# United States Patent [19]

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[54] **STRESSED STRUCTURE FOR SUPPORTING WEIGHT**


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[51] **Int. Cl.²** ..... **A47C 4/00**

[58] **Field of Search** ..... 297/16, 25, 45, 440, 441, 297/445, 449, 457; 52/648



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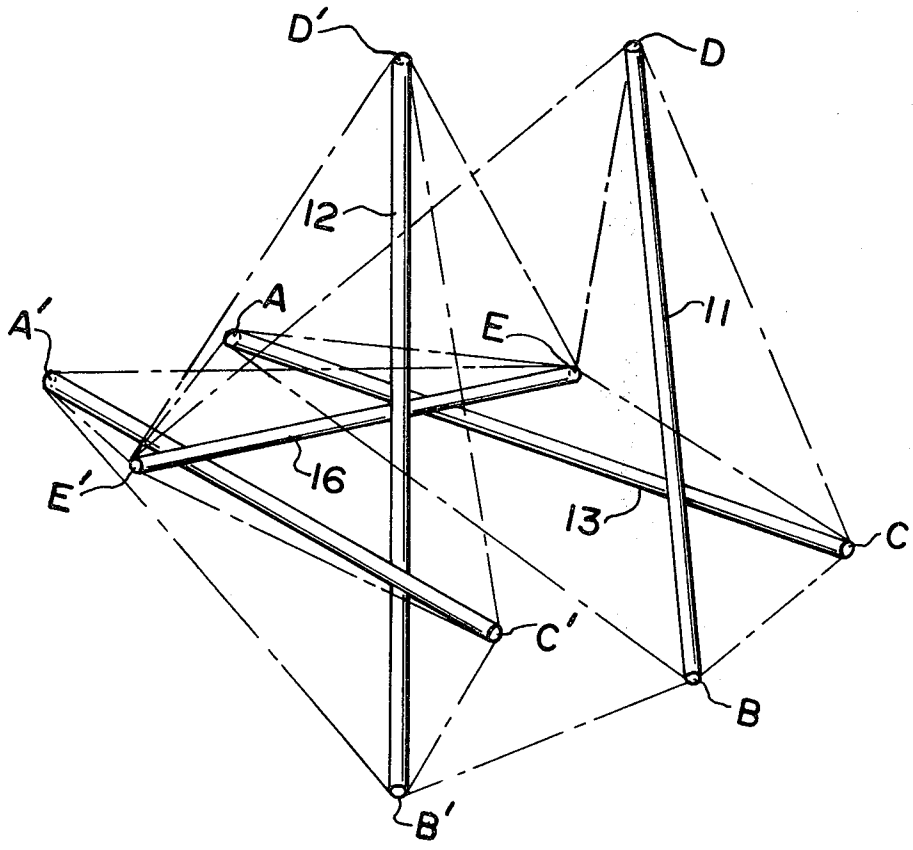
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[57] **ABSTRACT**

A stressed structure assembly providing support for a predetermined maximum weight, such as a chair having a framework supporting a seat. Framework members are assembled so that each member is in pure compression or tension. Framework member configuration is of comparatively light cross section due to the absence of necessity for supporting bending stress. The framework includes means for supporting the assembly on a surface which is conformable to irregularities in the surface.


**3 Claims, 3 Drawing Figures**



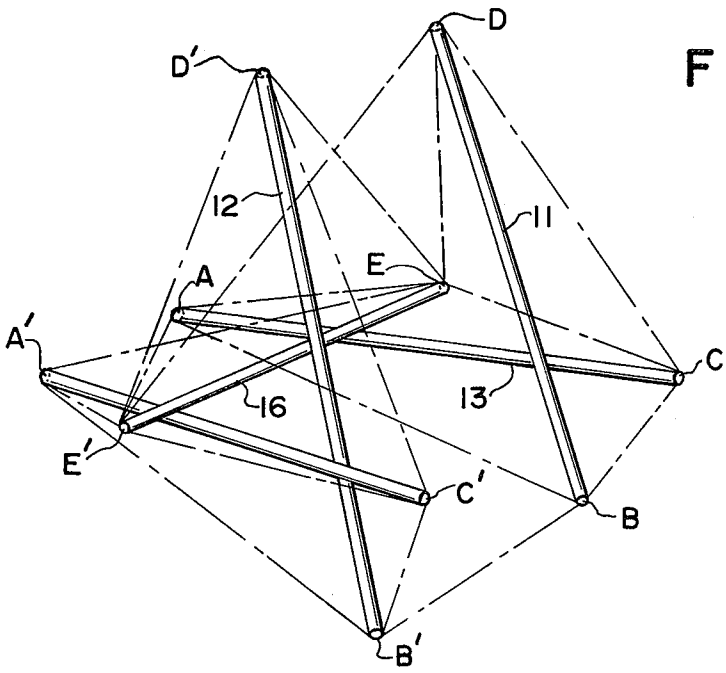



FIG.-1

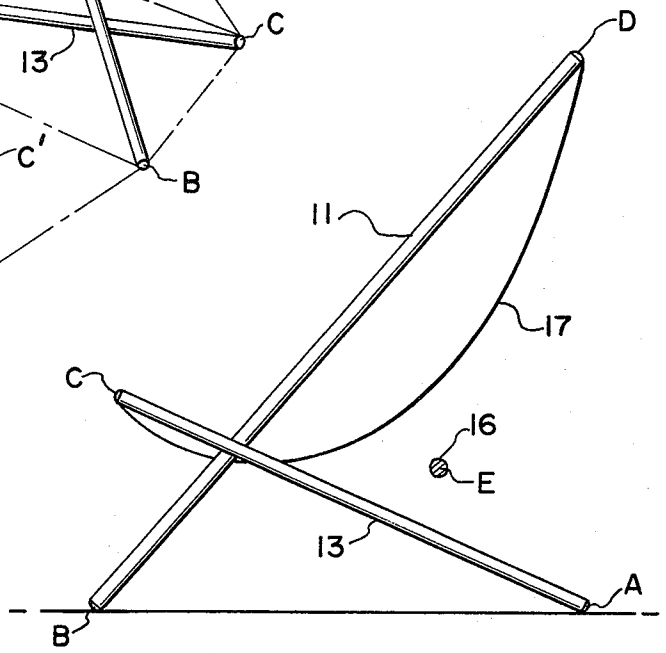



FIG.-2

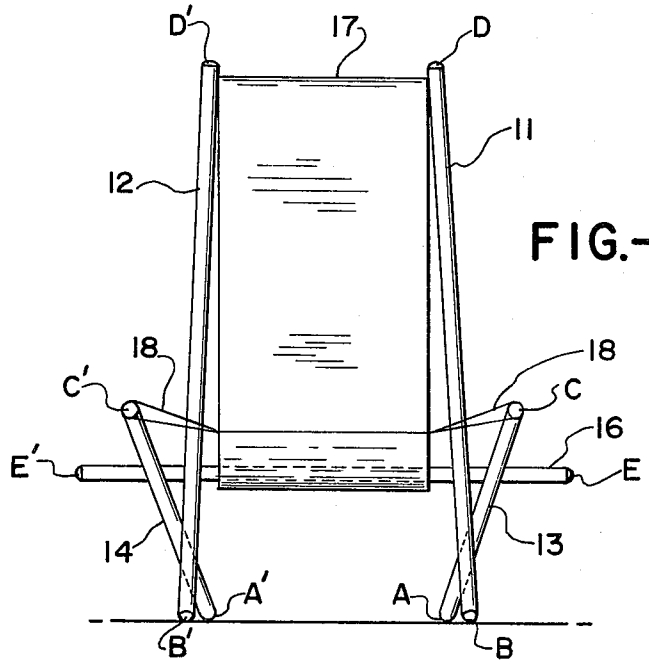



FIG.-3

# STRESSED STRUCTURE FOR SUPPORTING WEIGHT

## BACKGROUND OF THE INVENTION

This invention relates to a stressed structural assembly for supporting a weight, and more particularly to such a structure having a base conformable to a supporting surface and including a seat to serve as a chair.

In the past lightweight structures for utilization as pieces of furniture, for example, have been constructed of materials having high strength derived from superfluous mass resulting in material and assembly cost disadvantages. This has generally been due to the requirement for supporting stress arising from any combination of tension, compression, torsion, and bending. Various base configurations have been tried with limited success in an effort to acquire stability on irregular surfaces. Individual structural members in assemblies for supporting weights, such as chairs, have necessarily been designed to support the combinations of stresses mentioned above. The result is over design from the stress capability standpoint in nearly every member of the structural assembly. There is, therefore, a need for a lightweight, structurally strong assembly, for supporting weight which is stable when placed on an irregular supporting surface.

## SUMMARY AND OBJECTS OF THE INVENTION

A structure is disclosed having members stressed during assembly to provide an assembly for supporting a predetermined weight. The structural members provide a framework which is stable as it rests on a supporting surface even if the surface includes considerable irregularities. The framework includes a plurality of compression members and a plurality of tension members wherein the forces in compression and tension are imposed at assembly. The compression members define a plurality of structure vertices at their ends. The tension members are connected between the structure vertices and all members are designed to withstand the forces imposed by the stress at assembly and by the support of the maximum predetermined weight. Means for contacting the predetermined weight is suspended between certain of the structure vertices, and means for contacting a supporting surface are included in the framework. The structure contains a soft mode whereby the means for contacting the supporting surface is conformable to the shape of irregularities in the supporting surface for providing stability in the structure.

In general it is an object of the present invention to provide a weight supporting structure having a minimum mass and conforming to irregular supporting surfaces.

Another object of the invention is to provide a weight supporting structure which will serve as a chair providing stability on an irregular supporting surface.

Another object of the present invention is to provide a weight supporting structure which may be easily assembled for use and collapsed for storage.

Another object of the present invention is to provide a weight supporting structure which is easily assembled from readily attainable materials.

Another object of the present invention is to provide a weight supporting structure which has several soft modes providing structural compliance and subsequent comfort when used as a chair.



Another object of the present invention is to provide a weight supporting structure which has an esthetically pleasing form.

Additional objects and features of the invention will appear from the following description in which the preferred embodiment has been set forth in detail in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an isometric view of the framework of a stressed structure chair assembly with the seat removed.

FIG. **2** is a side elevational view of a stressed structure chair assembly with the framework tension members removed.

FIG. **3** is a front elevational view of a stressed structure chair assembly with the framework tension members removed.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

A stressed structure assembly for supporting a predetermined weight is disclosed herein in the form of a chair assembly having a framework containing members stressed in pure compression and pure tension at assembly. The chair assembly has a base which due to a soft mode in the structure adapts to irregularities in a supporting surface, such as rough ground found in an outdoor picnic area or uneven cobble stones forming a patio area.

Initially a definition of "soft modes" for a structure of the type disclosed will be presented. Referring to FIG. **1** a stressed structure assembly is shown in the form of a framework for a chair with the seat removed. A plurality of compression members are shown including a left upright member **11**, a right upright member **12**, a left arm member **13**, a right arm member **14**, and a horizontal cross member **16**. Each compression member has two ends designated by A through E and A' through E' as shown in FIG. **1**. The ends of all the members represent the ten vertices of the disclosed embodiment. The framework of the embodiment of FIG. **1** also includes seventeen tension members designated in terms of the vertices between which they extend, i.e. tension member DC extends between the upper end of the left arm member **13** and the upper end of the left upright member **11**. The seventeen tension members are listed in the table below. A plane of symmetry is defined as the vertical plane perpendicular to and intersecting horizontal cross member **16** at its mid point.

TABLE A

| Location | Tension Member |
|---|---|
| Left Side Of Plane Of Symmetry | AB |
| | BC |
| | CD |
| | DE |
| | EA |
| | EC |
| Right Side Of Plane Of Symmetry | A'B' |
| | B'C' |
| | C'D' |
| | D'E' |
| | E'A' |
| | E'C' |
| Crossing Plane Of Symmetry | DE' |
| | D'E |
| | AE' |
| | A'E |
| | BB' |

In defining a soft mode consider a general space frame such as that in FIG. 1 having V vertices with coordinates $X_{\alpha,i}$ where $\alpha$ is 1 through 3 indicating a triaxial coordinate system. The symbol $i$ indicates the particular vertices 1 through V. If the symbol H is designated as the stored or potential energy level contained in the component frame parts the condition of stability is that the partial derivative of H with respect to $X_{\alpha,i}$ must be equal to zero for all $\alpha$ and $i$. As this is a space frame the effects of gravity do not contribute to the potential energy level in the frame parts. Letting the vertices V be acted upon by small forces $F_i$ with components $F_{\alpha,i}$ results in the deformation:

(b) $$X^1_{\alpha,i} = X_{\alpha,i} + \zeta_{\alpha,i}$$

When the small forces $F_i$ act the energy function is modified to;

(c) $$H^1 = H - \Sigma_{\alpha,i} F_{\alpha,i} \zeta_{\alpha,i}$$

and the condition for stability becomes;

(d) $$\frac{\delta H^1}{\delta \zeta_{\alpha,i}} = \frac{\delta H}{\delta \zeta_{\alpha,i}} - F_{\alpha,i} = 0$$

These last partial derivatives are evaluated at the displaced coordinates X′ which are designated by Δ;

(e) $$\left(\frac{\delta H}{\delta \zeta_{\alpha,i}}\right)_{\Delta} = \frac{\delta H}{\delta \zeta_{\alpha,i}} + \Sigma_{\beta,j} \frac{\delta^2 H}{\delta \zeta_{\alpha,i} \delta \zeta_{\beta,j}} \zeta_{\beta,j}$$

Since the structure was initially stable, and the partial derivative of H evaluated at coordinates X was equal to zero, the following results:

(f) $$F_{\alpha,i} = \Sigma_{\beta,j} \frac{\delta^2 H}{\delta \zeta_{\alpha,i} \delta \zeta_{\beta,j}} \delta \zeta_{\beta,j}$$

This last relation provides the expression for the externally applied forces corresponding to an arbitrarily small deformation. The coefficients

(g) $$\frac{\delta^2 H}{\delta \zeta_{\alpha,i} \delta \zeta_{\beta,j}}$$

from (f) above are the elements of the stiffness matrix.

Proceeding further the discussion will be specialized to pertain specifically to a pin jointed frame. The energy relationship may then be written;

(h) $$H = \sum_{L=1}^{N} hL$$

In this last relationship $h_L$ represents the potential energy in the L′th compression strut and N is the total number of compression struts. Each compression strut connects two vertices V and the potential energy contained therein will be a function of the distance between the vertices V;



(j) $$S_L^2 = \sum^{N} (X_{\alpha,i} - X_{\alpha,j})^2$$

The strut of interest L runs between vertices *ij*. In such a case the elements of the stiffness matrix are expressed by the following relationship;

(k) $$\frac{\delta^2 H}{\delta X_{\alpha,i} \delta X_{\beta,j}} = \Sigma \frac{\delta}{\delta X_{\alpha,i}} \left[\left(\frac{\delta h_L}{\delta S_L}\right)\left(\frac{\delta S_L}{\delta X_{\beta,j}}\right)\right] = \Sigma_L \frac{\delta^2 h_L}{\delta S_L^2}\left(\frac{\delta S_L}{X_{\alpha,i}}\right)\left(\frac{\delta S_L}{X_{\beta,j}}\right) + \frac{\Sigma \delta h_L}{L \delta S_L} \cdot \frac{\delta^2 S_L}{\delta X_{\alpha,i} \delta X_{\beta,j}}$$

In the last relationship the quantity;

(l) $$\frac{\delta h_L}{\delta S_L}$$

is the tension on strut L and the quantity

(m) $$\frac{\delta^2 h_L}{\delta S_L^2}$$

is the spring constant of strut L. The following results;

(n) $$\frac{\delta^2 H}{\delta X_{\alpha,i} \delta X_{\beta,j}} = \Sigma_L k_L \left(\frac{\delta S_L}{X_{\alpha,i}}\right)\left(\frac{\delta S_L}{X_{\beta,j}}\right) + \Sigma T_L \frac{\delta^2 S_L}{\delta X_{\alpha,i} \delta X_{\beta,j}}$$

The first term in relationship (n) is the principal term and the second term is the stress term.

The principal term in the stiffness matrix of (n) is proportional to the intrinsic stiffness of the compression struts and the second term is proportional to the stress contained in them. The stress term will be zero unless the space frame of FIG. 1 is stressed at assembly. In general, it tends to have a magnitude of one tenth or less of the principal term. The stress term is of interest only when there exist displacements for which the principal term is identically zero. This latter type of displacement may be defined as a soft mode. Stated in another way, a soft mode of a space frame is a displacement where the stiffness term approaches zero when the tension approaches zero. Soft modes are important because for most loadings of a structural framework they account for most of the motion. Referring again to relationship (n) such modes occur when displacement creates little or no principal term magnitudes while small magnitudes of the tension or stress term are created.

In the relationship (n) the primary term is the only one present when no stress is imposed in the structural members. In this state the soft modes are the zeros of the stiffness matrix, i.e., they are motions to which the structure provides no resistance. There is an easy and well known way of calculating the number of such motions which are linearly independent. One first imagines that the vertices were present without any struts joining them in which case there would be three degrees of freedom for each vertex. Then from this total each strut removes one degree of freedom, provided there is no redundancy among the struts. The following relationship arises:

(r) Degrees of freedom $= 3V - S + R$

In (r) above V is the number of vertices, S is the number of compression struts, and R is the redundancy of the struts.

If R were equivalent to zero there would be freedom to vary the length of each compression strut independently making it impossible to impose stress at assembly. This redundancy is equivalent to the number of struts, tension or compression, which must be cut in order to remove all internal stress imposed at assembly. The number of degrees of freedom in the relation (r) determines the soft modes, but includes six trivial soft modes which are the whole body rotations and translations of the structure. Excluding these the soft modes are determined from the following;

(s) Soft modes $= 3\ V - S + R - 6$

In the structure of FIG. **1**, $V = 10$, $S = 22$ (the sum of tension and compression struts), and $R = 1$. Soft modes for the framework of FIG. **1** therefore number three.

The structure represented by the chair framework of FIG. **1** is a structure which has stress imposed in the tension and compression members at assembly. The soft modes provide for a cushioning effect and for adaptation of the base of the framework to an irregular supporting surface. The redundancy R is set at the minimum value of 1 in the interest of easy assembly and disassembly. Thus the framework is easily set up for use and easily collapsed for storage.

The embodiment of FIG. **1** uses five non-touching compression strut members eliminating joints between rigid members in the framework and simplifying construction. Seventeen tension members are present, as indicated in Table A, which are called upon to support tensile forces only. Since the compression members do not touch and the tension members need support tensile forces only, none of the framework components need be configured to have the necessary strength to support bending stresses. Thus, all members are reduced in mass to support only the stresses imposed at assembly plus the stress imposed when a predetermined maximum weight is supported by the structure.

Referring to FIG. **2** a seat member **17** is shown supported from vertices D and D′ and vertices C and C′. The seat member **17** describes an approximate catenary curve when empty, and readily conforms to the body contours of a person when seated therein. Seat member **17** has loops **18** formed at the lower end thereof for securing the seat member to the vertices C and C′ as seen in FIG. **3.** Similar means are used to support the upper ends of seat **17** from vertices D and D′.

The most beneficial soft mode in the disclosed embodiment appears as torsion about the axis of the horizontal cross member **16.** To a first approximation torsion about the axis of cross member **16** does not change the length of any strut and the stiffness of the struts does not restrain motion in this mode. This is the softest mode in the disclosed embodiment. This mode allows the chair to set firmly with four point contact at the lower ends of left and right arm members **13** and **14** and left and right upright members **11** and **12** providing stability on irregular supporting surfaces. Preferably this mode is sufficiently soft to allow the weight of the chair itself to provide the aforementioned four point contact on all but the most uneven surfaces. The supporting surface prevents further motion in this mode once four point contact is made therewith.

A second soft mode exists which gives the seat a certain vertical springiness. This mode is symmetric with the chair framework vertical plane of symmetry. When a weight is placed in the seat member **17,** left and right arm members **13** and **14** move closer together at their upper ends represented by vertices C and C′ allowing the lower portion of the seat **17** to move down slightly. This mode must be fairly stiff to prevent the maximum predetermined weight from bringing arm members **13** and **14** into contact with upright members **11** and **12** respectively. The minimum acceptable stress at assembly is determined as that stress which will maintain separation between the upright and arm members for the maximum predetermined weight to be supported. The upper limit of stress imposed at assembly is determined by the consideration requiring that the softest mode, torsion about the axis of cross member **16,** be as soft as possible.

A third soft mode is stiffer than the second mode and allows a forward motion of vertices on one side of the symmetry plane relative to those on the other. The third soft mode may be substantially eliminated by replacing the tension member B, B′ with two tension members A, B′ and A′, B. Once vertices A, A′, B and B′ are all in contact with a supporting surface this last configuration would not contain the third soft mode.

Disassembly or collapse of the structure of FIG. **1** is elementary. As discussed above the quantity R in relation (r) is **1.** If one tension member is released from a vertex the redundancy is reduced to zero, no tension or compression may exist in the members, and the structure may be arranged in the most convenient configuration for storage.

The compression struts in one embodiment of the invention forming a stressed chair assembly are formed of one and one eighth inch dowels such as those used for broom handles. Strut lengths for this embodiment may be seen in Table B below:

TABLE B

| Strut | Inches Length | Dowel | Rope |
|---|---|---|---|
| AC | 43 | X | |
| A′C′ | 43 | X | |
| BD | 46¾ | X | |
| B′D′ | 46¾ | X | |
| EE′ | 38¼ | X | |
| AB | 37½ | | X |
| A′B′ | 37½ | | X |
| BC | 21¼ | | X |
| B′C′ | 21¼ | | X |
| CD | 28 | | X |
| C′D′ | 28 | | X |
| DE | 21 | | X |
| D′E′ | 21 | | X |
| EA | 17½ | | X |
| E′A′ | 17½ | | X |
| EC | 23¾ | | X |
| E′C′ | 23¾ | | X |
| EA′ | 28¼ | | X |
| E′A | 28¼ | | X |
| ED′ | 32¼ | | X |
| E′D | 32¼ | | X |
| BB′ | 24¼ | | X |

Holes having the diameter of the tension members, or ropes, are drilled near the vertices in the compression members, or dowels. A single tension member passes through each hole and the holes are oriented radially to allow the tension members to run through with minimum bending. Means are provided to secure the tension members in place in the holes to prevent longitudinal motion therein after tension is imposed at assembly.

A continuous tension member may run between vertices C, E, A, B, C, D and E. Another tension member may run through the corresponding tension members on the opposite side of the plane of symmetry. Lighter tension members may run between vertices D, E', A and between D', E, A'. Another light tension member is placed between BB'.

The following tension and compression force ratios in Table C would exist in the indicated members where the imposed stresses at assembly are normalized relative to tension member AB:

TABLE C

| Strut | Tension | Compress. | Force Ratios - Rel. AB Computed | Measured |
|---|---|---|---|---|
| AB | X | | 1.00 | 1.00 |
| A'B' | X | | 1.00 | |
| BC | X | | 1.30 | 1.41 |
| B'C' | X | | 1.30 | |
| CD | X | | 1.28 | 1.38 |
| C'D' | X | | 1.28 | |
| DE | X | | 0.58 | 0.55 |
| D'E' | X | | 0.58 | |
| DE' | X | | 0.59 | 0.57 |
| D'E | X | | 0.59 | |
| EC | X | | 1.27 | 1.48 |
| E'C' | X | | 1.27 | |
| EA | X | | 1.70 | 2.20 |
| E'A' | X | | 1.70 | |
| EA' | X | | 0.59 | 0.53 |
| E'A | X | | 0.59 | |
| BB' | X | | 0.30 | 0.30 |
| AC | | X | −2.49 | |
| A'C' | | X | −2.49 | |
| BD | | X | −1.79 | |
| B'D' | | X | −1.79 | |
| EE' | | X | −2.24 | |

Table C shows computed values for all twenty two struts. Compression is indicated as negative ratios and tension is positive. The measured ratio values were derived from measurements in the tension struts using strut AB as the norm. A typical tensile force in strut AB for a chair application for adults is 70 pounds. A tension member having a low force ratio is selected generally as the tension member which is stressed at assembly. DE' or D'E are ideal members for stressing at assembly requiring 0.59 times 70 pounds or 41 pounds in this embodiment. The other members thereby experience force ratios as seen in Table C by virtue of their interconnection as seen in the drawings.

A stressed structure has been disclosed of lightweight construction from readily available materials. The tension members may be metallic or they may be of some common fiber depending upon the tensile forces to be supported therein. The compression members may also be metallic, solid or tubular, wooden, or any other material capable of supporting the compression forces to be applied therein. A structure providing soft modes in conjunction with stability on irregular supporting surfaces is provided affording an ideal construction for a chair assembly.

I claim:

**1.** A stressed chair assembly for supporting a weight comprising

left and right upright compression members, left and right arm compression members, a crossing compression member, said compression members being non-touching and stressed in the assembly to thereby include substantially compressive force only, whereby compression member mass may be minimized while providing structural strength for supporting forces from the assembly stress and the supported weight,

a plurality of structure vertices defined by the ends of said compression members,

a plurality of tension members extending between predetermined ones of said structure vertices, said tension members being stressed in the assembly to include tensile force only, whereby tension member mass may be minimized while providing structural strength for supporting forces from the assembly stress and the supported weight, a single one of said plurality of tension members being a redundant member, so that when tensile force is removed from said redundant member the tensile and compressive forces are removed from all of said tension and compression members so that the chair assembly may be collapsed and stored,

said compression and tension members being disposed so that a plane of symmetry extends through the center thereof,

said crossing compression member being substantially orthogonal to and passing through said plane of symmetry,

said left and right upright and arm compression members having one end each for contacting an underlying support surface,

and a flexible seat member suspended between the other ends of said left and right upright and arm compression members for supporting the weight,

said compression and tension member assembly having at least one soft mode allowing said one ends of said compression members to adapt to the shape of the underlying surface for stabilizing the structure,

said left and right upright compression members and said left and right arm compression members each having three tension members connected to each end thereof, and

said crossing compression member having five tension members connected at each end thereof.

**2.** A stressed chair assembly as in claim **1** wherein said compression and tension members are disposed so that a second soft mode operates to provide a limited motion in a generally vertical direction of said flexible seat member.

**3.** A stressed structure assembly as in claim **2** wherein said one soft mode is softer than said second soft mode.

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