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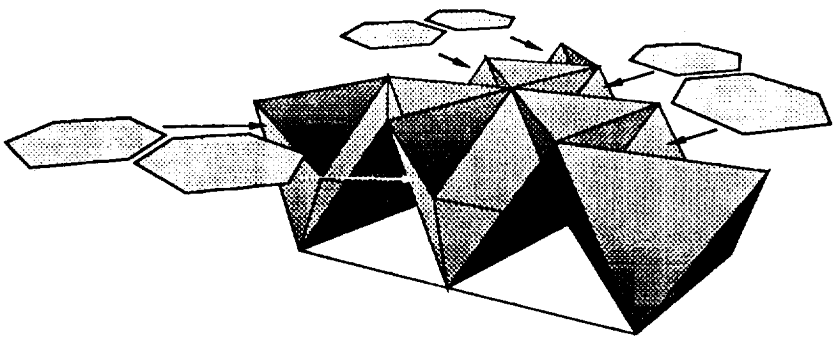
COMPONENT COUNT AND PRELIMINARY ASSEMBLY CONSIDERATIONS FOR LARGE SPACE TRUSS STRUCTURES



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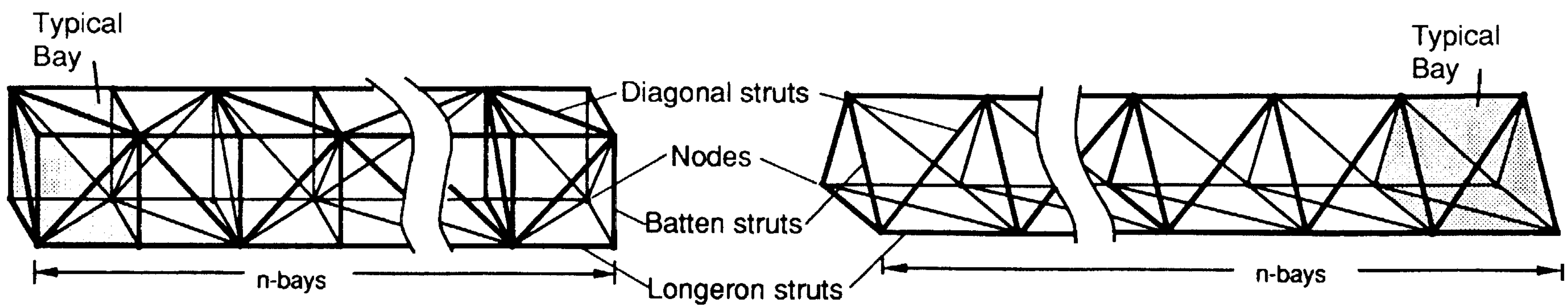
Introduction

Many proposed space missions involve the use of panels and instruments which must be supported on large truss substrates. Examples of some typical missions which require trusses are reported in references 1-4. These missions incorporate various forms of trusses such as beams, planar trusses, and doubly curved dishes. The layout and cost estimates of systems that incorporate these large trusses frequently require the designer to evaluate the number of component parts necessary for the support truss. Also, mission applications such as aerobrakes and segmented reflectors require that hexagonal panels arranged in circular mosaic patterns be attached to the truss. The resulting total panel surface area and dimensions are also frequently required. Since these missions require truss systems which are too large to be transported to orbit in an assembled form, in-space assembly of both the truss and any required panel system may be required. The designer must have insight into methods for assembling these structures in an efficient manner.

This paper presents the results of a limited study of truss-structure component count, and of a preliminary investigation of some on-orbit assembly procedures. To evaluate the number of truss components, mathematical expressions were developed that quantify the number of component parts as a function of truss divisions. Expressions for the area and dimensions of an arbitrary number of rings of hexagonal panels are also presented. To assist in automated or astronaut truss/panel assembly operations, a concept for assembling a tetrahedral truss with hexagonal panels is presented. While additional considerations must be incorporated in the planning of these missions, the information presented provides a base from which to initiate design studies.

Figure 1

Figure 1 contains component count expressions for three-and four-longeron truss beams. Illustrations of both truss beam types and their two components, i.e., struts (batten, longeron, and diagonal) and nodes, are shown above the table. The basic repeating element of both beams is a bay. The component count expressions for both trusses are functions of the number of truss bays. It was assumed in developing these expressions that the strut members of a given type are all of the same length; therefore, the four-longeron beam has a square cross-section and the three-longeron beam has an equilateral triangular cross-section. The three-longeron beam has fewer members per bay than the four-longeron beam; however, the four-longeron beam has some redundant members. Some examples of truss beams considered for space applications can be found in references 5-7.



4-Longeron truss beam

3-Longeron truss beam

Truss components	4-Longeron truss	3-Longeron truss
Nodes	$N_N = 4n + 4$	$N_N = 3n + 3$
Batten struts	$N_{BS} = 4n + 4$	$N_{BS} = 3n + 3$
Longeron struts	$N_{LS} = 4n$	$N_{LS} = 3n$
Diagonal struts	$N_{DS} = 5n + 1$	$N_{DS} = 3n$
Redundant struts	$N_{RS} = n - 1$	—
Struts (total)	$N_S = 13n + 5$	$N_S = 9n + 3$
Truss $_{\text{nodes + struts}}$	$N_T = 17n + 9$	$N_T = 12n + 6$
n is the number of bays		

Figure 1. Component count expressions for 4-and 3-longeron truss beams.

Figure 2

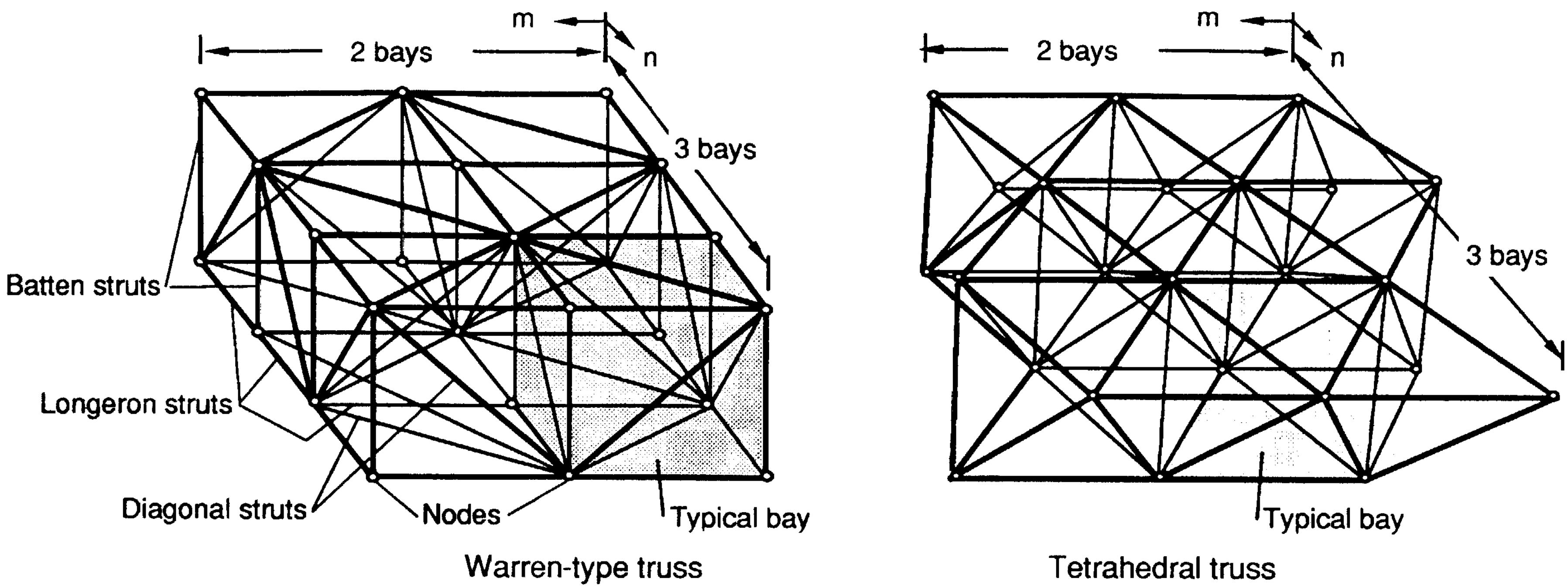
Figure 2 contains component count expressions for two planar truss configurations. Illustrations of both truss types and their components are shown above the table. As with the beam of figure 1, the repeating element of the truss is referred to as a bay. The Warren truss has a typical box-type configuration with one diagonal per face.

The tetrahedral truss is a configuration formed by connecting tetrahedral cells. All of the struts in a regular tetrahedral truss are of the same nominal length. By rearranging its diagonals and displacing alternating rows of nodes by one half bay, the Warren truss is made to be a tetrahedral truss. Therefore, the total numbers of struts in n-bay configurations of these planar trusses are the same.

The component count expressions in this figure were developed by assuming the component count expression in the form

$$f(m, n) = Am + Bn + Cmn + D$$

By relating the number of parts in specific m by n bay configurations and solving the resulting equations simultaneously, the coefficients A, B, C, and D were determined. For a one-bay-wide planar truss the expressions reduce to those for the four-longeron beam shown in figure 1.



Nodes	$N_N = 2(m + n + mn + 1)$
Batten struts	$N_{BS} = m + n + mn + 1$
Longeron struts	$N_{LS} = 2m + 2n + 4mn$
Diagonal struts	$N_{DS} = m + n + 4mn$
Redundant struts	$N_{RS} = -2m - 2n + 3mn + 1$
Struts (total)	$N_S = 4(m + n) + 9mn + 1$
Truss $_{\text{nodes + struts}}$	$N_T = 6(m + n) + 11mn + 3$
m and n are the number of bays on adjacent sides of a truss	

Figure 2. Component count expressions for a planar truss.

Figure 3

Many of the proposed space antennas mentioned in the Introduction incorporate tetrahedral trusses with frontal profiles that approximate a circle, as opposed to the rectangular tetrahedral truss described in figure 2. Figure 3 contains perspective views of a generic planar tetrahedral truss, its components, and hexagonal panels. Regular hexagonal panels can conveniently be grouped in a mosaic to form a large coherent surface. Also, these hexagonal panels, when appropriately sized, have three apexes that lie at the same locations as the top surface truss nodes, thereby providing convenient attachment locations for the panels.

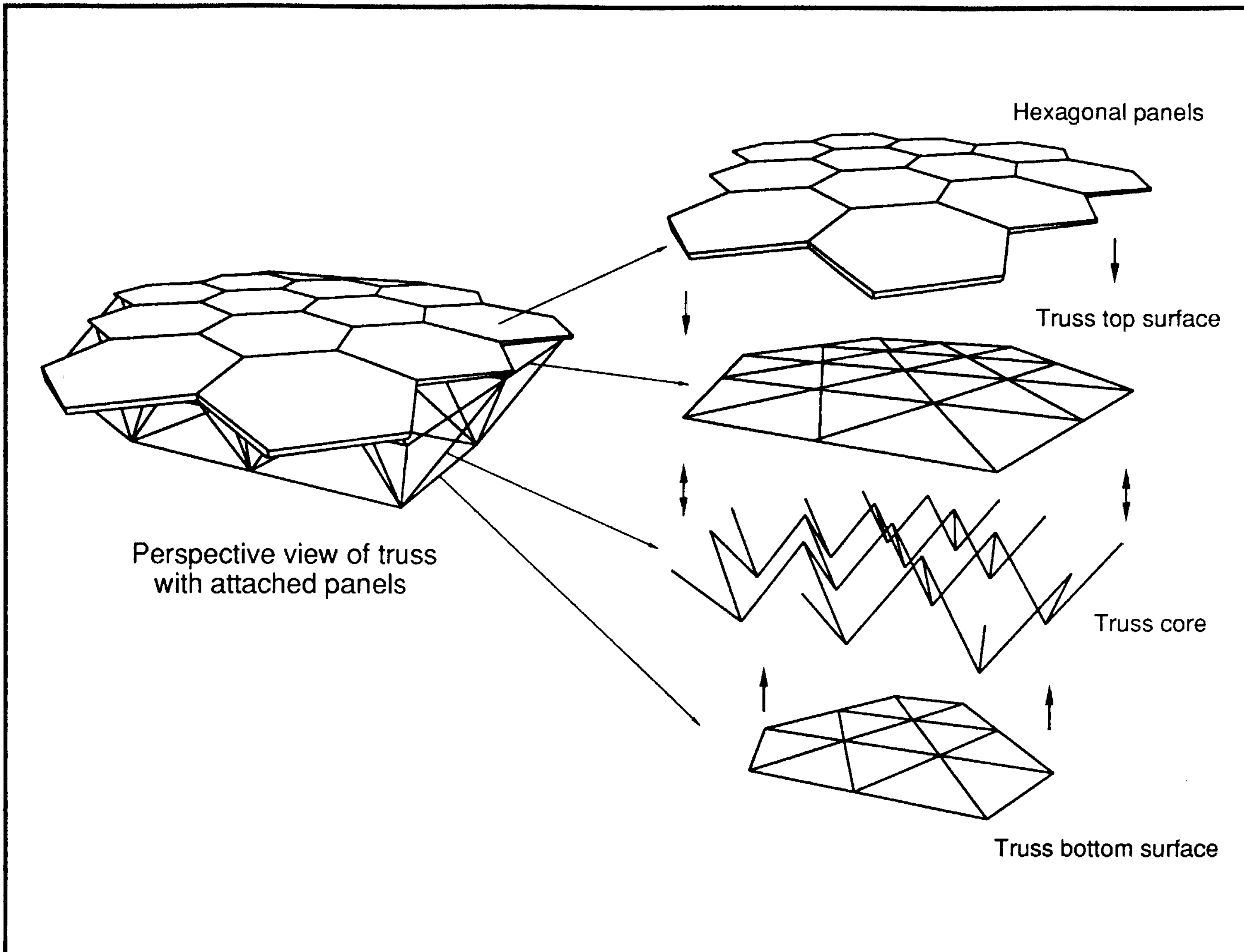


Figure 3 Perspective views of tetrahedral truss and hexagonal panels.

Figure 4

The tetrahedral truss can be assembled in two configurations which are of particular interest for antennas and aerobrakes. These two configurations are illustrated in figure 4 and identified hereinafter as a six-sector truss and a three-sector truss, based on the number of identical sectors in the top surface of the truss. Both trusses shown have three rings. The six-sector truss has a regular hexagonal top surface perimeter and a node in the center. The top surface is formed by regular hexagonal rings. The panels attached to the six-sector truss can be viewed as being assembled in rings that bear a one-to-one relationship with the rings of the truss. However, due to the alignment of the truss nodes with the panel apexes, the panel configuration exhibits three-sector rather than six-sector symmetry.

The three-sector truss has the same base unit as the six-sector truss with an additional half of an outer ring attached to the boundary. Instead of a central node, this truss has a central equilateral triangle. The rings are formed around the central triangle, which is considered to be in the first ring. The panel configuration associated with the three-sector truss has a regular hexagonal or six-sector symmetry. Some antennas and telescopes employ a Cassegrainian reflective system which requires that the center of the reflector be open for transmission of concentrated signals to instruments mounted behind the primary reflector. The three-sector truss is an ideal configuration for this application because the center panel can be removed, leaving an unobstructed path through the reflector surface where instrumentation can be installed.

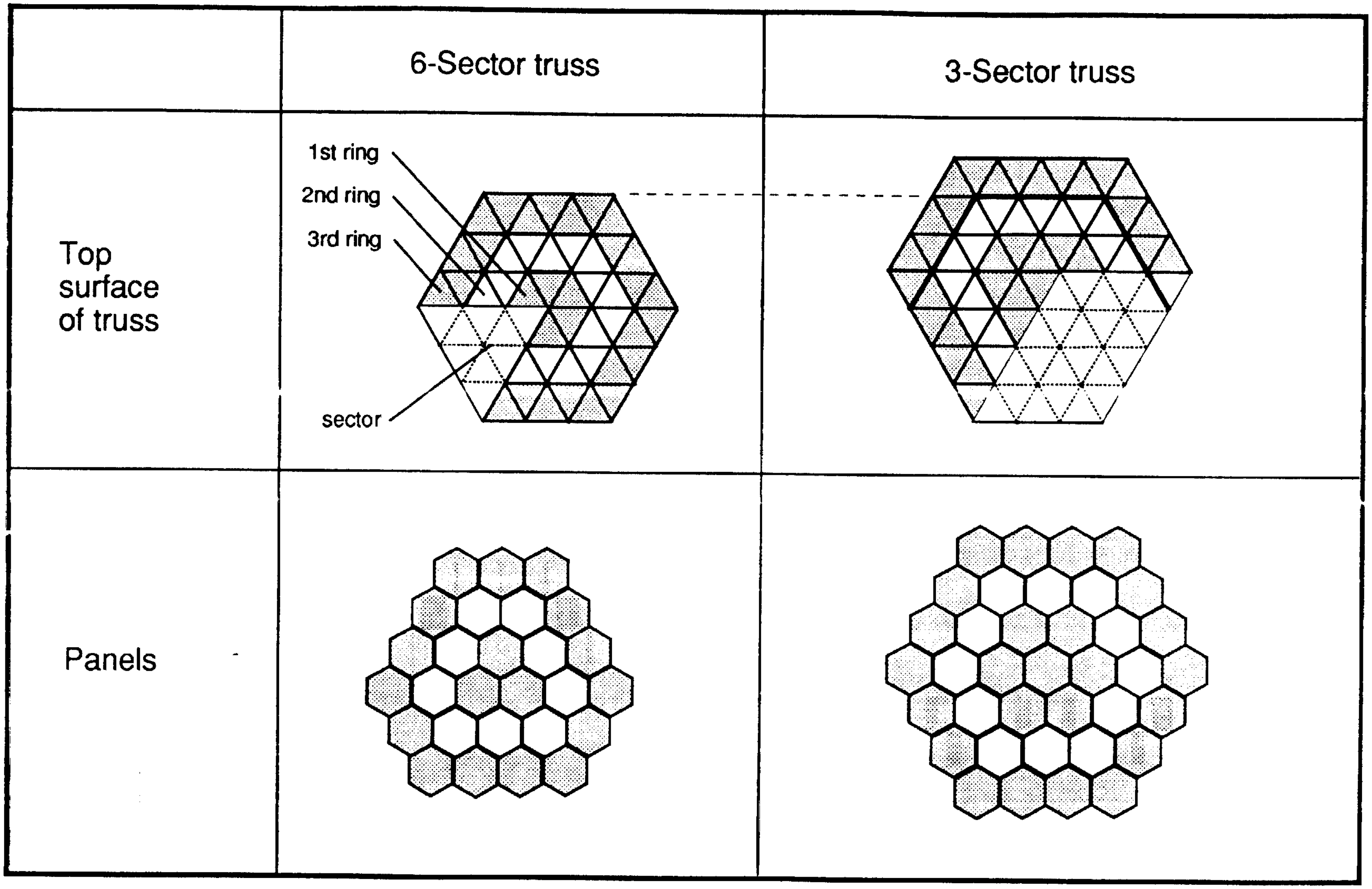


Figure 4. Nomenclature for two tetrahedral trusses with hexagonal panels.

Figure 5

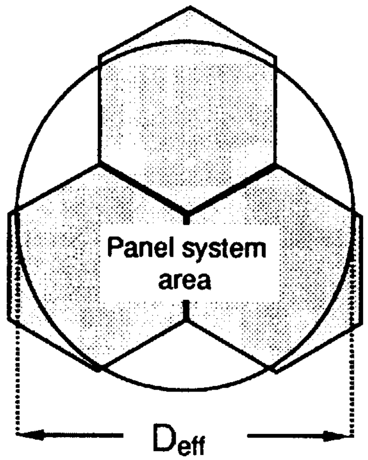
Expressions for the number of panels, struts, and nodes as functions of the number of rings (r) for the two configurations of the tetrahedral truss are shown in figure 5. These expressions were developed using the same technique as that described for figure 2, and since an increase in the number of rings represents a one-parameter areal expansion, all component expressions are functions of the square of the ring number. Note that the three-sector truss has more components than the six-sector truss of the same number of rings, due to the additional one-half boundary ring.

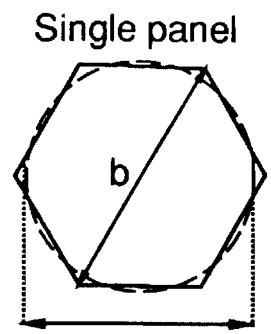
	6-Sector truss	3-Sector truss
Panels	$N_P = 3r^2$	$N_P = 3r^2 + 3r + 1$
Surface struts	$N_{SS} = 9r^2 + 3r$	$N_{SS} = 9r^2 + 12r + 3$
Core struts	$N_{CS} = 9r^2$	$N_{CS} = 9r^2 + 9r$
Bottom struts	$N_{BS} = 9r^2 - 6r$	$N_{BS} = 9r^2 + 3r - 3$
Struts (total)	$N_S = 27r^2 - 3r$	$N_S = 27r^2 + 24r$
Redundant struts	$N_{RS} = 9r^2 - 12r + 3$	$N_{RS} = 9r^2 - 3r - 3$
Surface nodes	$N_{SN} = 3r^2 + 3r + 1$	$N_{SN} = 3r^2 + 6r + 3$
Bottom nodes	$N_{BN} = 3r^2$	$N_{BN} = 3n^2 + 3n$
Nodes (total)	$N_N = 6r^2 + 3r + 1$	$N_N = 6r^2 + 9r + 3$
$Truss_{struts + nodes}$	$N_T = 33r^2 + 1$	$N_T = 33r^2 + 33r + 3$
r is the number of rings		

Figure 5. Component count expressions for tetrahedral trusses with hexagonal panels.

Figure 6

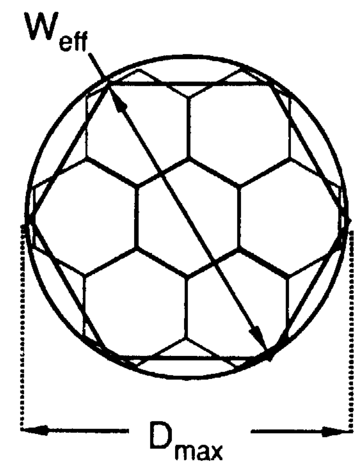
In the design of mosaic hexagonal panel systems for doubly curved trusses, it is important to quantify the area and dimensions of a panel system. Approximations to the dimensions of a curved panel system can be obtained by examining a planar panel system. Figure 6 contains some geometric relationships for six-sector and three-sector hexagonal flat panel systems. The various panel system geometric terms are defined in the sketches at the top of the figure. The expressions are functions of the number of rings of a truss and the maximum panel width (b). Three of the terms are explained below. The effective width (W_{eff}) of a panel system is the diameter of a single hexagon that has the same area as the panel system. The panel system's effective diameter (D_{eff}) is the diameter of a circle with the same area as that of the panel system. The panel system's maximum diameter (D_{max}) is the diameter of a circle that circumscribes a panel system.





$$D_{eff} = b\sqrt{\frac{3\sqrt{3}}{2\pi}}$$

$$A_P = \frac{3\sqrt{3}}{8} b^2$$

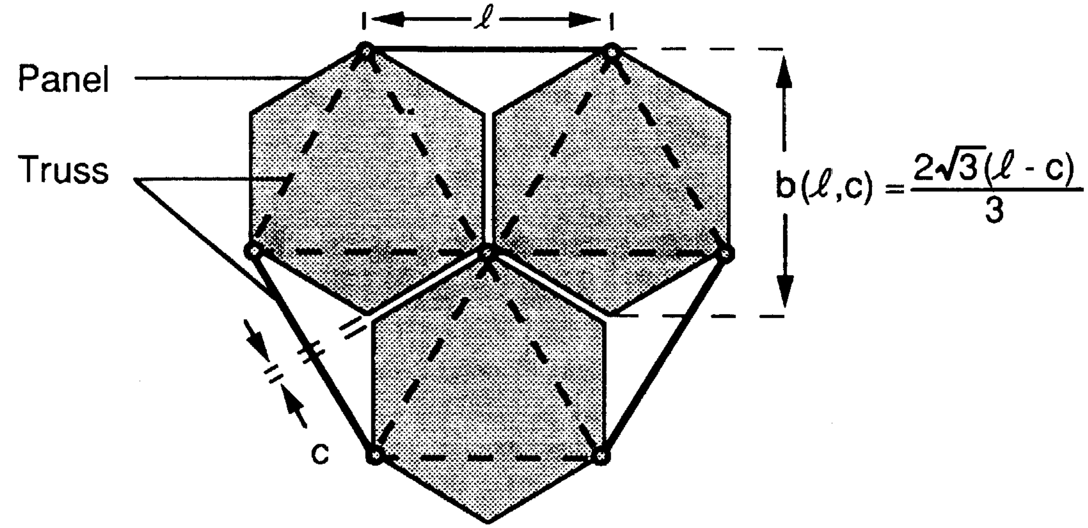


	6 Sector truss	3 Sector truss
Panel system diameter	$D_{max} = b\sqrt{3r^2 + 1}$	$D_{max} = b\sqrt{3r^2 + 3r + 1}$
Width of equivalent hexagon	$W_{eff} = br\sqrt{3}$	$W_{eff} = b\sqrt{3r^2 + 3r + 1}$
Diameter of equivalent circle	$D_{eff} = 3br\sqrt{\frac{\sqrt{3}}{2\pi}}$	$D_{eff} = b\sqrt{\left(\frac{3\sqrt{3}}{2\pi}\right)(3r^2 + 3r + 1)}$
Panel system surface area	$A_{PS} = b^2 r^2 \frac{9\sqrt{3}}{8}$	$A_{PS} = \left(\frac{3\sqrt{3}}{8} b^2\right)(3r^2 + 3r + 1)$
r is the number of rings		

Figure 6. Panel system geometrical relations.

Figure 7

In many segmented panel systems some clearance between individual panels will be required for installing the panels, to allow for differential thermal expansion, figure control adjustments, and manufacturing tolerances. Expressions for this lost area are shown in figure 7 as a function of the clearance (c) between the panels, the truss strut length (ℓ) and the number of rings (r). For example, a five-ring, six-sector segmented reflector with a panel width of 2 meters and a clearance of 5 mm would lose about .44 percent of its total area.



Panel systems clearance	6-Sector truss	3-Sector truss
Clearance area	$A_C = c\ell\sqrt{3}(3r^2 - 2r)$	$A_C = c\ell\sqrt{3}(3r^2 + r)$
Clearance area / Panel system area	$\frac{A_C}{A_{PS}} = \frac{2(\frac{c}{\ell})(3r - 2)}{3r[1 - 2(\frac{c}{\ell}) + (\frac{c}{\ell})^2]}$	$\frac{A_C}{A_{PS}} = \frac{2(\frac{c}{\ell})(3r - 2)}{(3r^2 + 3r + 1)[1 - 2(\frac{c}{\ell}) + (\frac{c}{\ell})^2]}$
r is the number of truss rings		

Figure 7. Panel system clearance expressions.

Figures 8

In addition to the parametric analysis of segmented hexagonal panel systems, a preliminary concept for integrated tetrahedral truss/hexagonal panel assembly is presented. This work has been done to support expanded operations in automated tetrahedral truss assembly (See ref. 8.) and a proposed in-space assembly flight experiment. The primary purpose of this effort is to develop simple, logical assembly techniques for use by automated devices or astronauts. One factor associated with the ease of truss/panel assembly is the number of required shifts between truss assembly devices and panel assembly devices. This concept attempts to minimize the number of these shifts. Additionally, the various truss configurations shown have accessible workspaces for panel insertion devices. The direction of insertion is also indicated. For convenience the truss can be mounted on a turntable and rotated for assembly operations (See ref. 8.).

To help explain the assembly concept, the assembly procedure for a two-ring truss is presented in figures 8a and b. The procedure for a two-ring truss begins with assembly of the first ring and a substantial part of the second ring, except for the six struts in the top surface (See figure 8a). The depicted truss contains 63 of the required 102 strut members and 22 of the 31 nodes. Note that the assembled truss is a structure, rather than a mechanism, with panel attachment nodes accurately located. Therefore, panels can be attached to the top of the truss surface over the triangular opening of the workspace, and the associated panel attachment device can be withdrawn without truss interference. After two panels have been locked in place on one side of the truss, the turntable can be rotated 120 degrees for the insertion of two more panels. When all six panels have been installed, the six top struts are inserted and the second truss configuration is assembled (See figure 8b.). This truss has 96 struts and 31 nodes. After the last six panels are installed, six additional struts are inserted to complete the truss/panel assembly operation.

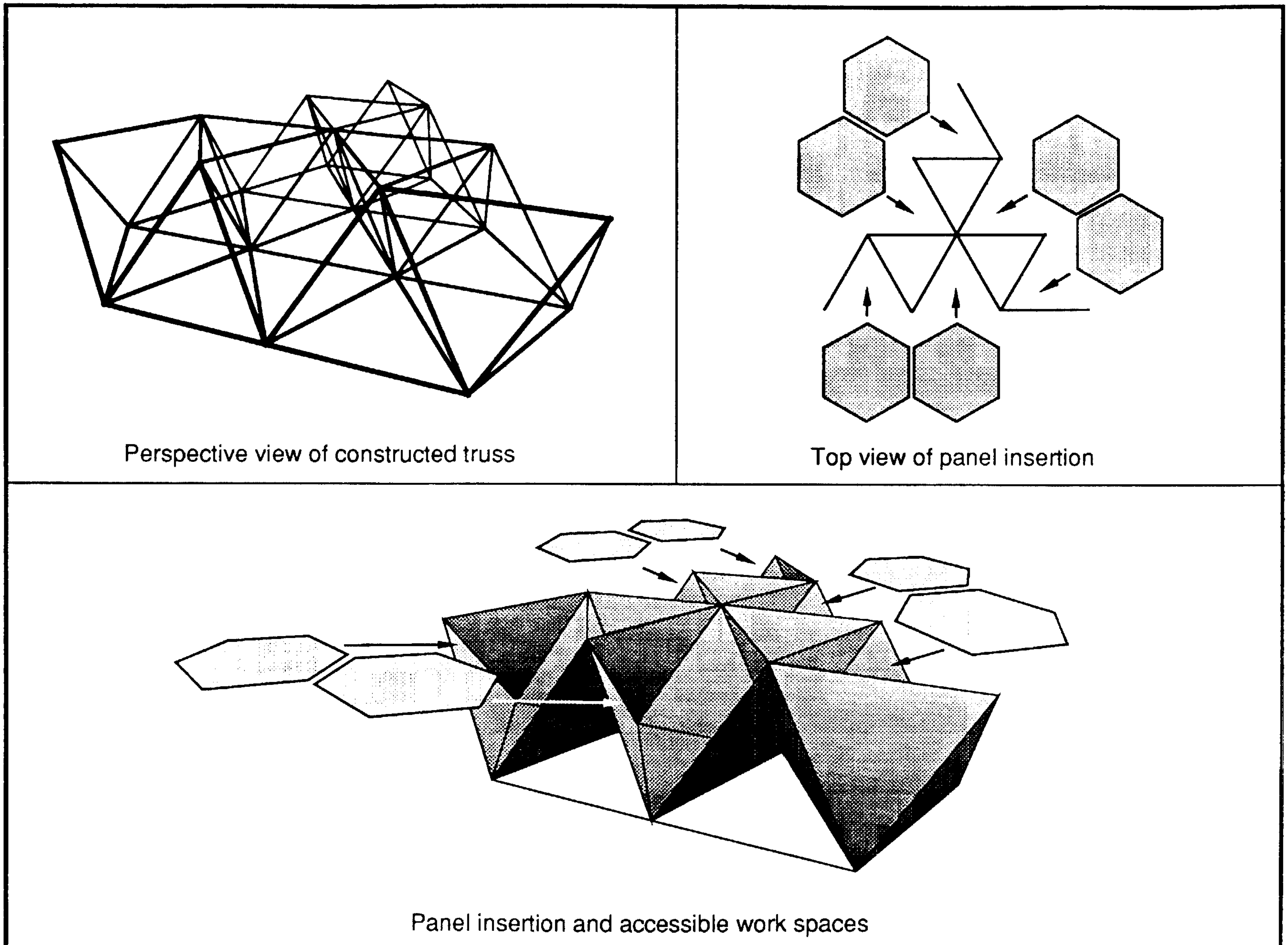


Figure 8a. Perspective views of the initial configuration of a six-sector truss with panels.

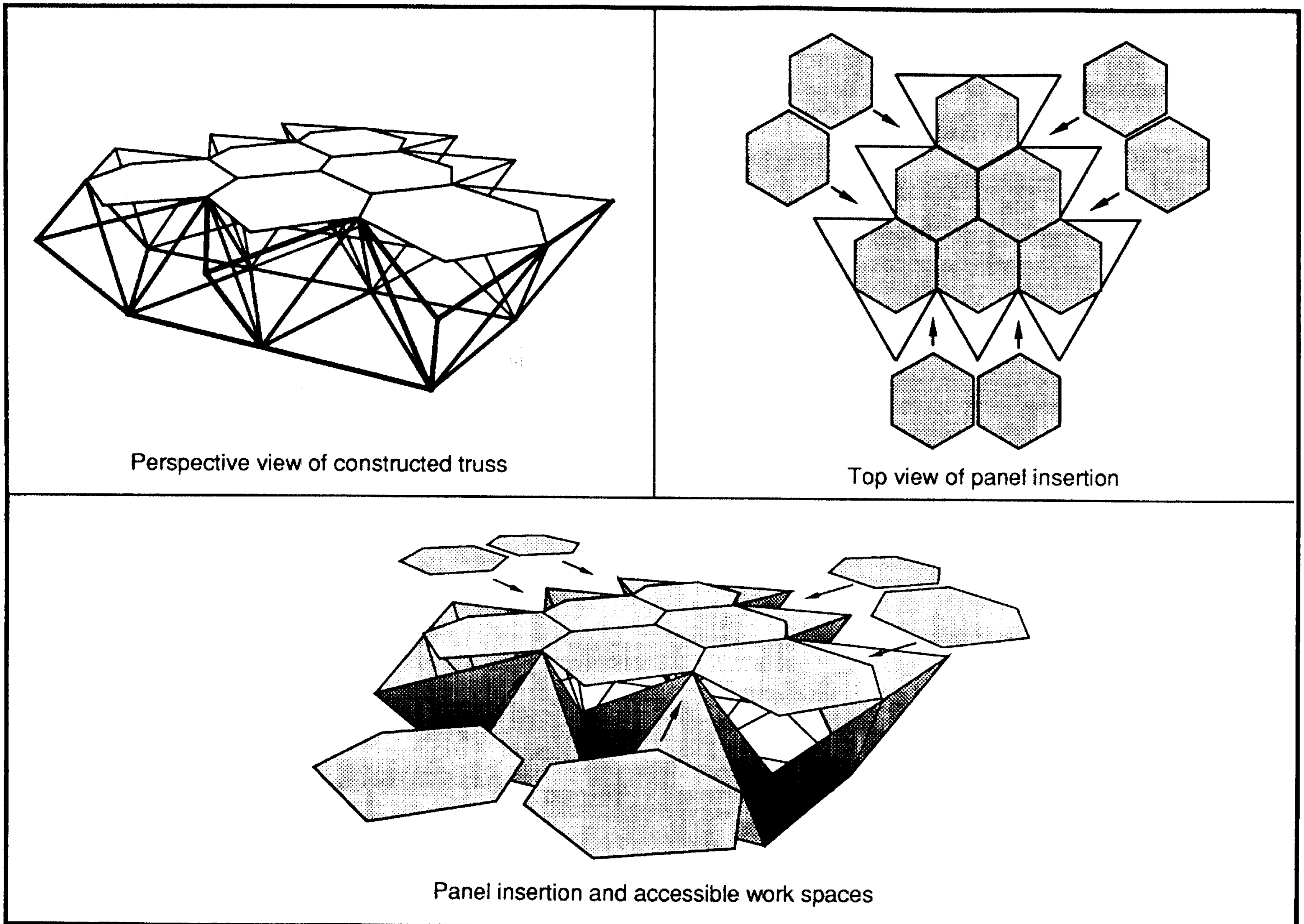


Figure 8b. Perspective views of the final configuration of a six-sector truss with panels.

Figures 9

Assembly operations discussed previously for both the three-and six-sector trusses are summarized in figures 9a and b. The assembly operations alternate between truss strut installation and panel installation. The shaded hexagons and bold lines represent the panels and struts installed during that step. The cumulative numbers of struts/nodes or panels in the system at the completion of each assembly phase are shown below the sketches. The assembly operations are efficient in that they minimize the number of shifts between truss and panel installation devices. This may be important for automated assembly operations because the truss assembly device and the panel installation device may be different. Sequences for trusses of up to three rings are shown; however, the concept can be applied to a general n-ring truss.

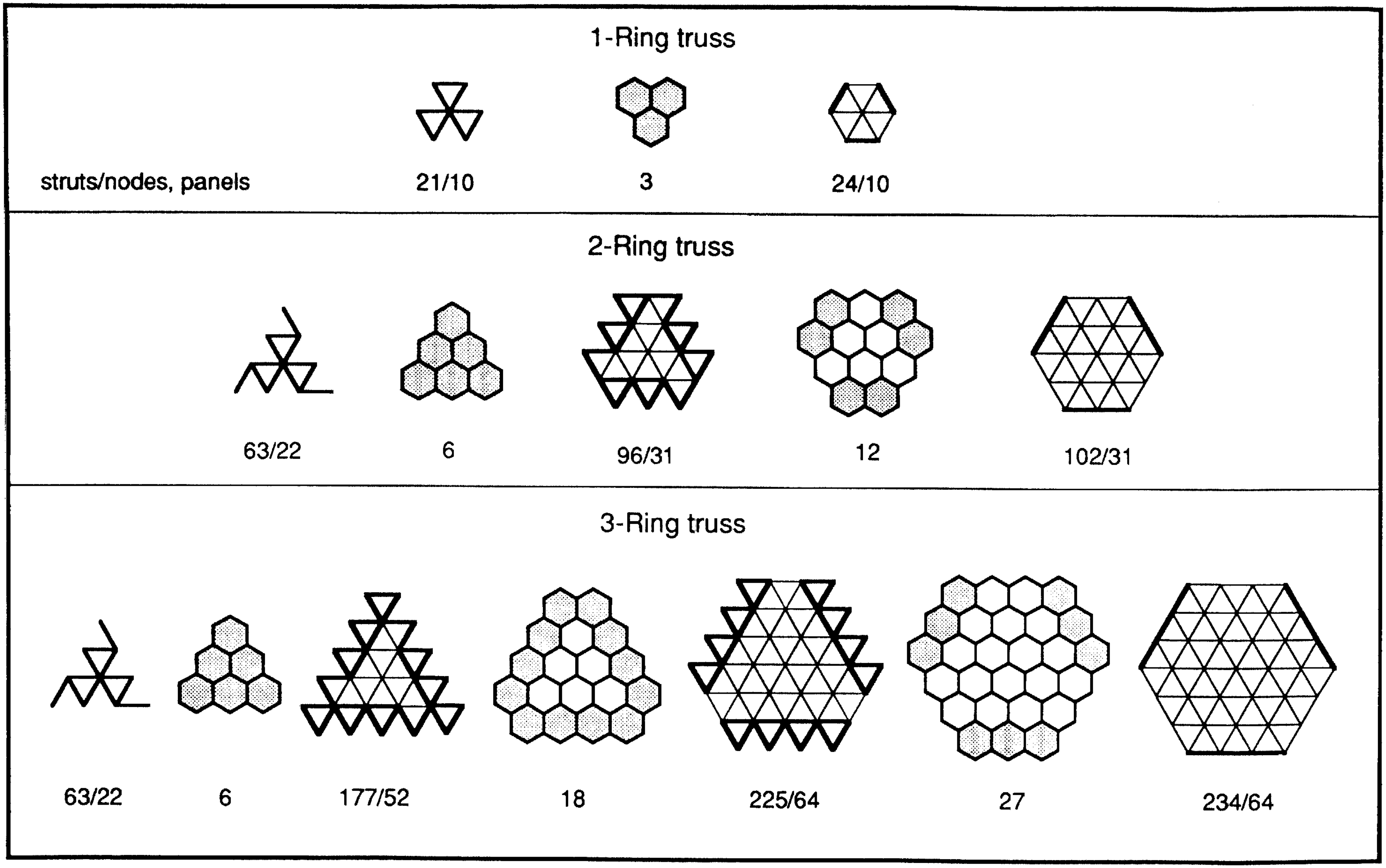


Figure 9a. Illustration of the assembly steps required for three 6-sector trusses with panels.

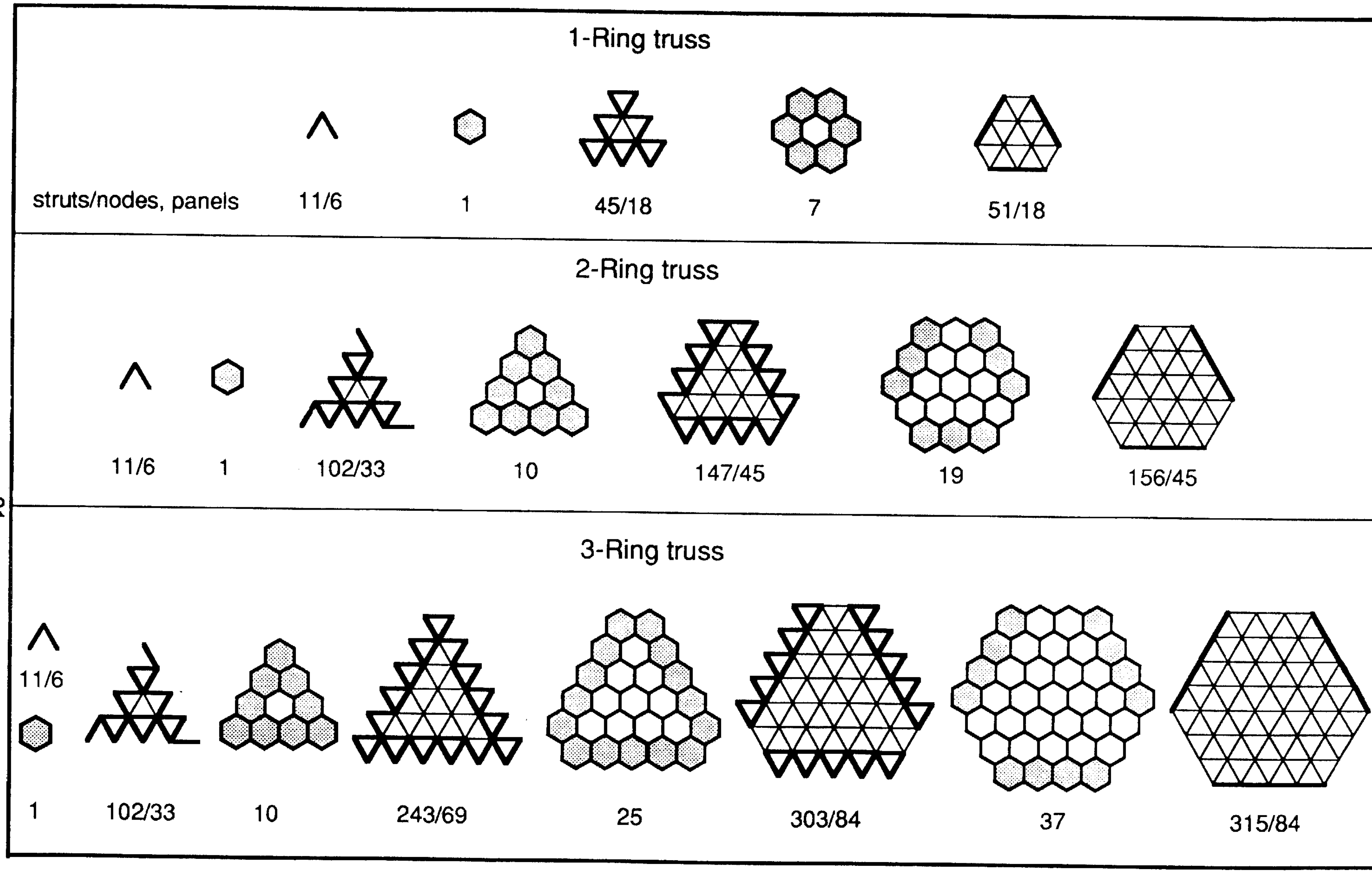


Figure 9b. Illustration of the assembly steps required for three 3 sector trusses with panels.

Summary

In the development of design concepts for space missions that require truss structures or panel systems, it is desirable to quantify the number of truss components and the area and dimensions of the panel system. Accordingly, mathematical expressions relating the number of truss components to the number of truss divisions were developed for two types of truss beams and two types of planar trusses. Additionally, expressions that quantify the area and dimensions of two types of hexagonal panel systems are presented.

To assist in on-orbit automated or astronaut assembly, an assembly concept for a tetrahedral truss with hexagonal panels is presented. The concept minimizes the number of shifts between truss-assembly and panel-installation devices. The various truss configurations presented also have accessible work spaces to accommodate panel-insertion operations. Assembly procedures for trusses of one to three rings are presented; however, the concept can be generalized to an n-ring panel system.

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16. Abstract

Expressions for the number of truss components per truss division are presented along with expressions for the area and dimensions of mosaic hexagonal panel arrangements. The expressions were developed by substituting the number of truss components in specific truss divisions into associated polynomial equations and solving for the coefficients of the polynomials. To assist in automated or astronaut truss/panel assembly operations, a concept for assembling a tetrahedral truss with hexagonal panels is presented. The assembly concept minimizes the exchange of truss assembly devices and panel attachment devices, assuming that the number of exchanges is a driving assembly concern.

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