fourth mode plot of five: six-longeron truss combined with the IEA at 10.195500 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

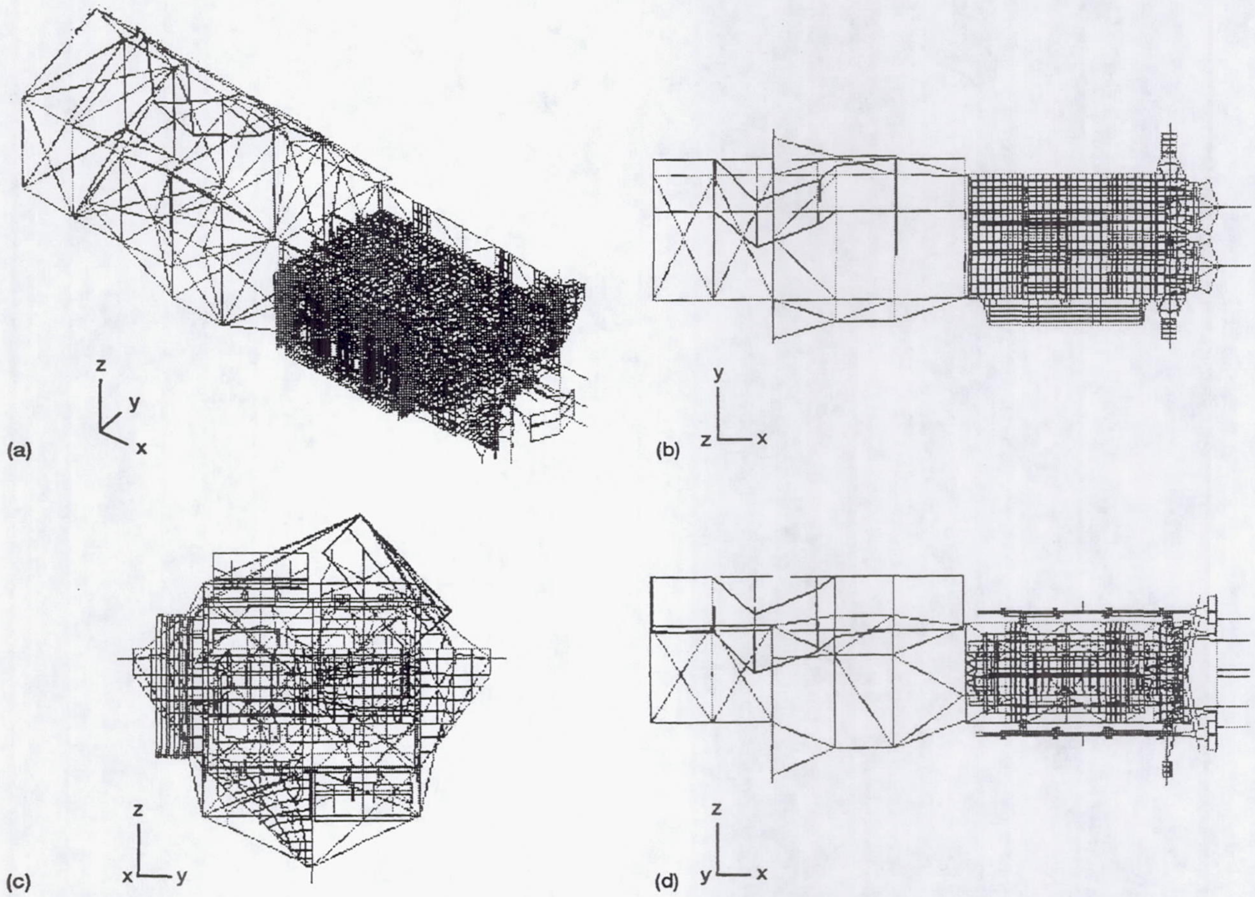
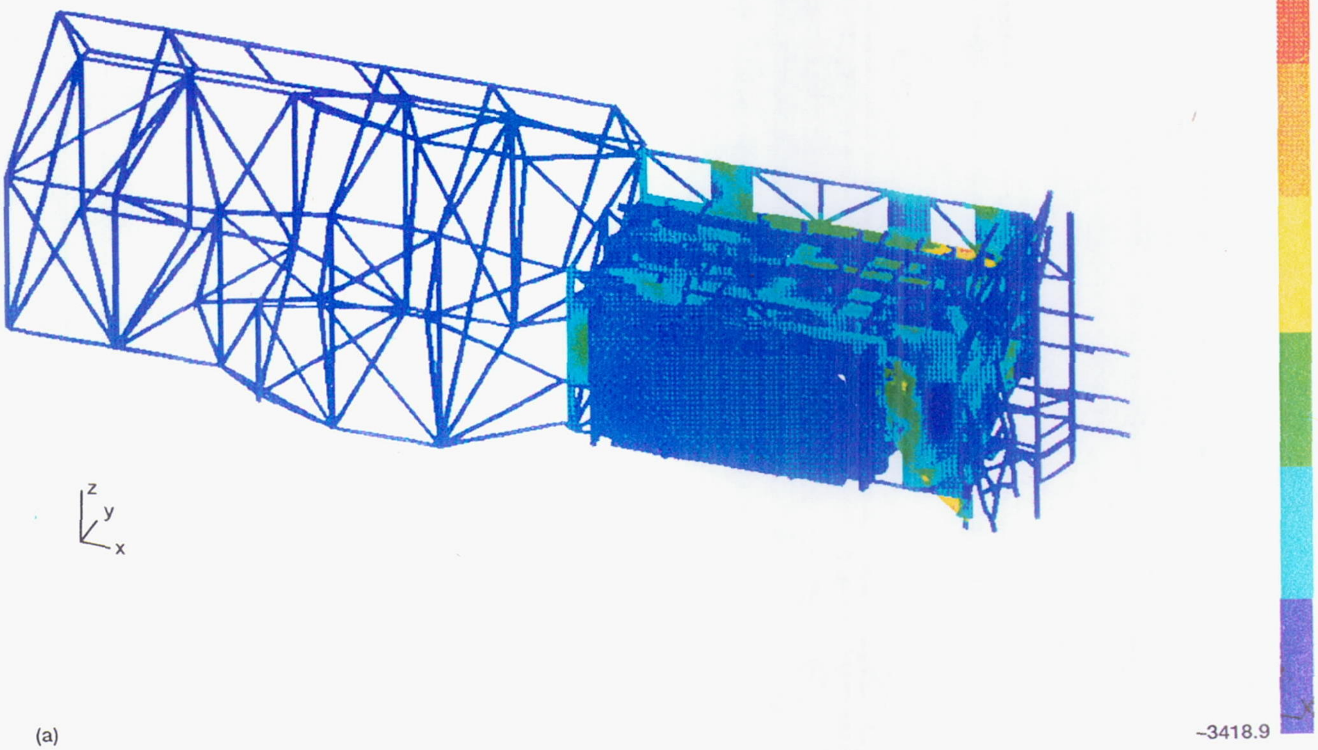



Figure 18.—Fifth mode plot of five: six-longeron truss combined with the IEA at 10.431900 Hz. (a) Oblique view. (b) Top view. (c) Side view. (d) Front view.

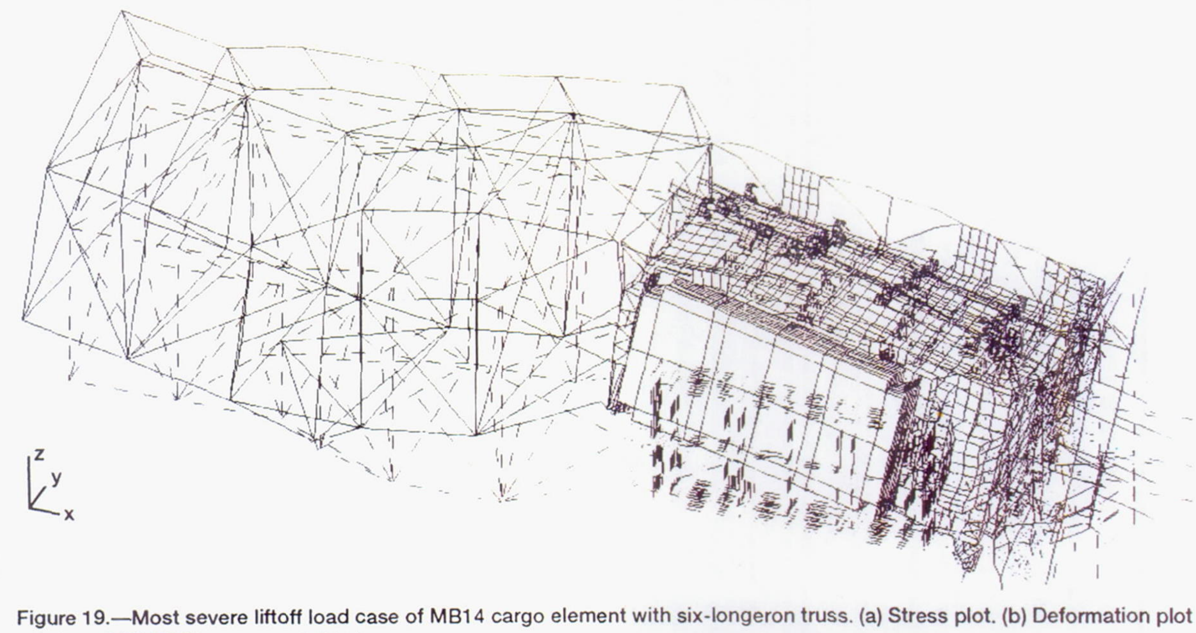
Stress, psi

20447.97




(a)

–3418.9




(b)

Figure 19.—Most severe liftoff load case of MB14 cargo element with six-longeron truss. (a) Stress plot. (b) Deformation plot (min. = 0.084730 in.; max. = 1.5 in.).



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**13. ABSTRACT *(Maximum 200 words)***

The structural design and configuration feasibility of the long spacer truss assembly that will be used as part of the Space Station Freedom is the focus of this study. The structural analysis discussed herein is derived from the transient loading events presented in the Space Transportation System Interface Control Document (STS ICD). The transient loading events are liftoff, landing, and emergency landing loads. Quasi-static loading events were neglected in this study since the magnitude of the quasi-static acceleration factors is lower than that of the transient acceleration factors. Structural analysis of the proposed configuration of the long spacer truss with four longerons indicated that negative safety margins are possible. As a result, configuration changes were proposed. The primary configuration change suggested was to increase the number of truss longerons to six. The six-longeron truss appears to be a more promising structure than the four-longeron truss because it offers a positive margin of safety and more volume in its second bay (BAY2). This additional volume can be used for resupply of some of the orbital replacement units (such as a battery box). Note that the design effort on the long spacer truss has not fully begun and that calculations and reports of the negative safety margins are, to date, based on concept only.

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