Sept. 19, 1961 J. H. SCHULZE ET AL 3,000,386

EXPANSIBLE FRAME STRUCTURE

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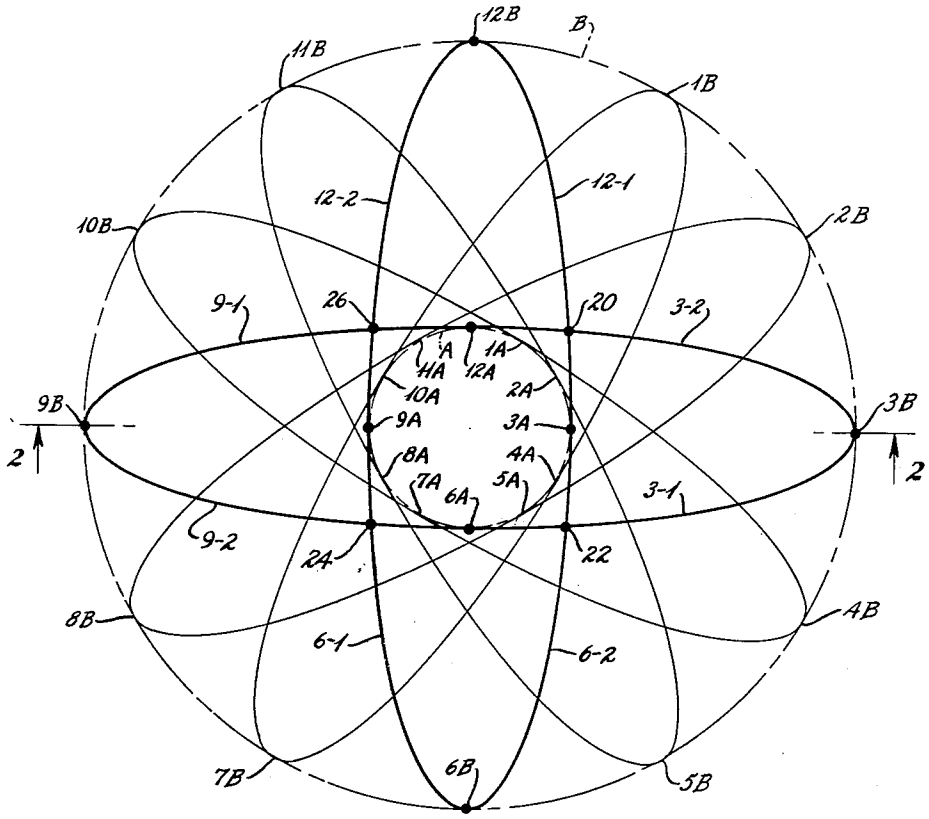

Fig. 1

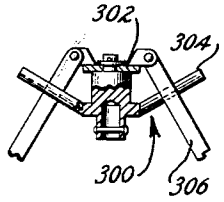

Fig. 12

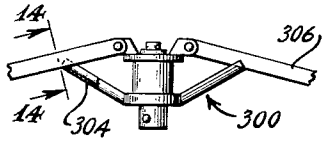

Fig. 13

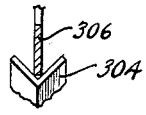

Fig. 14

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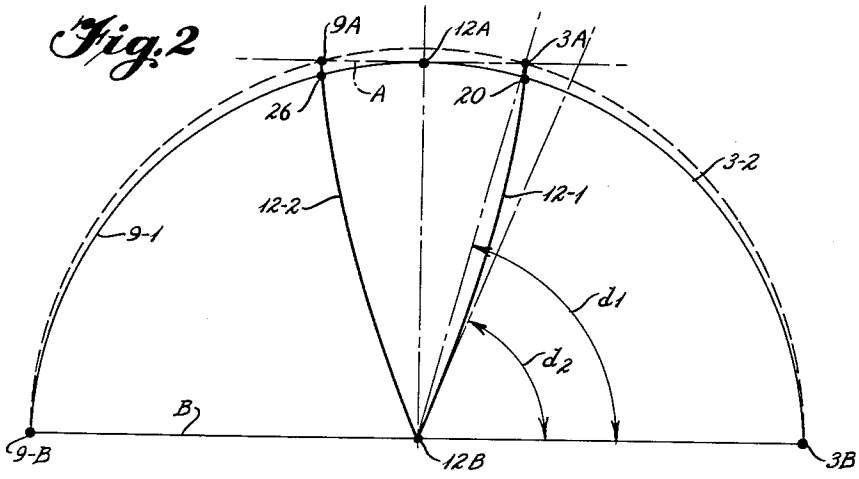
Fig. 2



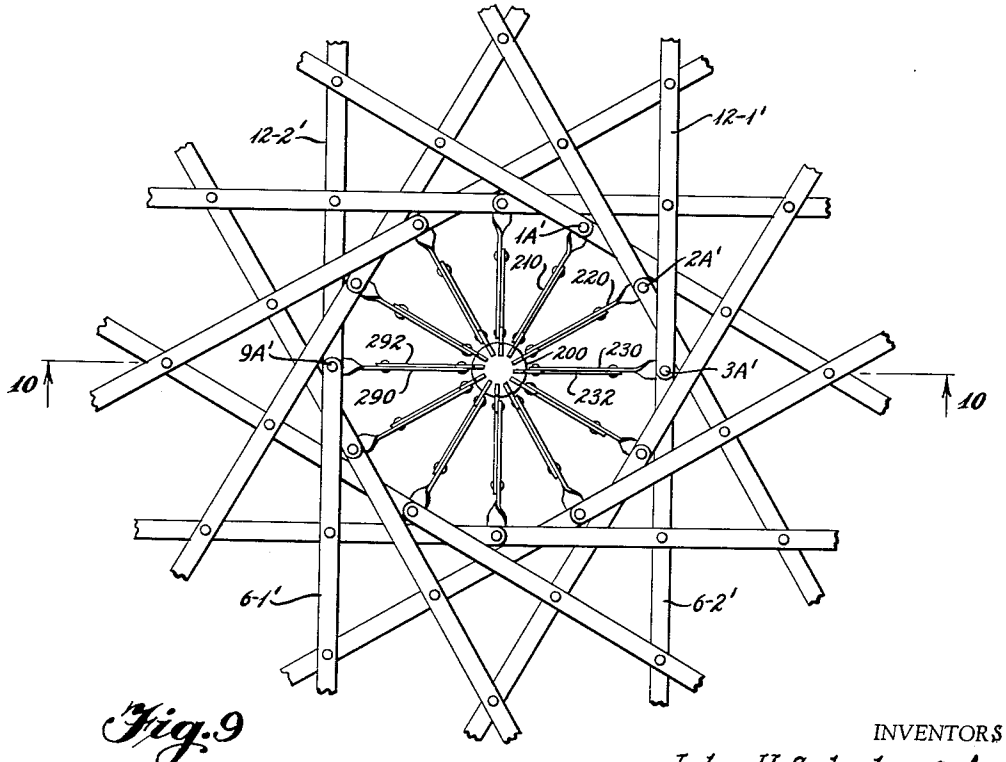


Fig. 9

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EXPANSIBLE FRAME STRUCTURE

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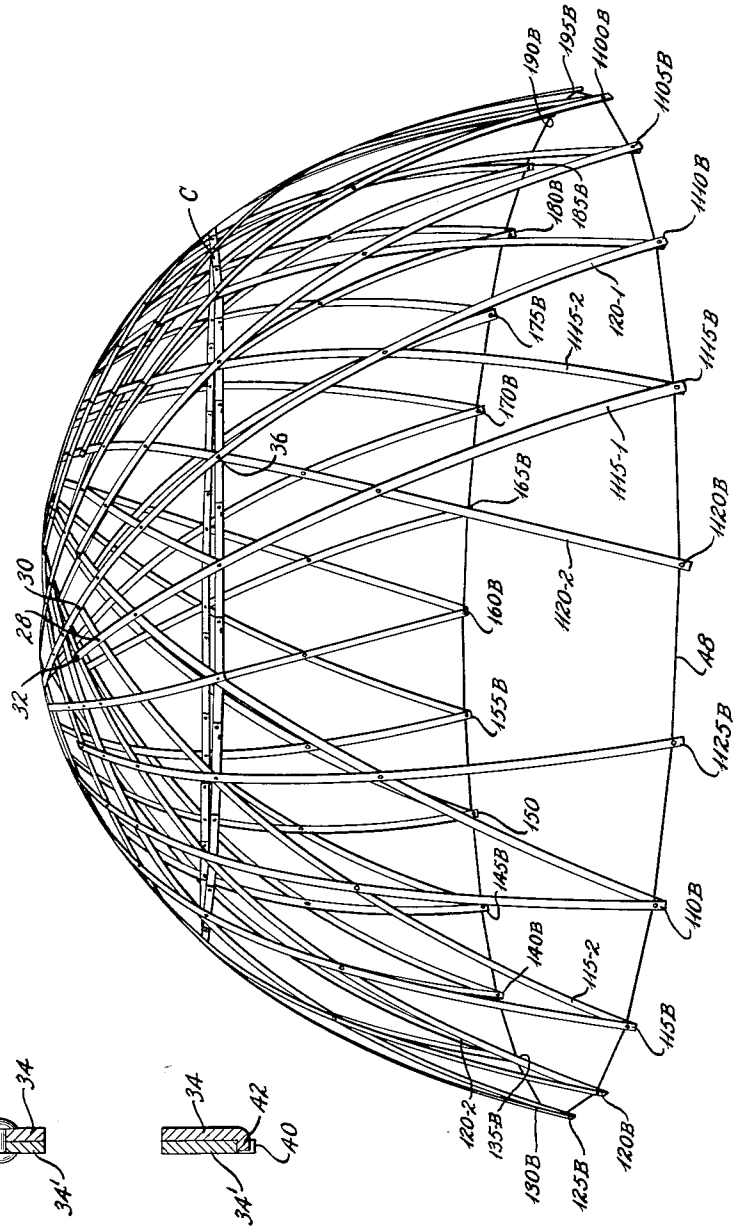

Fig. 3

Fig. 7

Fig. 8

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EXPANSIBLE FRAME STRUCTURE

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Fig. 4

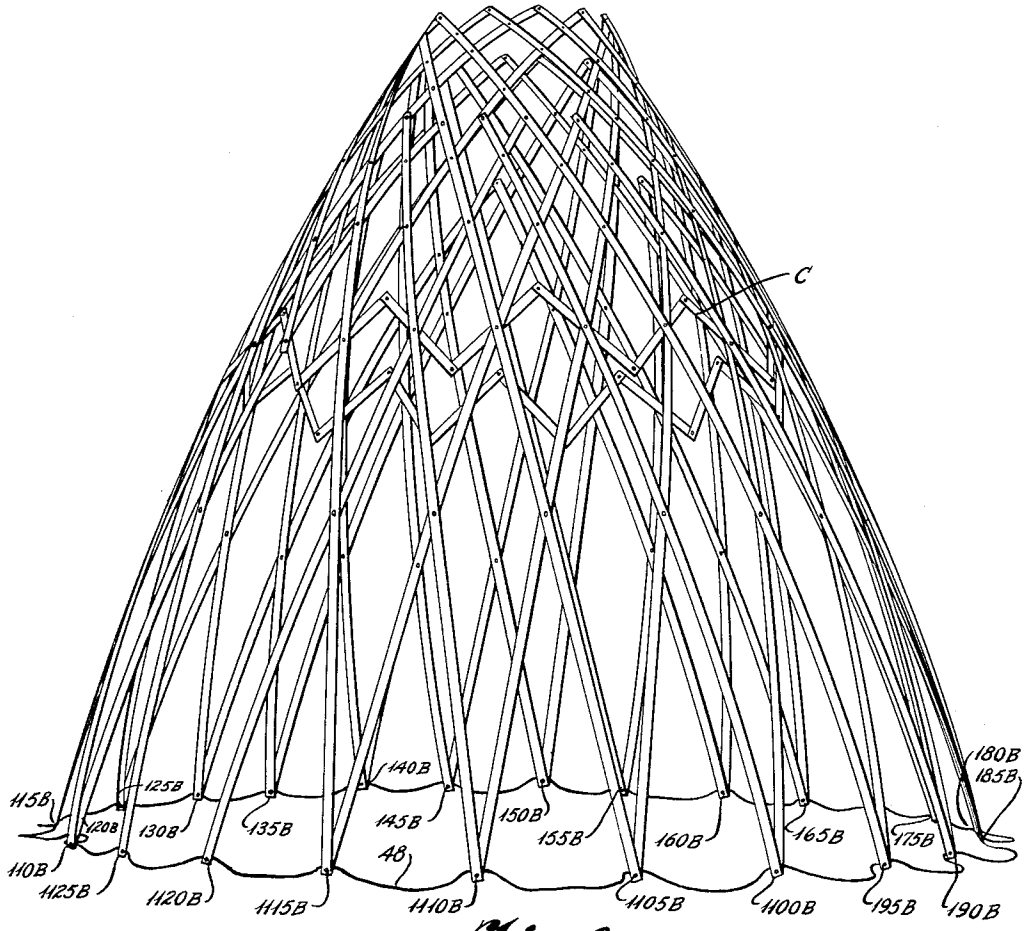
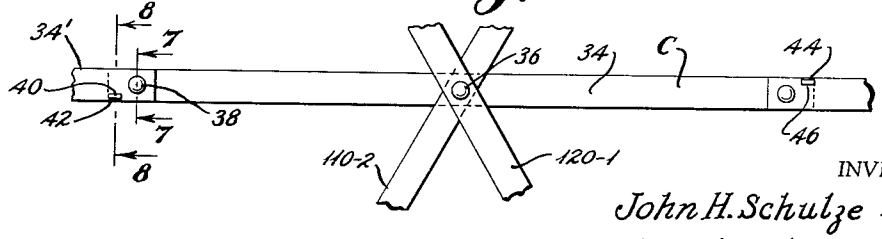


Fig. 6



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EXPANSIBLE FRAME STRUCTURE

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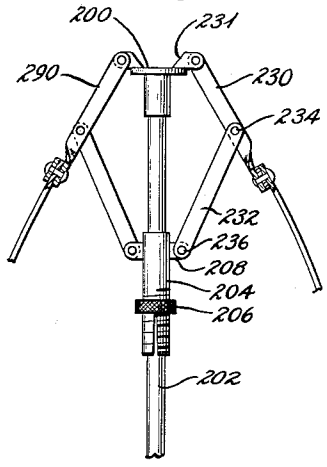
Fig. 11



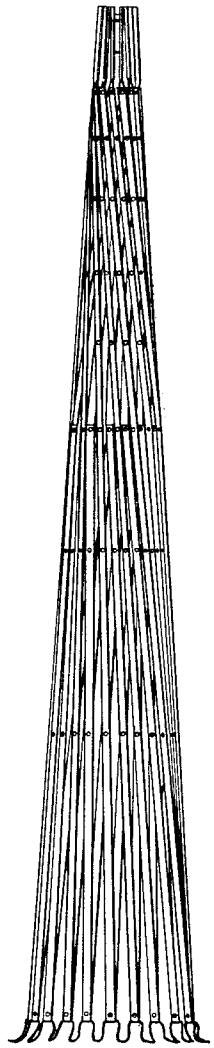


Fig. 5

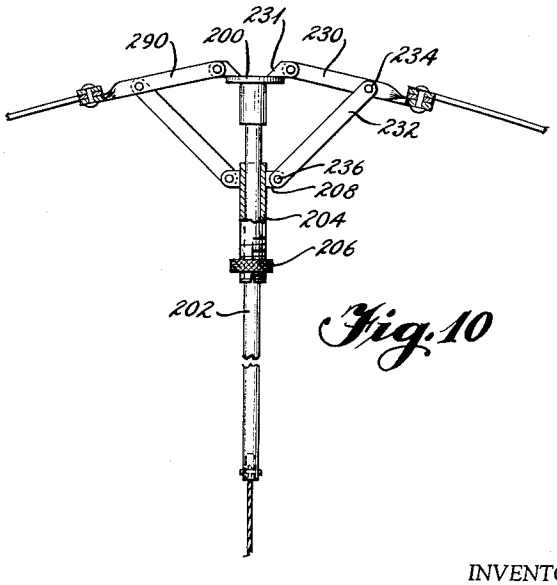


Fig. 10

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United States Patent Office 3,000,386 Patented Sept. 19, 1961

3,000,386

EXPANSIBLE FRAME STRUCTURE

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Filed Dec. 3, 1958, Ser. No. 778,012
7 Claims. (Cl. 135—4)

This invention relates to expansible frame structures, and more particularly to such structures adapted when in their expanded positions to approximate a curved surface of revolution generated about a vertical axis.

A primary object of the invention is to provide a collapsible frame structure of relatively light weight and compact shape when in its collapsed position which may be rapidly expanded to define a rigid hollow dome-like structure.

Another object of the invention is to provide an expansible frame structure assembled from relatively light weight flexible strips interconnected to form a dome-like structure of substantial rigidity in its expanded position.

Still another object of the invention is to provide an expansible frame structure collapsible into a substantially tubular form and expansible to define a hollow dome-like frame.

In the achievement of the foregoing and other objects, a frame structure embodying the present invention is constructed from a plurality of flat flexible light weight metallic strips. The strips are located with their lower ends on a base circle which is centered upon a vertical axis of symmetry of the structure in either its expanded or collapsed form. One series of strips extends upwardly and circumferentially of the axis in one direction to have their upper ends located on an apex circle which is likewise centered upon the axis of symmetry. Each strip in a second group of strips is pivotally connected at its lower end to one of the strips in the first series of strips and extends upwardly and circumferentially of the axis in an opposite circumferential direction to the apex circle. At the apex circle each strip of the second group is pivotally connected to a strip of the first group. Between its upper and lower ends, each second strip passes across one or more first strips and is pivotally connected to each first strip. The points of pivotal interconnection between the ends of the strips are located so that when the structure is expanded the strips are flexed into a curved configuration. When the expanded structure defines a hemispherical dome, all strips extend along great circle arcs of the hemispherical dome.

The upper ends of the strips may be coupled by a suitable locking means to lock the structure in its expanded position or in a position intermediate the collapsed and fully expanded position. A series of links pivotally interconnecting the strips is located to extend circumferentially around the expanded structure along a circle intermediate the base and apex circles. When in the expanded position, the links define a compression ring serving to hold the structure in the desired form.

Other objects and advantages of the invention will become apparent by reference to the following specification taken in conjunction with the accompanying drawings.

In the drawings:

FIG. 1 is a schematic diagram in plan elevation of a frame structure embodying the invention;

FIG. 2 is a schematic diagram representing a sectional view of the diagram of FIG. 1 taken on line 2—2 of FIG. 1;

FIG. 3 is a perspective view of a structure embodying the invention in a fully expanded condition;

FIG. 4 is a perspective view of the structure of FIG. 3 in a partially collapsed condition;

FIG. 5 is a side view of the structure of FIG. 3 in a nearly fully collapsed condition;

FIG. 6 is a detail view of a portion of the structure of FIG. 3;

FIG. 7 is a cross-sectional view taken on line 7—7 of FIG. 6;

FIG. 8 is a cross-sectional view taken on the line 8—8 of FIG. 6;

FIG. 9 is a partial plan view of a modified form of structure in a fully expanded condition;

FIG. 10 is a cross-sectional view of the structure of FIG. 9 taken on line 10—10 of FIG. 9;

FIG. 11 is a view similar to FIG. 10 showing the structure in a partially collapsed condition;

FIG. 12 is a detail view of a modified form of structure with certain parts broken away and others shown in section showing the parts in a partially collapsed condition;

FIG. 13 is a view similar to FIG. 12 showing the structure of FIG. 12 in a fully expanded condition; and

FIG. 14 is a detail cross-sectional view taken on line 14—14 of FIG. 13.

The frame structure disclosed in the drawings is constructed from a plurality of flexible metallic strips of relatively flat rectangular cross-section. By virtue of the structural relationship of the strips in the completed structure, relatively light weight strips such as aluminum may be employed to achieve a substantially rigid structure.

It is believed that the relationship of the strips in the completed structure may be best understood by first referring to the simplified schematic showing of FIGS. 1 and 2. FIG. 1 is an approximate plan view of the interrelationship of a simplified frame structure embodying the invention when the structure is expanded into a hemispherical dome-shape. To point out the relationship of the strips, it is convenient to make reference to an imaginary base circle B and an imaginary apex circle A. The base circle and apex circle are both centered upon a vertically extending axis of symmetry. In the schematic view of FIG. 1, twelve symmetrically spaced base locations 1B through 12B are indicated. For the sake of clarity, those strips having their lower ends located at base locations 3B, 6B, 9B and 12B have been indicated in heavy line, the remaining strips being shown in relatively light lines. In the simplified schematic cross-sectional view of FIG. 2, the strips shown in light line in FIG. 1 have been omitted entirely.

At each of base locations 3B, 6B, 9B and 12B a pair of like strips are pivotally interconnected at their lower ends to form a strip pair. The pair of strips having their lower ends pivotally interconnected at base location 12B are identified as 12–1 and 12–2. It is convenient to describe the strip pair as comprising a first strip 12–1 which extends upwardly from base location 12B to an upper end located at apex location 3A. Strip 12–1 not only extends upwardly from base location 12B but also extends circumferentially about the vertical axis of symmetry in a generally clockwise direction. The other strip of the strip pair, strip 12–2, extends upwardly from base location 12B to apex location 9A. The second strip, 12–2 of the strip pair under consideration extends circumferentially about the vertical axis in an opposite sense from the direction of inclination of strip 12–1.

Corresponding nomenclature has been applied to the various strips extending from base locations 3B, 6B and 9B. In each case the first strip which is inclined in a clockwise circumferential direction as viewed in FIG. 1 has been designated by the subscript 1, the second strip of the strip pair being designated by the subscript 2.

All strips are of equal length and each strip extends from a location on the base circle to a location on the apex circle.

Strips 6–1 and 6–2 are pivotally connected at their lower ends at base location 6B which is diametrically opposed from base location 12B. Strip 6–1 is pivotally interconnected at location 9A to the upper end of strip 12–2, while strip 6–2 is pivotally connected at its upper end to the upper end of strip 12–1 at apex location 3A. The pivotally interconnected strips 12–1, 12–2, 6–1 and 6–2 define a unit of the complete frame structure. Each strip of the unit extends along a great circle arc of the hemispherical dome defined by the expanded frame structure, and each unit may be said to define the boundary of a spherical lune.

Strips 3–1, 3–2 and 9–1 and 9–2 are pivotally interconnected in a similar fashion to define a second unit which, as best seen in FIG. 1, extends transversely of the structure with respect to the unit extending between locations 6B and 12B. At each point of intersection between the strips of different units, the strips are pivotally interconnected to each other as at 20, 22, 24 and 26.

It is believed apparent that the strips having their lower ends located at the remaining base locations are pivotally interconnected in a similar fashion. At each intersection of each strip, the strips are pivotally interconnected. In all cases, the axis of the pivotal interconnection between strips is oriented so that a projection of the axis in the expanded condition of the frame would pass through the vertical axis of symmetry at the intersection of the axis with the center of base circle B. In other words, the axes of pivotal interconnections all extend radially of the hemispherical surface defined by the expanded frame members.

While the structure schematically represented in FIGS. 1 and 2 shows the base circle divided into twelve equally spaced base locations, it is believed apparent that any even number of symmetrically disposed base locations could be employed, dependent largely upon the size of the completed structure.

The specific locations of the points of pivotal intersection between the various strips may be determined either geometrically or mathmatically from their relationships in the expanded position of the structure.

One exemplary form of expansible frame structure embodying the invention is shown in FIGS. 3 through 8. Referring first to FIG. 3, the first structural embodiment shows a hemispherical dome framework in its expanded position, the structure having an imaginary base circle divided into twenty-four equally spaced base locations. The embodiment of FIGS. 3 through 8 may be compared with the schematic representations of FIGS. 1 and 2 by stating that base locations 110B, 120B and 1100B, etc., numbered in sequence corresponding to hour positions on a clock face, correspond respectively to base locations 1B, 2B, and 10B of FIGS. 1 and 2. From each of the even numbered base locations in FIG. 3, a strip pair extends upwardly from the base circle to a location on an apex circle corresponding to the apex circle A of FIGS. 1 and 2. Thus, as in FIGS. 1 and 2, the strip pair projecting upwardly from base location 130B, for example, is joined at its upper ends to the respective upper ends of the strip pair projecting upwardly from the diametrically opposed base location 190B.

Midway between base locations 110B and 120B, an intermediate base location 115B denotes the base location of a strip pair 115–1 and 115–2. Strips 115–1 and 115–2 do not extend completely from the base circle to the apex circle but terminate at a location somewhat below the apex circle. Strip 115–1 and strip 1115–2 perhaps illustrate the extent of these strips most clearly. Thus, strips 115–1 and strip 1115–2 intersect each other at a location 28 well below the apex circle. The two strips are pivotally interconnected at location 28 and are respectively projected beyond their point of intersection to be pivotally interconnected as at 30 and 32 to strips 120–1 and 1110–2. The strips projecting upwardly from remaining odd numbered base locations such as 125B, 135B, etc. are constructed in identical fashions to strips 115–1 and 1115–2.

To provide a doorway for access to the interior of the completed structure, certain strips are cut away as indicated at base locations 110B and 1125B.

To increase the rigidity of the expanded structure, a compression ring assembly indicated generally at C in FIG. 3 is pivotally interconnected with the various strips in a manner best seen in FIGS. 6 through 8. As is apparent from FIG. 3, when the structure is in its expanded position, compression ring assembly C extends around the circumference of the structure in a circular path at a location between the base circle and apex circle of the completed structure. Compression ring assembly C is constructed from a plurality of like links 34 (see FIG. 6), each link 34 being pivotally connected at a point of intersection between various strips such as the point 36 at the intersection of strips 110–2 and 120–1. The pivotal interconnection 36 extends through both of the strips and link 34.

The links 34 are pivotally connected to each other at each end in a head to tail relationship by a simple pivotal connection 38 connecting the strip 34 of FIG. 6 to an adjacent strip 34'. As best seen in FIG. 6, strip 34' is notched as at 40 to receive a lug 42 on the end of strip 34. An oppositely disposed lug 44 on the opposite end of link 34 is received within a complementary notch 46 on the adjacent link. This form of connection prohibits the various links 34 from pivoting beyond the position shown in FIG. 3 but permits them to collapse in the fashion shown in FIG. 4 as the structure is collapsed.

To further assist the framework in maintaining its expanded shape, a base line 48 is interconnected between the points of pivotal interconnection of the lower ends of the various steps to prevent the strips from moving outwardly beyond the imaginary base circle of the completed structure.

As can be observed by comparing FIGS. 3, 4 and 5, the structure may be collapsed from the hemispherical dome defining expanded position of FIG. 3 successively into a substantially paraboloid structure of FIG. 4, and a conical shape structure as shown in FIG. 5. When fully collapsed, the structure defines a substantially tubular form.

Referring now to FIGS. 9–11, one exemplary form of structure for interconnecting the upper ends of the various strips is disclosed. The structure of FIGS. 9–11 serves two purposes—first to assist in expanding or collapsing the frame structure, and second to lock the structure against movement in either direction from its expanded position.

For convenience in description, it will be assumed that the structure of FIGS. 9–11 is employed upon a six unit frame structure corresponding to the schematic diagram of FIGS. 1 and 2. For convenience, a numbering system similar to that employed in FIGS. 1 and 2 is employed in FIGS. 9–11 with the reference numerals in FIGS. 9 and 10 being primed.

From the discussion of the schematic diagram of FIG. 1, it will be recalled that one unit of the structure consisted of strips 6–1 and 6–2 which were pivotally interconnected to each other at their lower ends and pivotally connected at their upper ends respectively to strips 12–2 and 12–1, strips 12–2 and 12–1 being pivotally interconnected to each other at their lower ends at a base location diametrically opposed from the base location of strip pair 6–1 and 6–2. Referring now to the corresponding strips 6–1', 6–2', 12–1', and 12–2' of FIG. 9, it is seen that the pivotal interconnection between the upper ends of strips 6–2 and 12–1 is extended through the respective strips and through an additional link 230 which extends radially inwardly from the pivotal interconnection at 3A'. The inner end of link 230 is pivotally con-

nected to a lug **231** fixedly secured to a circular plate **200**. The pivotal interconnection between link **230** and lug **231** establishes an axis of pivotal movement which extends horizontally as opposed to the direction of the pivotal axis at 3A' which, as will be recalled, extends radially of the expanded hemispherical structure.

A similar link **290** extends radially from the pivotal interconnection at 9A' between strips **6–1'** and **12–2'** to a similar lug **291** fixed to plate **200** and to which the link **290** is pivotally connected for relative rotation about a horizontal axis. Similar link and lug connections are provided between plate **200** and all twelve pivotal interconnections located on the apex circle, such as link **210** from the pivotal connection at 1A', link **220** from the pivotal connection at 2A' etc.

A vertically extending shaft **202** is fixed to and extends downwardly from plate **200**. A sleeve **204** is slideably mounted upon shaft **202** and is split axially and threaded at its lower end to receive a compression lock-nut **206** by means of which sleeve **204** may be clamped to shaft **202** at selected axial positions on the shaft. At its upper end, a plurality of radially extending lugs such as **208** are fixed to sleeve **204** to provide structure for pivotally interconnecting a series of links such as **232** to the sleeve. Referring specifically to the link **232**, it will be noted that the upper end of link **232** is pivotally interconnected to link **230** as at **234** while its lower end is pivotally connected to a lug **208** as at **236**. Twelve equally spaced radially projecting lugs **208** are secured to sleeve **204**, each lug providing a pivotal mounting for the lower end of a link which is pivotally interconnected at its upper end to one of the upper links corresponding to **210**, **220**, **230** etc. at the various positions.

It is believed apparent that when the structure is in its expanded position, see FIGS. 9 and 10, sleeve **204** will be moved to its upper limit of movement and clamped in position with lock-nut **206**. The coupling between the shaft and strips by means of the various links rigidifies the structure at its upper portion. When the structure is partially expanded, as in the position shown in FIGS. 4 and 11, downward forces applied to shaft **202** will assist in moving the structure to its fully expanded position.

IN FIGS. 12–14, a modified form of expanding and locking assembly is disclosed. As in the case of the embodiment of FIGS. 9–11, a radially disposed link extends between each upper pivotal connection between strips inwardly to a common plate upon which the strips are pivotally secured for rotation about respective horizontal axes. In the FIG. 12–14 embodiment, a rigid frame structure **300** is suspended from a central plate **302** and is coupled to the plate to be capable of rotation about a vertical axis with respect to the plate. From the lower end of the framework a plurality of upwardly and outwardly inclined struts **304** of V-shaped cross-section project in radial directions. The struts are located symmetrically about the vertical axis of the framework and, when the structure is in the expanded position, each strut is located to engage one of a plurality of links such as **306** at its outer end in the fashion best shown in FIG. 14. Links such as **306** correspond to links **210**, **220**, **230** etc. of FIG. 9, each link **306** being coupled to frame strips in the same fashion as the links of FIG. 9. When the structure is to be collapsed, rigid frame **300** is pulled downwardly to disengage the links from the struts and rotated about the vertical axis to locate the struts out of alignment with the respective links, as in FIG. 12.

The structures described above provide a relatively light expansible framework which may be easily expanded to form a frame which may be covered with fabric to form a tent or weatherproof enclosure. The construction is such that the framework may be easily collapsed into a substantially tubular form of relatively small diameter and is thus readily portable.

While we have disclosed certain illustrative embodiments of our invention, it will be apparent to those skilled in the art that the disclosed embodiments may be modified. Therefore, the foregoing description is to be considered exemplary rather than limiting, and the true scope of our invention is that defined in the following claims.

We claim:

1. An expansible frame structure shiftable between a contracted position in which said structure defines an elongate substantially frusto-conical shape and an expanded position in which said structure defines a hollow substantially hemispherical dome-like shape, said structure in either of said positions having a vertical axis of symmetry extending upwardly from the center of a base circle to the center of an apex circle, said structure comprising a plurality of elongate flexible first strips having their lower ends located at symmetrically spaced locations upon said base circle, said first strips being inclined upwardly from said base circle to extend circumferentially in a first direction about said axis to terminate at their upper ends at symmetrically spaced locations on said apex circle, a plurality of elongate flexible second strips having a length equal to the length of said first strips, a first pivot located on the lower end of each of said second strips pivotally connecting the lower end of the second strip to the lower end of one of said first strips to define a strip pair, the second strip of each strip pair being inclined upwardly from said first pivot to extend circumferentially about said axis in a direction opposite to said first direction to terminate upon said apex circle at a location where the first and second strips of each strip pair are symmetrically disposed relative to each other on opposite sides of a vertical plane containing said axis and the first pivot of the strip pair, a second pivot on the upper end of each of said second strips pivotally connecting the upper end of the second strip of each strip pair to the upper end of a first strip of another strip pair, a series of third pivots interconnecting said strip pairs to each other at locations intermediate the ends of the strips, restraining means interconnecting the lower ends of said strip pairs to each other to maintain said first pivots on a base circle of relatively large maximum radius when said structure is in said expanded position, and means pivotally interconnecting said strips at a location above said base circle operable when said structure is in said expanded position to flex said strips to extend along great circle arcts of a hemispherical surface of radius substantially equal to said relatively large maximum radius and to establish a maximum radius of said apex circle materially smaller than said relatively large maximum radius.

2. A frame structure as defined in claim 1 wherein said means pivotally interconnecting said strips above said base circle comprises a compression ring assembly comprising a plurality of links pivotally connected between adjacent strips to extend circumferentially around said structure along a circle located intermediate said base circle and said apex circle when said structure is in said expanded position.

3. A frame structure as defined in claim 1 wherein said means pivotally interconnecting said strips above said base circle comprises a shaft extending along said axis, a plurality of link means pivotally connected at one end to the upper end of said shaft, each of said link means being pivotally connected at its other end to one of said second pivots, a sleeve slideably mounted upon said shaft, a plurality of actuating links, each actuating link being pivotally connected at one end to said sleeve and at the other end to one of said link means, and means for locking said sleeve to said shaft to selected locations thereon.

4. A frame structure as defined in claim 1 wherein said means pivotally interconnecting said strips above said base circle comprises a plate, a plurality of links, each link being pivotally connected at one end to said plate and at its opposite end to one of said second pivots, a rigid frame pivotally connected at its upper end to said plate for rotation relative to said plate about said axis of symmetry, said frame including a central shaft depending

from said plate and a plurality of upwardly and outwardly projecting fingers rigidly connected to said shaft, each of said fingers being engageable with one of said links to maintain said structure in said expanded position.

5. An expansible frame structure shiftable between a contracted position in which said structure defines an elongate substantially frusto-conical shape and an expanded position in which said structure defines a hollow substantially hemispherical dome-like shape, said structure in either of said positions having a vertical axis of symmetry extending upwardly from the center of a base circle to the center of an apex circle, said structure comprising a plurality of elongate flexible first strips of uniform length having their lower ends located at symmetrically spaced locations upon said base circle, said first strips being inclined upwardly from said base circle to extend circumferentially in a first direction about said axis and terminating at their upper ends at symmetrically spaced locations on said apex circle, a plurality of elongate flexible second strips having a length equal to the length of said first strips, a first pivot located on the lower end of each of said first strips pivotally connecting the lower end of a first strip to the lower end of a second strip to define a strip pair, the second strip of each strip pair being inclined upwardly from its lower end to extend circumferentially about said axis in a direction opposite to said first direction to terminate upon said apex circle at a location where the first and the second strip of each strip pair of symmetrically disposed relative to each other on opposite sides of a vertical plane containing said axis and the first pivot of the strip pair, a second pivot on the upper end of each of said first strips pivotally connecting the upper end of the first strip of each strip pair to the upper end of a second strip of a first other strip pair, a third pivot on each first strip spaced a first distance from the upper end of the first strip pivotally connecting the first strip of each strip pair to a second strip of a second other strip pair at a location spaced said first distance from the upper end of the second strip, first tension means interconnecting the lower ends of said strip pairs to each other to maintain the lower ends of said strips on a base circle of relatively large maximum radius when said structure is in said expanded position, and second tension means pivotally interconnecting the upper ends of said strips to each other to maintain the upper ends of said strips upon an apex circle having a maximum radius materially smaller than said relatively large maximum radius to thereby flex said strips to extend along great circle arcs of a substantially hemispherical surface of radius substantially equal to said relatively large maximum radius.

6. A frame structure as defined in claim 5 wherein said second tension means comprises a shaft extending along said axis, a plurality of first links each pivotally connected at one end to the upper end of said shaft, each of said first links being pivotally connected at its opposite end to one of said second pivots, a sleeve slideably mounted upon said shaft, and a plurality of second links, each of said second links being pivotally connected at one end to said sleeve and at its other end to one of said first links whereby axial movement of said sleeve upon said shaft expands and contracts said apex circle, and means for locking said sleeve to said shaft at selected axial positions thereon.

7. A frame structure as defined in claim 5 wherein said second tension means comprises a plate, a plurality of links each pivotally connected at one end to said plate, each of said links being pivotally connected at its other end to one of said second pivots, a rigid frame pivotally connected to said plate for movement relative to said plate about said axis of symmetry, said frame comprising a shaft depending downwardly from said plate, and a plurality of fingers projecting upwardly and outwardly from said shaft, each of said fingers being engageable with one of said links to maintain said structure in said expanded position.

References Cited in the file of this patent

UNITED STATES PATENTS

2,571,634	Von Gunten	Oct. 16, 1951
2,865,387	Annibaldi	Dec. 23, 1958

FOREIGN PATENTS

83,677	Austria	Apr. 25, 1921
114,827	Australia	Mar. 19, 1942