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[54] **SEQUENTIALLY DEPLOYABLE MANEUVERABLE TETRAHEDRAL BEAM**

[75] Inventors: **Martin M. Mikulas, Jr.,** Williamsburg, Va.; **Robert F. Crawford,** Santa Barbara, Calif.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration,** Washington, D.C.

[21] Appl. No.: **530,339**

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[51] **Int. Cl.⁴** **E04H 12/18**
[52] **U.S. Cl.** **52/646;** 52/632; 52/637; 52/648; 16/242; 16/390; 403/64; 403/171
[58] **Field of Search** 182/178, 179; 403/64, 403/171, 176, 49; 16/242, 254, 365, 382, 384, 387, 389, 390; 52/116, 117, 118, 121, 632, 637, 646, 648, 721, 654, 655; 14/14

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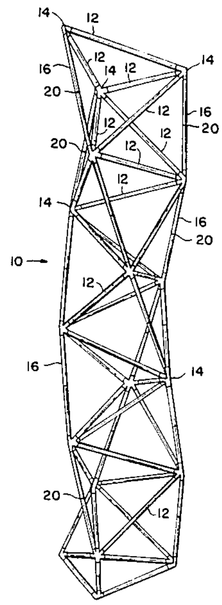
Primary Examiner—John E. Murtagh
Assistant Examiner—Andrew Joseph Rudy
Attorney, Agent, or Firm—Howard J. Osborn; Wallace J. Nelson; John R. Manning

[57] **ABSTRACT**

The invention relates to a tetrahedral beam that can be compactly stowed, sequentially deployed, and widely manipulated to provide a structurally sound yet highly maneuverable truss structure. The present beam is comprised of a plurality of repeating units comprised of tandem tetrahedra sharing common sides. Tetrahedra are comprised of fixed length battens **12** joined by joint **14** into equilateral triangles called batten frames. Apexes of adjacent triangles are interconnected by longerons **16** having mid-point folding hinges **20.** Joints **14** are comprised of gussets **24,34** pivotably connected by links **25.** Joints **14** permit two independent degrees of rotational freedom between joined adjacent batten frames, and provide a stable structure throughout all stages of beam deployment, from packaged configuration to complete deployment. The longerons and joints can be actuated in any sequence, independently of one another. The present beam is well suited to remote actuation. Longerons **16** may be provided with powered mid-point hinges **20***a* enabling beam erection and packaging under remote control. Providing one or more longerons **16** with powered telescoping segments **16***a* permits the shape of the beam central axis to be remotely manipulated so that the beam may function as a remote manipulate arm.

6 Claims, 9 Drawing Figures



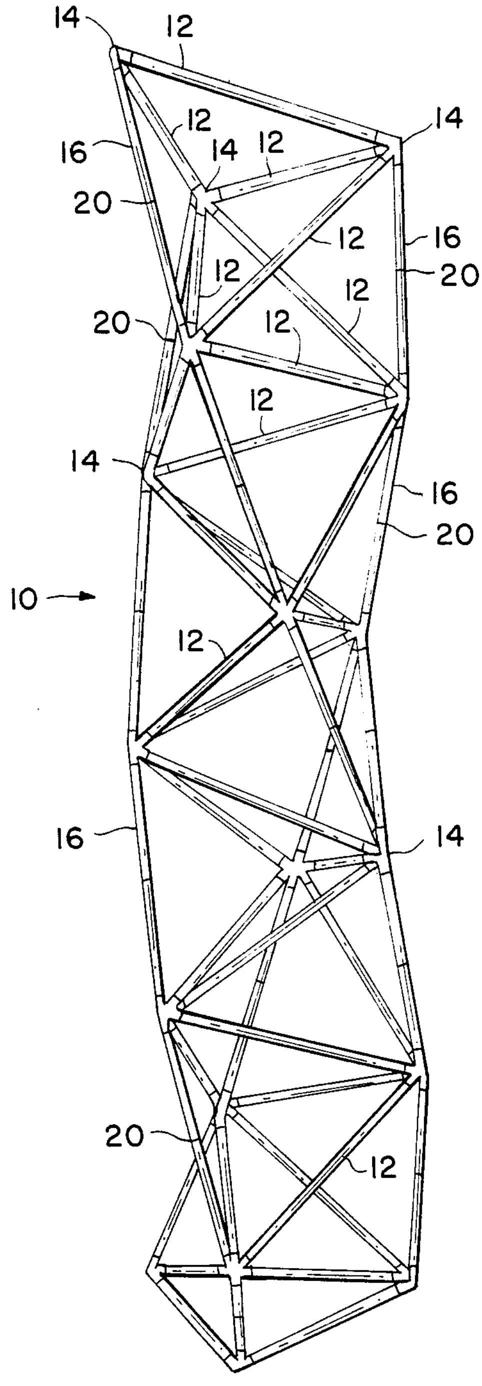

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FIG. 1

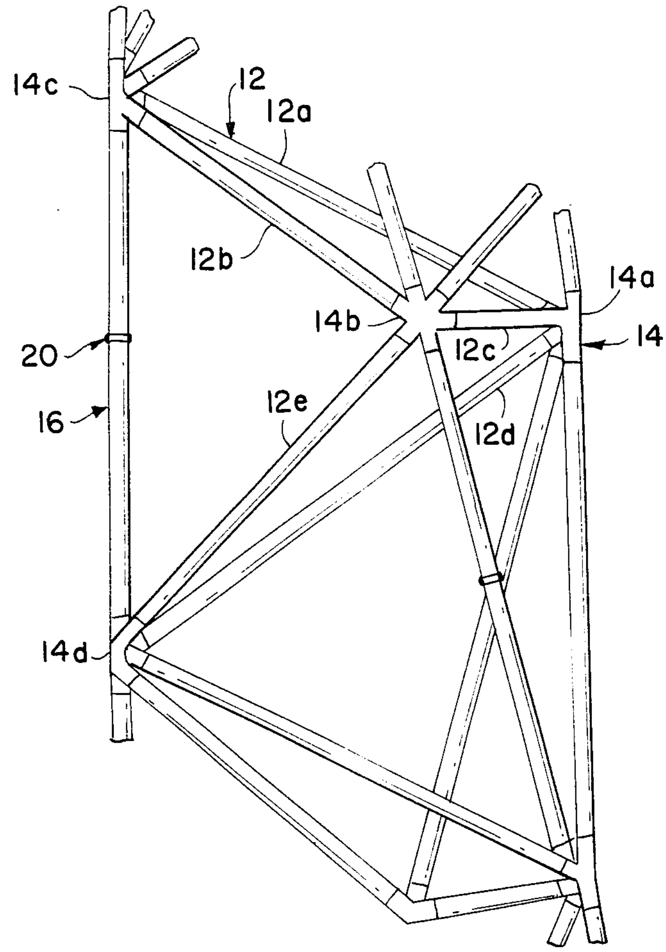


FIG. 2

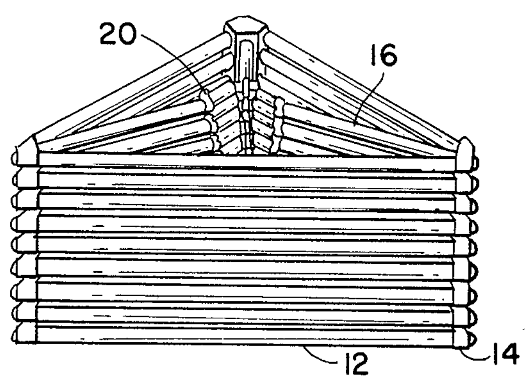


FIG. 3

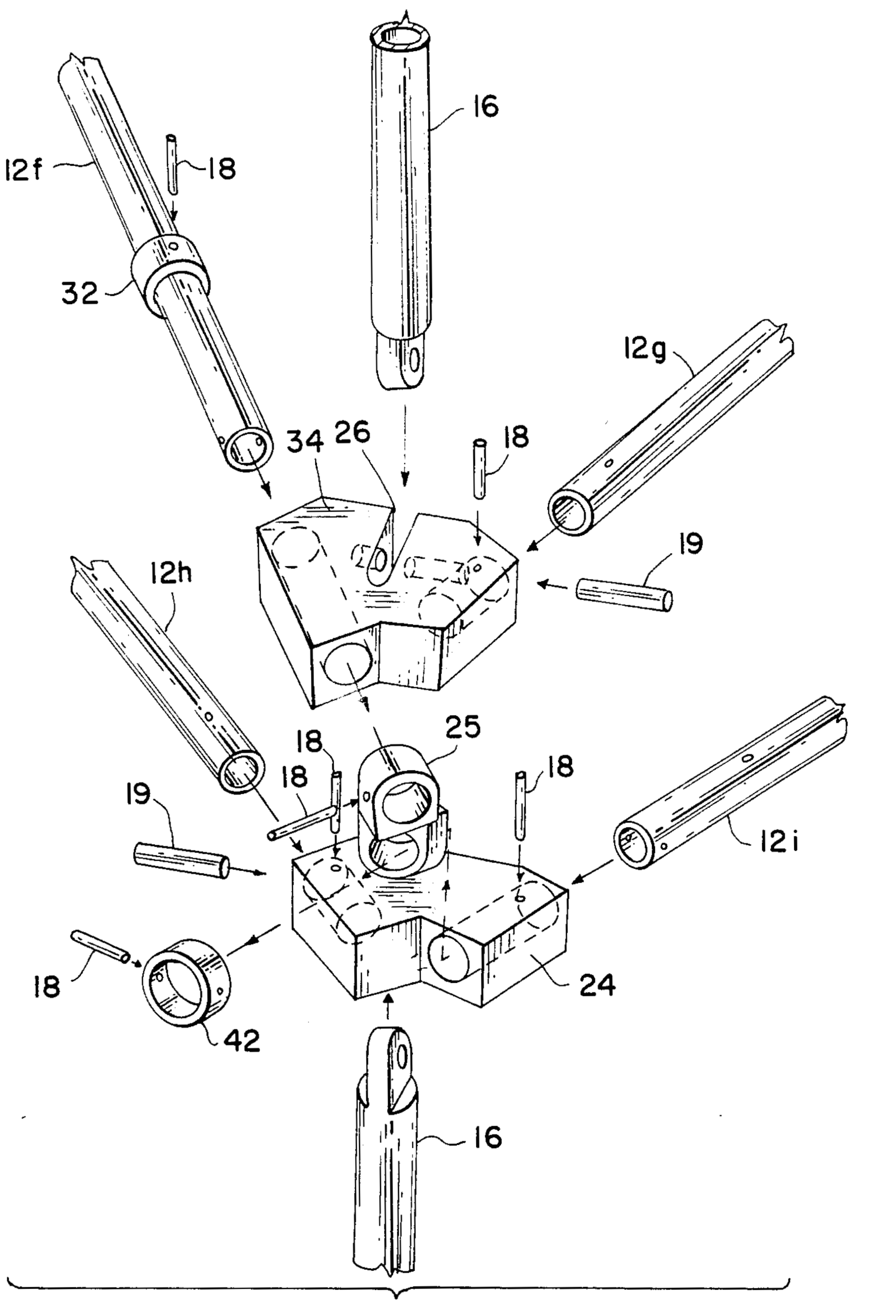


FIG. 4

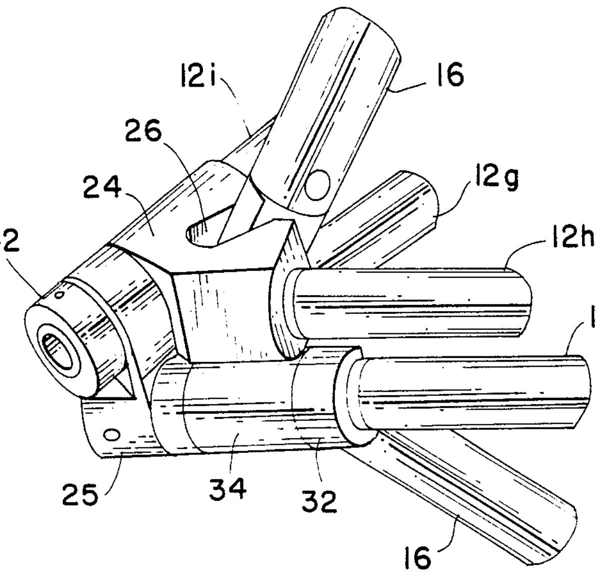


FIG. 5

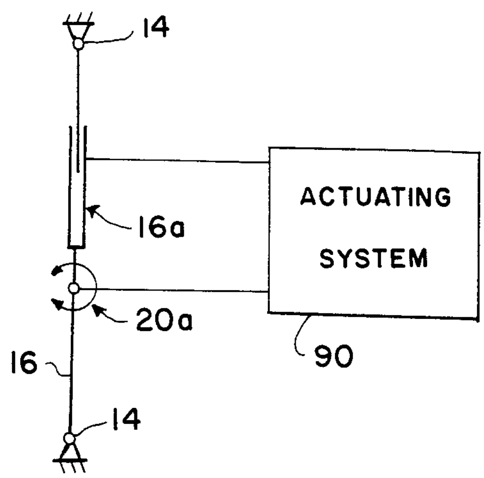


FIG. 9

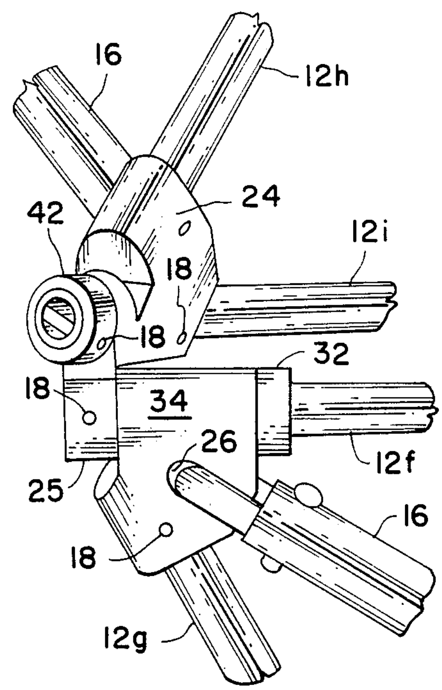


FIG. 8

FIG. 6

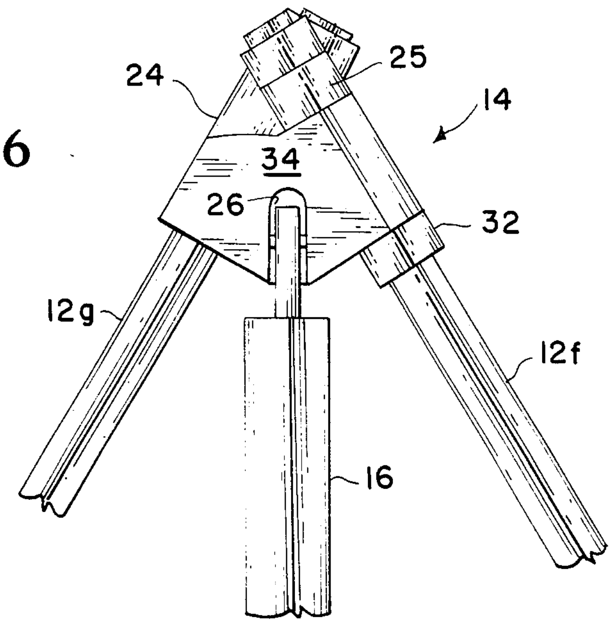
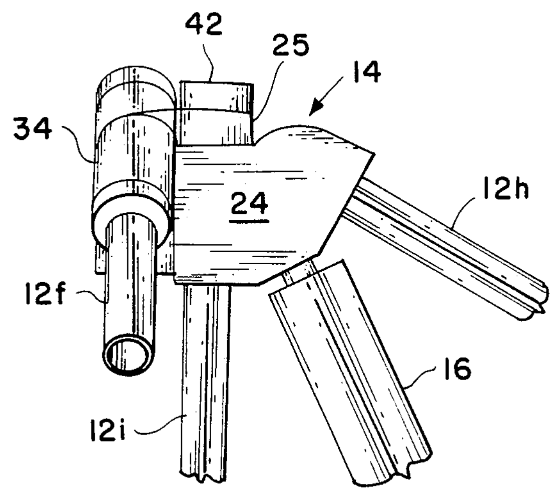


FIG. 7



SEQUENTIALLY DEPLOYABLE MANEUVERABLE TETRAHEDRAL BEAM

ORIGIN OF THE INVENTION

The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85-568 (72 Stat. 435; 42 USC 2457).

BACKGROUND OF THE INVENTION

The present invention relates generally to deployable truss structures and more specifically to a tetrahedral beam that can be compactly stowed, sequentially deployed, and widely manipulated to provide a structurally sound yet highly maneuverable truss structure.

The Space Shuttle Transportation System developed by the National Aeronautics and Space Administration has greatly facilitated the research and development of both small and large space structures. Projects presently under consideration include extremely large antennae for communications or Earth surveillance, orbital laboratories, and space-based manufacturing facilities. These missions will be characterized by a need for linear structural members, such as the tetrahedral beam, which are automatically deployable and capable of varying geometry during use.

A variety of expandable and deployable structures for both space and terrestrial applications are found in the prior art. Hedgepeth et al (U.S. Pat. No. 4,334,391) discloses a deployable lattice column comprised of longerons connected together by diagonals and battens. The column can be compactly packaged, then erected into a structurally sound column. Additionally, the column employs redundant structural members to preserve integrity should some elements fail.

Although the Hedgepeth column, as well as many others, have enjoyed commercial success, a deployable column which is maneuverable in a direction other than along its axis has yet to be demonstrated. None of the deployable beams found in the prior art are capable of varying the shape of their axes so as to function, for example, as a remote manipulator arm. Manipulator arms presently in use are designed to resemble human arms; they have rigid sections connected by flexible joints. Such manipulator arms do not provide the strong, stable structure provided by the present deployable and manipulatable tetrahedral beam structure.

It is therefore an object of the present invention to provide a novel structural column comprised of repeating units of tandem tetrahedra.

It is a further object of the present invention to provide a novel joint for flexibly joining tetrahedral beam structural members.

Another object of the present invention is to provide a tetrahedral beam which can be compactly packaged and remotely deployed.

An additional object of the present invention is to provide a deployable beam that does not require a separate canister or deployer.

Yet another object of the present invention is to provide a tetrahedral beam capable of widely varying the shape of its central axis so as to enable it to function as a remotely controlled manipulator arm.

A further object is to provide a stable beam comprised of fewer structural members per unit length than prior art truss beams.

BRIEF SUMMARY OF THE INVENTION

According to the present invention, the foregoing and other objects are attained by forming a tetrahedral truss beam comprised of a series of interconnected tetrahedra. Two tandem tetrahedra sharing common sides comprise the repeating unit of the present beam; a plurality of repeating units can be interconnected by the novel joint disclosed herein to form a beam of desired length.

The present beam compactly packages into a generally triangular solid about one-fourteenth as long as the extended beam. Longeron structural members can be remotely actuated by appropriate state of the art means to sequentially deploy the beam from the packaged geometry, as well as to operate the beam as a remote manipulator arm. The present joint design constitutes a stable linkage system throughout the entire range of deployment, from packaged configuration to complete deployment.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be more clearly understood by reference to the following detailed description when considered in connection with the accompanying drawings, wherein:

FIG. **1** is a view of an exemplary tetrahedral beam of the present invention;

FIG. **2** is a view of one repeating unit of the present beam;

FIG. **3** is a view of the folded configuration of the present invention;

FIG. **4** is an exploded view of the novel joint of the present invention;

FIG. **5** is a view of the novel joint of the present beam in a folded configuration;

FIG. **6** is a partial view of the novel joint of the present beam;

FIG. **7** is a view of the novel joint of the present invention in a partially deployed configuration;

FIG. **8** is a view of the novel joint of the present invention in a fully deployed configuration; and

FIG. **9** is a schematic view of the powered activating members of the present beam.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to the drawings wherein like reference numerals designate identical parts throughout the several views, and more particularly to FIG. **1**, there is shown a tetrahedral beam constructed in accordance with the present invention and designated by reference numeral **10**. Tetrahedral beam **10** is constructed of a plurality of identical, fixed length battens **12**. Battens **12** may be fabricated of tubular aluminum, composite, or other strong yet lightweight material. Joints **14** as described in detail later join battens **12** and longeron members **16**. Longerons **16** include folding hinges **20** at longeron mid-points. As can be seen in FIG. **1**, the beam is comprised of repeating units comprised of tandem tetrahedra. Adjacent tetrahedra share common sides as a beam of desired length is assembled of an appropriate number of repeating tandem tetrahedral units joined by joints **14**. In the interest of clarity, joints **14** have not been drawn in detail in FIG. **1**, but are fully described below and in subsequent FIGS.

By referring to FIG. **2** (which depicts one repeating unit of tandem tetrahedra as well as partial views of several members of adjoining repeating units), the basic construction of the present beam may be more readily appreciated. Battens **12***a*, **12***b*, **12***c*, joined by joints **14***a*, **14***b*, **14***c* form an equilateral triangle herein referred to as a batten frame. A second batten frame is formed of battens **12***c*, **12***d*, **12***e* joined by joints **14***a*, **14***b*, **14***d*. The apexes of these two batten frames, at joints **14***d*, **14***c*, are held apart and interconnected by hinged longeron **16** thus, it is readily apparent that the two batten frames have a "common base batten" **12**C. Longeron **16** is hinged at its mid-point by hinge **20** to enable compact packaging of the beam, as will be hereinafter described. In the interest of clarity, joints **14** have not been illustrated in fine detail in FIGS. **1–3**, but will be hereafter completely disclosed by further reference to this specification and the accompanying drawings.

Referring now to FIG. **3**, tetrahedral beam **10** of the present invention is depicted in folded configuration. Batten frames now lie on parallel planes in a stacked configuration with battens **12** stacked on top of other battens and joints **14** stacked on joints. Longerons **16** have completely folded about their mid-point hinges **20** and are stacked in the interior of the triangular solid formed by the stacked batten frames. When completely folded as in FIG. **3** the present beam continues to provide a stable structure, and does not require a canister or other external packaging. The present packaging geometry is extremely efficient, as the folded length of the beam is only one-fourteenth as long as the fully deployed beam (FIG. **1**).

To provide a tetrahedral beam with the ability to be maneuvered and compactly packaged, a novel joint designated generally by reference numeral **14**, and shown in FIGS. **4–7**, was constructed. Joint **14** is comprised essentially of gusset **24** connected to gusset **34** by link **25**. Link **25** permits gusset **34** to swivel about gusset **24** with two degrees of freedom as follows. First from a folded position in which gussets **34**,**24** lie on parallel planes (FIG. **4**), gusset **34** swivels counterclockwise about batten **12***f*, to any desired angle, while link **25** and gusset **24** remain fixed. Secondly, link **25** swivels about the end of batten **12***i* which protrudes from gusset **24**. In this latter swiveling, gusset **34** rotates along with link **25** to any other desired angle. These two rotational degrees of freedom thus permit each corner to deploy to any desired angle, independently of other corners. The beam axis may be straight or crooked when deployed, depending on whether all joints are deployed equally or unequally, respectively.

Referring now to FIG. **4**, an exploded view of joint **14**, the structure of joint **14** can be readily appreciated. Battens **12***f*, and **12***g* are joined by gusset **34**. Batten **12***g* is fixed within gusset **34** by keeper pin **18**, but batten **12***f* is free to rotate (swivel) within gusset **34**. Collar **32** with a keeper pin **18** retains batten **12***f* within gusset **34** from one direction. Link **25** and keeper pin **18** retains batten **12***f* within gusset **34** from the other direction. A longeron **16** is pivotably mounted in slot **26** by hinge pin **19**.

A second gusset **24** joins battens **12***h*, **12***i*. Batten **12***h* is fixed within gusset **24** by keeper pin **18**. Batten **12***i* is also fixed within gusset **24** with a keeper pin **18**. Link **25** swivels about batten **12***i* and is retained from slipping off batten **12***i* by gusset **24**, retaining collar **42**, and a keeper pin **18**. A longeron **16** is pivotably mounted by a hinge pin **19** in a slot (not shown) in gusset **24**.

Link **25** serves to pivotably join gussets **24**,**34**. Batten **12***i* of gusset **24** passes through an aperture of link **25** and is secured by retaining collar **42** with a keeper pin **18**. Batten **12***f* of gusset **34** passes through a second aperture of link **25** and is secured therein by a keeper pin **18**. Throughout FIGS. **5–9** and the accompanying specification, the operation and structure of various parts of joint **14** will be further detailed.

Referring now to FIG. **5**, joint **14** is depicted in completely folded configuration. Gussets **24**, **34** lie on parallel planes, as do all battens **12***f*, **12***g*, **12***h*, and **12***i*. Longerons **16** have been illustrated as deflected from their folded position in which they would be parallel to battens **12** to illustrate that longerons are free to pivotally deflect even when gussets **24**, **34** are folded. As seen in FIG. **5**, gusset **24** fixedly joins battens **12***h* and **12***i* in a 60° angular relationship. Gusset **24** contains a slot **26** in which longeron **16** is pivoted by a simple hinge. Link **25** circumferentially surrounds batten **12***i* between gusset **24** and collar **42**. Gusset **24** along with link **25** is free to rotate about batten **12***i*.

Referring now to FIG. **6**, further details of joint **14** are illustrated. Gusset **34** is circumferentially disposed about the shaft of batten **12***f* between collar **32** and link **25** and rotates about the shaft of batten **12***f*, the end of which protrudes through gusset **34**. Batten **12***g* is fixedly disposed within gusset **34** at a 60° angular relationship to batten **12***f*. Longeron **16** is pivotally disposed within slot **26** of gusset **34** such that longeron **16** bisects the angle formed by battens **12***f*, **12***g*. In the interest of clarity, further components of joint **14** have been omitted from FIG. **6** but are described below.

Referring to FIG. **7**, gusset **24** is shown with battens **12***h*, **12***i* fixedly attached thereto and forming a 60° angular relationship. Gusset **34** is depicted as having rotated about batten **12***i* relative to the folded configuration of FIG. **4**. Gusset **34** has rotated about batten **12***i* via link **25** which is circumferentially disposed around batten **12***i* between gusset **24** and collar **42**. Referring now to FIG. **8**, joint **14** is shown in its completely unfolded or deployed configuration. Gusset **34** has further rotated about batten **12***f*, as well as about batten **12***i* via link **25**.

In the preferred embodiment, tetrahedral beam **10** is powered by suitable state-of-the-art actuators to deploy and retract the longerons and to thus provide a beam capable of acting as a remotely controlled manipulator arm. To first provide the capability of powered erection, longerons **16** are provided with powered elbow-type hinges **20***a* as schematically depicted in FIG. **9**. Such hinges are known in the art and commonly employ an electric motor driven worm gear to drive a spur gear, thereby folding and unfolding the longeron. To provide the ability to vary the shape of the beam central axis, one or more longerons **16** are equipped with powered telescoping segments **16***a*. Telescoping tubular segments driven by electric, hydraulic and pneumatic means are well known in the art. Electric powered automobile radio antennae provide an excellent example of telescoping segments suitable for actuating the present beam. In the embodiment schematically depicted in FIG. **9**, one-half of longeron **16** is comprised of telescoping segments **16***a*. The other half of longeron **16** is comprised of a fixed length tubular segment. An actuating system **90** to provide power to and suitable control over powered hinges **20***a* and telescoping longeron segments **16***a* is also schematically depicted in FIG. **8**. Although both longeron halves could be equipped with telescoping segments **16***a*, the depicted embodiment retains much maneuverability. Although all longerons **16** of the present beam could be equipped with powered telescoping segments **16***a*, one-half of the longerons **16**, or fewer, could be so equipped and still render a highly maneuverable beam.

OPERATION

Operation of the present beam should now be apparent. From a fully packaged configuration (FIG. **3**) the present beam **10** is erected by unfolding longerons **16**. In the powered embodiment this is accomplished by operating the actuating system **90** (FIG. **9**) which provides electrical power to powered hinges **20***a*. Each powered hinge **20***a* is provided with a separate control switch, thus the beam may be sequentially deployed by powering successive powered hinges **20***a*. Once erected, the beam may be maneuvered as desired by selectively powering individually powered telescoping segments **16***a*, to lengthen or shorten longerons **16**, with the actuating system **90** (FIG. **9**). To collapse the beam, powered telescoping segments **16***a* are returned to their neutral position with the actuating system **90**, after which powered hinges are operated to sequentially collapse the beam in reverse order of erection.

Although the invention has been described relative to specific embodiments it is not so limited and many modifications and variations thereof will be readily apparent to those skilled in the art in light of the above teachings. For example, a combination folding hinge and telescoping members in place of respective hinge **20***a* and telescoping members **16***a*, with appropriate power and control means, could be employed.

What is claimed as new and desired to be secured by Letters Patent is:

1. A highly maneuverable and fully collapsible tetrahedral beam comprised of a plurality of interconnected tetrahedral, each tetrahedron including:

(a) five fixed length battens;

(b) joint means joining said battens into batten frames to form two equilateral triangles and providing two rotational degrees of freedom at each joint;

(c) two batten frames sharing a common base batten; and

(d) a longeron connecting each of the apexes of said batten frames, said longeron including a foldable hinge at its mid-point and being pivotally hinged at its ends to said joint means.

2. A fully collapsible tetrahedral beam as in claim **1** including means for independently inducing movement of said joint means relative to other joints in said tetrahedral beam.

3. A fully collapsible tetrahedral beam as in claim **1** wherein said joint means includes:

(a) a first gusset maintaining two battens in a fixed 60° relationship and pivotably hinging a longeron located as to bisect said 60° angle;

(b) a second gusset maintaining two battens in a fixed 60° relationship and pivotably hinging a longeron located as to bisect said 60° angle; and

(c) a link pivotably connecting said first gusset and said second gusset to form a joint assembly such that said upper gusset and said lower gusset pivot to provide two degrees of rotational freedom at each joint assembly whereby, said joint assembly can be folded or actuated independently of and in any sequence relative to other joints of the tetrahedral beam permitting the tetrahedral beam to deploy to any desired position.

4. A fully collapsible tetrahedral beam as in claim **1** wherein said foldable hinge is electrically powered.

5. A fully collapsible tetrahedral beam as in claim **1** wherein said longeron contains telescoping segments.

6. A fully collapsible tetrahedral beam as in claim **4** including power means for inducing telescoping movement of said telescoping segments, said power means being selected from hydraulic, pneumatic and electrical power means.

* * * * *