P-27

NASA CASE NO. LAR 14513-1-SB

PRINT FIG. 3C

NOTICE

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Serial No.: 08/126,286
09/23/93 LaRC

(NASA-Case-LAR-14513-1-SB) N94-29360
DEPLOYABLE REFLECTOR STRUCTURE
Patent Application (NASA. Langley
Research Center) 27 p Unclas

G3/32 0003653

DEPLOYABLE REFLECTOR STRUCTURE

The present invention relates to large reflector structures for deployment in outer space.

Referring to FIGS. 1A - 1D, a deployable reflector structure according to the invention comprises a number of movable reflector panels pivotably supported on rigid arms. Several such arms are pivotably connected to a central structure, so the arms can move in starburst fashion from a packaged stage, where all arms are vertical, to a deployed stage, where all of the arms are horizontal. All of the movable reflector panels are maintained at a predetermined angle to an axis of the reflector structure when the arms are pivoted, so the reflector panels are stacked tightly on top of each other in the packaged stage. Simple mechanisms are provided for avoiding interference between panels on different arms in the packaged stage, and for fitting the movable panels together like tiles in the deployed stage.

The movable arms act as a stabilizing sub-structure for the reflecting panels in a deployable reflector structure according to the invention, so a highly accurate reflecting surface is assured. The invention also provides very compact packaging of the reflector structure in its packaged stage. A reflecting structure of 20 meter deployed diameter will fit in the cargo bay of the U.S. Space Shuttle.

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Initial Evaluator: Donald R. Rummler

Serial No.: 08/126,286
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DEPLOYABLE REFLECTOR STRUCTURE

Origin of the Invention

The invention described herein was jointly made by a U.S. Government employee and a contractor employee in the performance of work under NASA Contract NAS1-18599. In accordance with 35 U.S.C. 202, the contractor elected not to retain title.

Background of the Invention

Field of the Invention

This invention relates in general to large reflectors for light or microwave radiation, and specifically to large flat or parabolic reflectors for deployment in outer space.

Description of the Related Art

Space based parabolic reflectors are today widely used for collecting and focusing faint electromagnetic radiation in radio telescopy, and as part of antennae for receiving and transmitting radio signals. The energy collecting capability of a reflector is proportional to its surface area, so very large reflectors are highly desirable. Space based reflector structures must, however, be transported into space by rocket driven vehicles, such as the U.S. Space Shuttle, where storage space is limited. In order to deploy a large reflector structure in space, it must be possible to collapse it into a compact package for transportation, and to restore it to its final size and shape after it has been placed in orbit. Examples of deployable reflectors appear in patent literature. U.S. Patent No. 3,618,101 issued November 2, 1971 to Emde

et al.; U.S. Patent No. 4,529,277 issued July 16, 1985 to Gee et al.; and U.S. Patent No. 4,899,167 issued February 6, 1990 to Westphal describe three versions of deployable reflectors with outer parts of a reflector panel divided into movable segments. The movable segments are hingedly connected to a fixed part of the reflector panel, so they can be folded back towards the axis of the reflector to form a compact package for transportation, and extended to restore the desired reflector size and shape after deployment. These designs, however, do not provide for very compact packaging of the reflector structure for transportation, and are not suitable for very large reflector structures.

U.S. Patent No. 4,811,034 issued March 7, 1989 to Kaminskas describes a deployable reflector comprising a number of modules fitting together in tile fashion. For transportation, the modules are stacked compactly on top of each other, and each pair of modules are connected by a one step-down hinge with an axis generally orthogonal to the surface of the module. After the collapsed reflector is delivered in space, the restoration to final shape starts by turning the top module about its step-down hinge. After the top module no longer covers part of the second module in the stack, the step-down hinge moves the top module downward until its top surface is flush with the top surface of the second module, and the two modules are then locked together by a separate locking pin. Next, modules one and two are turned as a unit about the hinge connecting module two with module three in the stack, and so on until the complete reflector structure is restored. This deployable reflector design provides very compact packaging for transportation of very large reflectors, but it requires a cumbersome process for restoring the reflector structure to its final shape in space. The accuracy of the reflector surface is also poorly defined, unless an even more cumbersome to deploy structure of trusses are added for support.

U.S. Patent No. 4,343,005 issued August 3, 1982 to Han et al. illustrates a solar panel comprising sections arranged on scissor-type arms

extending radially outward. When the arms are extended, the solar panels form a flat array.

Summary of the Invention

Accordingly, it is an object of the present invention to provide a deployable reflector structure incorporating a plurality of rigid reflector panels and an underlying support, which can be transported as a very compact package.

It is another object of the present invention to provide a deployable reflector structure employing a highly reliable and synchronous deployment process requiring a small number of motors.

It is a further object of the present invention to provide a deployable reflector structure assuring a high degree of accuracy in the deployed reflector structure.

It is a still further object of the present invention to provide a deployable reflector structure wherein all structural elements are subject to minimum bending or torsional strains both during storage and deployment.

These and other objects are accomplished by a deployable reflector structure, which comprises a central structure, a movable arm, means for attaching a first end of the arm pivotally to the central structure for movement in a plane containing an axis of the reflector structure, means for pivoting the arm between a storage position substantially parallel to the axis and an operating position substantially orthogonal to the axis, a movable reflector panel having a reflector surface, means for attaching the movable reflector panel pivotally to the arm at a predetermined distance from the first end, and means for maintaining the movable reflector panel at a predetermined angle relative to the axis at all positions of the arm.

Brief Description of the Drawings

The present invention and the objects achieved by it will be understood from the description herein, with reference to the accompanying drawings, in which:

FIGS 1A - 1D are lateral views of a simplified first embodiment of the invention in different stages of deployment.

FIGS. 2A- 2D are lateral views of a simplified second embodiment of the invention in different stages of deployment.

FIGS. 3A - 3D are perspective views of an actual reflector structure according to a first embodiment of the invention in different stages of deployment.

FIGS. 4A - 4D are perspective views of a section of an actual reflector structure according to a second embodiment of the invention in different stages of deployment.

FIGS 5A - 5C are perspective views of a complete reflector structure according to a second embodiment of the invention in different stages of deployment.

FIGS. 6A - 6B are perspective views of one section of a further reflector structure according to the second embodiment of the invention in different stages of deployment.

FIGS. 7A - 7C are perspective views of a complete reflector structure utilizing one central structure and multiple arms as shown in FIGS. 6A - 6B in different stages of deployment.

FIGS. 8A - 8B are, respectively, a top view and a lateral view of the reflector structure shown in FIG. 7A in its packaged state.

FIGS. 8C - 8D are, respectively, a top view and a lateral view of the reflector structure shown in FIG. 7C in its deployed state.

Detailed Description of the Preferred Embodiments

FIGS. 1A - 1D show lateral views of a deployable reflector structure 10 according to a first preferred embodiment of the invention. The views are simplified to show only those elements necessary for an understanding of the invention. A central structure 12 has a base 14 and a top plate 50 connected by a post 18. The top plate 50 serves as a fixed reflector panel in the deployed reflector structure 10. A pair of movable reflector panels 60a and 60d are supported pivotably by arms 31a, 31d, which in turn are pivotably mounted on the central structure 12 via arm carriers 41a, 41d. The arm carriers 41a, 41d are slidably mounted on horizontal tracks 16a, 16d, which are mounted on the base 14. The reflector structure 10 has a reflector axis 11.

The length of arm 31d is larger than the length of arm 31a, but otherwise the two arms 31a, 31d are of similar construction. Each of the arms 31a, 31d comprises a pair of parallel rods 34, 36 (34a, 36a and 34d, 36d), which are connected to the arm carriers 41 (41a, 41d) via pivotable joints 44, and to links 62a, 62d via pivotable joints 64. The rods 34, 36 and the joints 44, 64 in each arm 31a, 31d form a parallelogram structure, so the links 62a, 62d remain at a fixed angle to the reflector axis 11 when the arms 31a, 31d are moved. The links 62a, 62d are rigidly connected to the movable reflector panels 60a, 60d, and are bent so the reflector panels 60a, 60d are parallel to the top panel 50.

In FIG. 1A, the deployable reflector structure 10 is shown in its packaged stage, with the movable arms 31a, 31d arranged parallel to the reflector axis 11. Because the movable arm 31d is longer than the movable arm 31a, the movable reflector panel 60d is stacked on top of or above the movable reflector panel 60a. It is readily apparent that the total diameter of the deployable reflector structure 10 in its packaged stage is only slightly larger than the diameter of the reflector panels 50, 60a, 60d, while the length

is about equal to the length of the longest arm 31d.

FIG. 1B shows the deployable reflector structure 10 in a partially deployed stage. The movable arms 31a, 31d have been pivoted to positions at about 45° angles to the reflector axis 11. The movable reflector panels 60a and 60d are displaced radially outward from the reflector axis 11, but they remain parallel to the fixed reflector panel 50, because of the parallelogram action of the movable arms 31a, 31d.

FIG. 1C shows the deployable reflector structure 10 at a later stage of deployment, where the movable arms 31a, 31d are pivoted to positions at substantially right angles to the reflector axis 11. The movable reflector panels 60a, 60d are now coplanar with the fixed reflector panel 50. An edge of the movable reflector panel 60a is close to an edge of the fixed reflector panel 50, but there is more of a gap between the edges of the fixed reflector panel 50 and the movable reflector panel 60d, because the movable arm 31d is longer than the movable arm 31a.

FIG. 1D shows the deployable reflector structure 10 at a stage of full deployment. The arm carrier 41d has been moved radially inward on its track 16d, so the movable arm 31d is retracted into the central structure 12. The edge of the movable reflector panel 60d is now close to the edge of the fixed reflector panel 50, so all three reflector panels 50, 60a, 60d are contiguous, forming a flat reflector with area much larger than the cross section of the deployable reflector structure 10 in its packaged stage.

FIGS. 2A - 2D show lateral views of a deployable reflector structure 20 according to a second embodiment of the invention. The views are simplified to show only those elements necessary for an understanding of the invention. A central structure 22 with a base 24 is connected to a top panel 50 by a number of supporting posts 28 distributed around the periphery of the central structure 22. A pair of movable reflector panels 60a and 60d are supported on arms 32a, 32d, which in turn are pivotably supported by the central structure 22 via arm carriers 42a, 42d. The arm carriers 42a, 42d are

mounted slidably on the vertical posts 28, which serve as tracks for the arm carriers 42a, 42d. The reflector structure has a reflector axis 21.

The deployable reflector structure 20 is essentially the same as the deployable reflector structure 10 described above with reference to FIGS. 1A - 1D, except for the following two differences: (i) the movable arms 32a and 32d are of equal length; and (ii) the arm carriers 42a and 42d are movable on axially arranged tracks 28a, 28d on vertical posts 28, instead of on tracks 16 parallel to the fixed reflector panel 50.

In FIG. 2A, the deployable reflector structure 20 is shown in its packaged stage, with the movable arms 32a, 32d arranged parallel to the reflector axis 21. The arm carriers 42a and 42d are at this stage located at different axial positions on their tracks 28a, 28d, so the movable reflector panels 60d and 60a are stacked on top of each other without interference.

FIG. 2B shows the deployable reflector structure 20 in a partially deployed stage. The movable arms 32a, 32d are at an angle of about 45° to the reflector axis 21. The movable reflector panels 60a and 60d have been moved radially outward from the reflector axis 21, but they remain parallel to the fixed reflector panel 50, because of the parallelogram action of the movable arms 32a, 32d.

FIG. 2C shows the deployable reflector structure 20 at a later stage of deployment, where the movable arms 32a, 32d are pivoted to substantially horizontal positions. The movable reflector panel 60a is coplanar with the fixed reflector panel 50, but the movable reflector panel 60d is axially displaced relative to the fixed reflector panel 50. Edges of the fixed reflector panel 50 are aligned with edges of both the movable reflector panels 60a, 60d.

FIG. 2D shows the deployable reflector structure 20 at a stage of full deployment. The arm carrier 42d has been moved axially upward on its track 28d, so the edge of the movable reflector panel 60d is coplanar with the fixed reflector panel 50. The three reflector panels 50, 60a, 60d are now coplanar

and contiguous, and form a flat reflector with area much larger than the cross section of the deployable reflector structure 20 in its packaged stage.

The invention is not limited to flat reflectors. A deployable reflector structure 10, 20 with a reflector surface forming a parabola of rotation ("a parabolic reflector") can be obtained by shaping both the fixed reflector panel 50 and the movable reflector panels 60a, 60d to form parts of the desired parabolic reflector surface. The links 62a, 62d have suitable dimensions and angles to hold the movable reflector panels 60a, 60d in proper alignment for the parabolic reflector surface.

For optimum packaging density in a reflector structure 10, 20 with a parabolic reflector surface, the movable reflector panels 60 should be substantially parallel to the fixed reflector panel 50 when the movable arms 31, 32 are in the packaged stage, but the reflector panels 60 should be slightly tilted to conform to the average slope of the parabola when the movable arms 31, 32 are in the fully deployed stage. Such a predetermined variation in the tilt angle of the movable panels 60 can readily be obtained by slight changes in the geometry of the rods 34, 36 and the links 42, 62, as is well known to those skilled in the art.

The description above has assumed simplified reflector structures 10, 20 having only two movable arms 31 or 32, each with one movable reflector panel 60, in order to make the illustrations easy to understand. A useful or more practical deployable reflector structure 10 or 20 according to the invention will contain a larger number of movable reflector panels and a plurality of supporting arms arranged like petals on a flower and deployed in starburst fashion. Three examples of such complete deployable reflector structures will be described below.

FIGS. 3A - 3D are perspective views of an actual deployable reflector structure 101 according to the first embodiment of the invention described above with reference to FIGS. 1A - 1D.

FIG. 3A shows the deployable reflector structure 101 in its packaged

stage. A central structure 121 carries one fixed reflector panel 501 and six movable arms 311a - 311f pivotally attached to it. The movable arms 311a - 311f are vertically oriented. Pivotably attached to the movable arms 311a - 311f are six rigid hexagonal reflector panels 601a - 601f. The six arms 311a - 311f are of different lengths, so the reflector panels 601a - 601f are stacked on top of each other without interference.

FIG. 3B shows the deployable reflector structure 101 in an intermediate stage of deployment. The six moveable arms 311a - 311f have been pivoted to orientations between the horizontal and the vertical position.

FIG. 3C shows the deployable reflector structure 101 in a further stage of deployment. The six movable arms 311a - 311f have been pivoted to essentially horizontal positions. The arms 311a - 311f act as parallelogram guides, so the six movable reflector panels 601a - 601f continue to lie in substantially horizontal positions. Because the six arms 311a - 311f are of different lengths, each of the six reflector panels 601a - 601f is positioned at a different distance from the central reflector panel 501. Only panel 601a, which is carried by the shortest arm 311a, abuts the central reflector panel 501.

FIG. 3D shows the deployable reflector structure 101 in a fully deployed stage. The movable arms 311b - 311f have been retracted within the central structure 121 so the movable reflector panels 601b - 601f abut the fixed reflector panel 501 and each other, providing a continuous reflecting surface.

FIGS. 4A - 4D are perspective views showing an actual deployable reflector structure 202 according to the second embodiment of the invention described above with reference to FIGS. 2A - 2D. In this modified second embodiment, a movable arm 322 supports two movable wedge shaped reflector panels 602, 702, but otherwise the arm 322 functions exactly as described above with reference to FIGS. 2A - 2D.

FIG. 4A shows a central structure 222 with twelve pairs of vertical

rods 282 connecting the base 242 to a fixed reflector panel 502. A movable arm 322 comprises two sets of parallel rods 342', 342'' and 362', 362'' mounted on an arm carrier 422 via pivotable joints 442, and two links 622 and 722 mounted on the two pairs of rods 342', 342'' and 362', 362'' by means of pivotable joints 642 and 742. The arm carrier 422 is mounted slidably on one pair of the vertical rods 282. The movable wedge-shaped reflector panels 602 and 702 are rigidly supported by the respective links 622 and 722.

FIGS. 4B - 4D show one arm 322 with reflector panels 602 and 702 in different stages of deployment. FIG. 4B shows the movable arm 322 with panels 602 and 702 in the packaged stage. The movable arm 322 is vertical, and the reflector panel 702 is positioned above reflector panel 602. FIG. 4C shows the movable arm 322 with panels 602 and 702 pivoted to a diagonal position. The panels 602 and 702 are constrained to maintain a horizontal position by the parallelogram action of the movable arm 322 and the links 622, 722. FIG. 4D shows the movable arm 322 pivoted to a horizontal position. The panels 602, 702 now form a continuous wedge shaped reflector surface.

FIGS. 5A - 5C are perspective views of a complete deployable reflector structure 202 comprising the central structure 222 and twelve of the arms 322 with panels 602, 702 shown in FIG. 4A.

FIG. 5A shows the deployable reflector structure 202 in its packaged stage, with all twelve arms 322a - 322l oriented vertically. The arms 322a - 322l are all of equal length, but their respective arm carriers 422a - 422l are positioned at different vertical positions on their tracks 282, so the panels 602, 702 on different arms 322a - 322l do not interfere.

FIG. 5B shows the deployable reflector structure 202 with all arms 322a - 322l fully extended horizontally, as was shown for one arm in FIG. 4D. The panels 602, 702 on each arm 322a - 322l form continuous wedge shaped surfaces, but the panels on different arms 322a - 322l are located at

different vertical levels.

FIG. 5C shows the reflector structure 202 fully deployed. The arm carriers 422 for the different arms 322a - 322l have now been moved to the same vertical level, so the all the reflector panels 602a-602l, 702a-702l form a continuous surface.

FIGS. 6A - 6B are perspective views of details of still another deployable reflector structure 203 at different stages of deployment. This reflector structure 203 comprises a pivotable arm 323 slidably mounted on vertical tracks 283 in a central structure 223 via an arm carrier 423. The pivotable arm 323 comprises one outer rod 363 and two parallel inner rods 343', 343''. The rods 363 and 343', 343'' are connected to the arm carrier 423 via pivotable joints 443, and to three links 623, 723, 823 via pivotable joints 643, 743, 843, forming a parallelogram structure. Three hexagonal reflector panel sets 603, 703, 803 are carried by the arm 323. Each reflector panel set 603, 703, 803 comprises a main reflector panel 603', 703', and 803', respectively, which is rigidly connected to respective links 623, 723, 823. Each of the main reflector panels 603', 703', 803' in turn supports a hexagonal sub-panel 603'', 703'', and 803'', respectively, via hinges 683, 783, 883.

FIG. 6A shows the pivotable arm 323 oriented vertically, corresponding to the packaged stage of the reflector structure 203. The sub-panels 603'', 703'', 803'' are folded flat on top of their respective main panels 603', 703', 803' at this stage.

FIG. 6B shows the arm 323 in a partially deployed position. The arm 323 has been pivoted to a position between vertical and horizontal. The links 623, 723, 823 maintain a horizontal orientation for the panel sets 603, 703, 803. Sub-panel 803'' is shown partially un-folded from its main panel 803'. It will be understood that main panel 803' and sub-panel 803'' will form a continuous reflecting surface when the sub-panel 803'' is fully un-folded on hinge 883, and that the same is true for the remaining pairs of main panels

603', 703' and sub-panels 603'', 703''.

FIGS. 7A - 7C are perspective views of a complete reflector structure 203 comprising six of the pivotable arms 323a - 323f shown in FIGS. 6A - 6B and as described above. Each of the six pivotable arms 323a - 323f supports three hexagonal main reflector panels 603', 703', 803' with hinged hexagonal sub-panels 603'', 703'', 803''.

FIG. 7A shows the reflector structure 203 in its packaged stage. The six pivotable arms 323a - 323f are all oriented vertically. The arm carriers 423a - 423f are arranged at different vertical levels on their tracks 283a - 283f, so the overlapping reflector panel sets 603, 703, 803 fit as a stack without interference.

FIG. 7B shows the reflector structure 203 with all the pivotable arms 323a - 323f fully extended in the horizontal direction. The sub-panels 803''a - 803''f have been un-folded from their respective main reflector panels 803'a - 803'f.

FIG. 7C shows the reflector structure 203 in its fully deployed stage. All the sub-panels 603'', 703'', 803'' have been unfolded from their respective main reflector panels 603', 703', 803'. The main reflector panels 603', 703', 803' and the sub-panels 603'', 703'', 803'' together form a continuous parabolic reflector surface.

FIGS. 8A and 8B are, respectively, a plan view and a lateral view of the deployable reflector structure 203 in its packaged stage, and FIGS. 8C and 8D are, respectively, a plan view and a lateral view of the deployable reflector structure 203 in its fully deployed stage. The scale is the same in all of FIGS. 8A - 8D.

By comparing FIGS. 8A and 8C, and FIGS. 8B and 8D it can be seen that the diameter of the packaged structure is approximately one fifth of the diameter of the fully deployed structure. This means that a reflector structure according to this embodiment of the invention with a deployed diameter of 20 meters can be packaged within the cargo bay of the U.S. Space Shuttle.

The reflector panels may be solid panels, as shown in FIGS. 3A - 3D and FIGS. 5A - 5C, or structural panels built from struts, as shown in FIGS. 6A - 7C. A solid reflector panel can be formed from a thin sheet of composite material with a metallized reflecting surface. The reflecting surfaces of structural panels will normally be covered by a thin metallized plastic film. Panels may also be made from sheets of composite material stiffened by a structure of struts.

In all the embodiments and examples of the deployable reflector structures according to the invention described above, a predetermined angle between the movable reflector panels and the axis of the deployable reflector structure during pivoting of the arms has been assured by a parallelogram linkage of rods and links. This is the preferred means for maintaining a predetermined angle for the movable panels, but other means are available, as is well known in the art. The angle of the movable reflector panels can, for instance, be controlled by cam followers, or by rope driven pulleys, or by servo motors acting on the links supporting the reflector panels. Whichever means is selected is strictly a matter of cost, weight, and reliability, and the invention is not limited to any specific choice of such mechanisms.

No specific means for pivoting the arms, or for moving the arm carriers along their tracks have been described above. Such means are, however, well known to those skilled in the art. For instance, the movable arms can be pivoted from its packaged orientation to its fully deployed orientation by means of motors under computer control, or the movable arms can be spring loaded for deployment, with releasable restraints keeping the movable arms in the packaged position until deployment is desired. Again, the choice of such mechanisms is strictly a matter of cost, weight, and reliability, and no specific means is required by the present invention.

The invention provides a deployable reflector structure that packs compactly for storage and transportation, and has excellent structural stability during and after deployment in outer space because the movable reflector

panels are supported by an underlying structure of rigid arms.

A deployable reflector structure according to the invention requires only few and simple means for deployment, and the deployment procedure for this reflector structure can be reversed, so the reflector structure can reliably be re-packaged for transportation while in outer space.

Numerous modifications and adaptations of the present invention will be apparent to those skilled in the art. Thus, the following claims and their equivalents are intended to cover all such modifications and adaptations which fall within the true spirit and scope of the present invention.

What is claimed is:

DEPLOYABLE REFLECTOR STRUCTURE

Abstract of the Disclosure

A deployable reflector structure of large size has a number of movable reflector panels pivotably supported on rigid arms. Several such arms are pivotably connected to a central structure, so the arm can move in starburst fashion from a packaged stage, where all arms are vertical, to a deployed stage, where all arms are horizontal. All of the movable reflector panels are maintained at a predetermined angle to an axis of the reflector structure when the arms are pivoted, so the reflector panels are stacked tightly on top of each other in the packaged state of the reflector structure. Simple mechanisms are used for avoiding interference between panels on different arms in the packaged stage, and for fitting the movable panels together like tiles in the deployed stage.

FIG. 1A

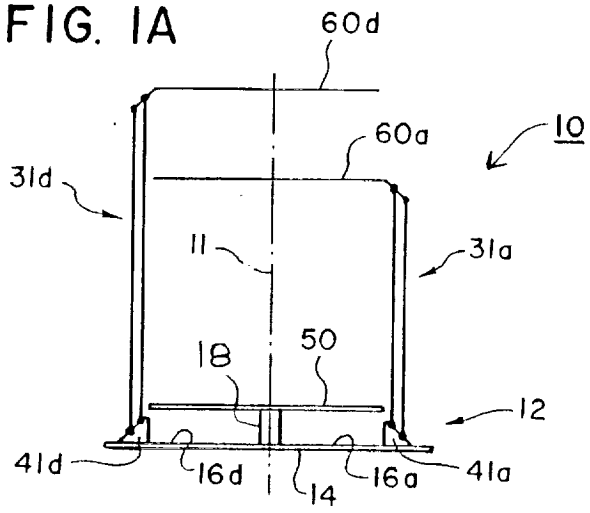


FIG. 1B

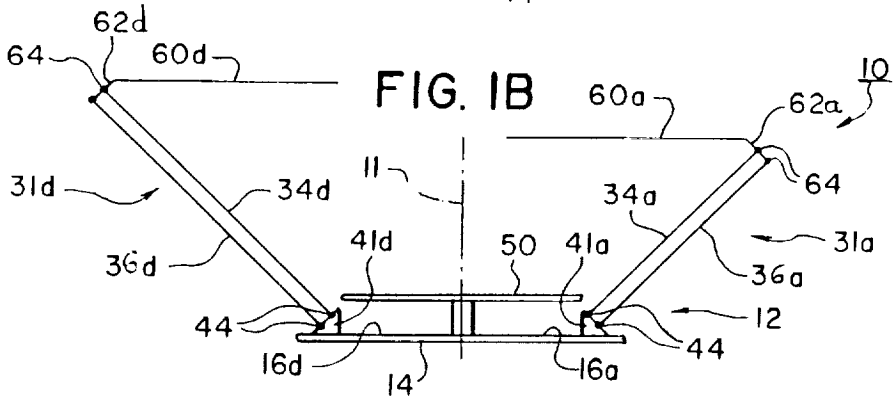


FIG. 1C

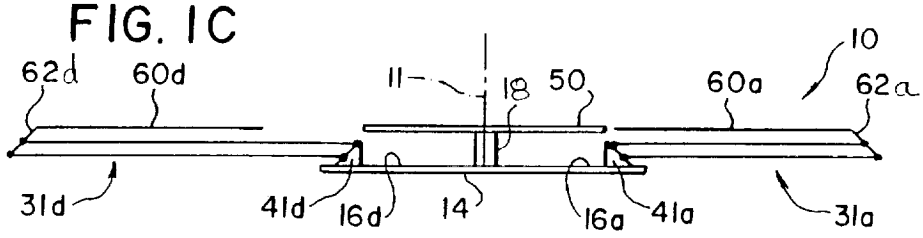


FIG. 1D

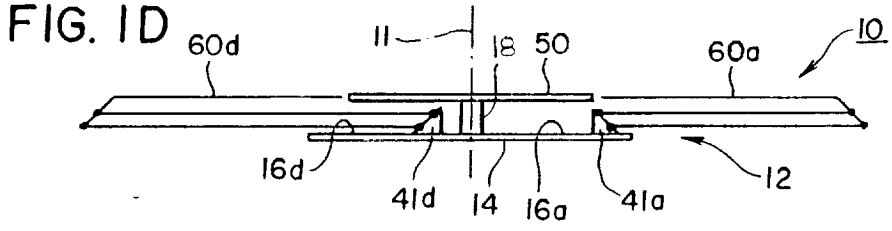


FIG. 2A

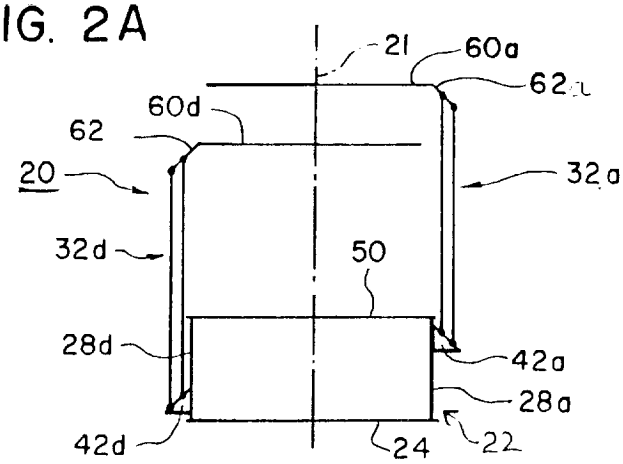


FIG. 2B

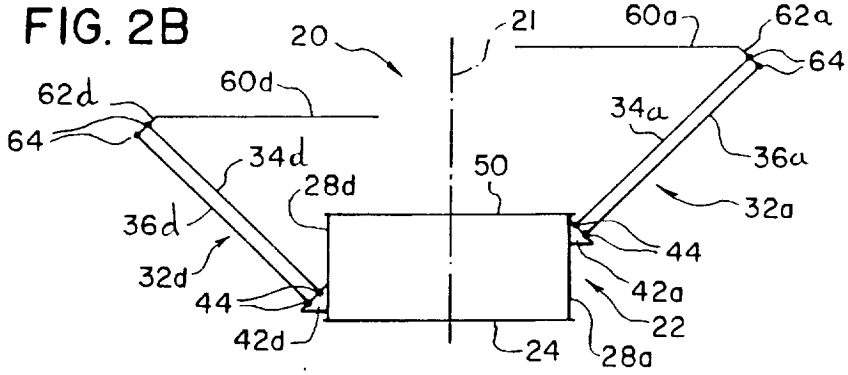
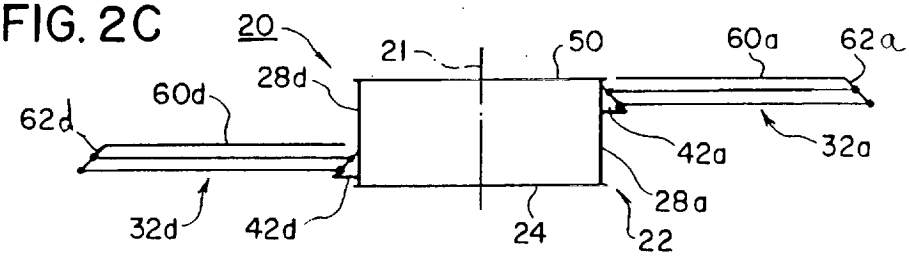


FIG. 2C



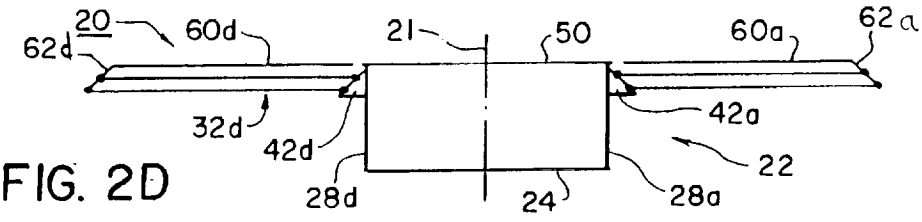


FIG. 2D

FIG. 3A

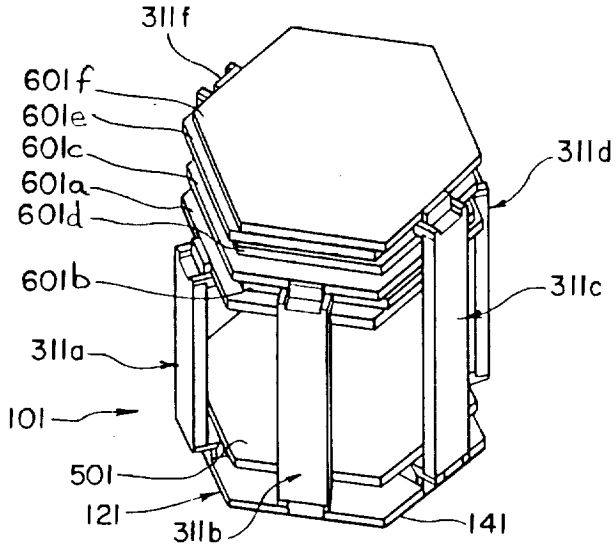

311f
601f
601e
601c
601a
601d
601b
311a
101
501
121
311b
311d
311c
141

FIG. 3B

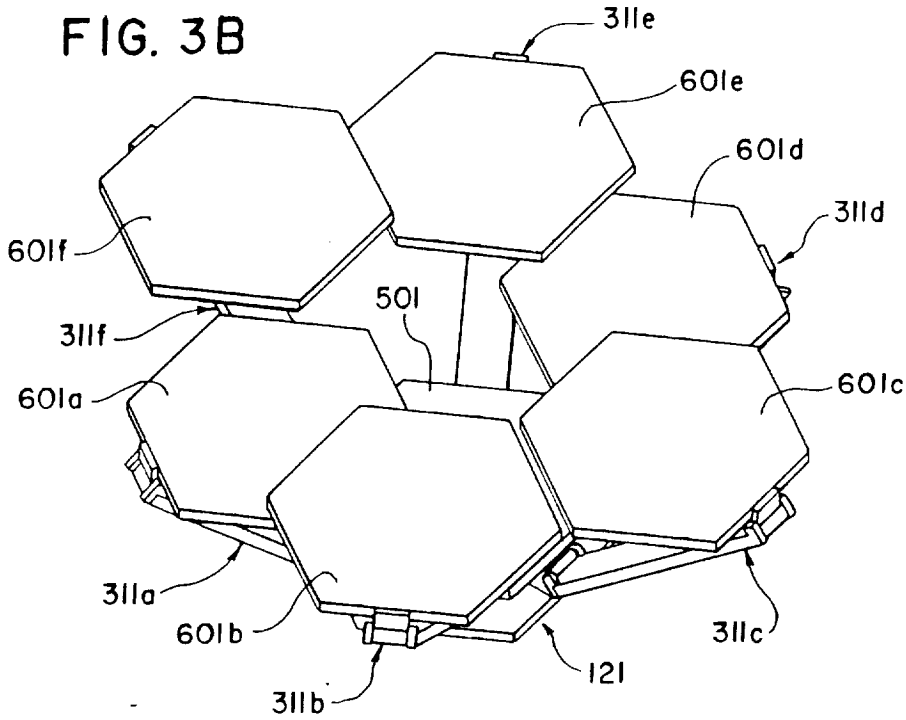

311e
601e
601d
311d
601f
501
311f
601a
601c
311a
601b
311c
121
311b

FIG. 3C

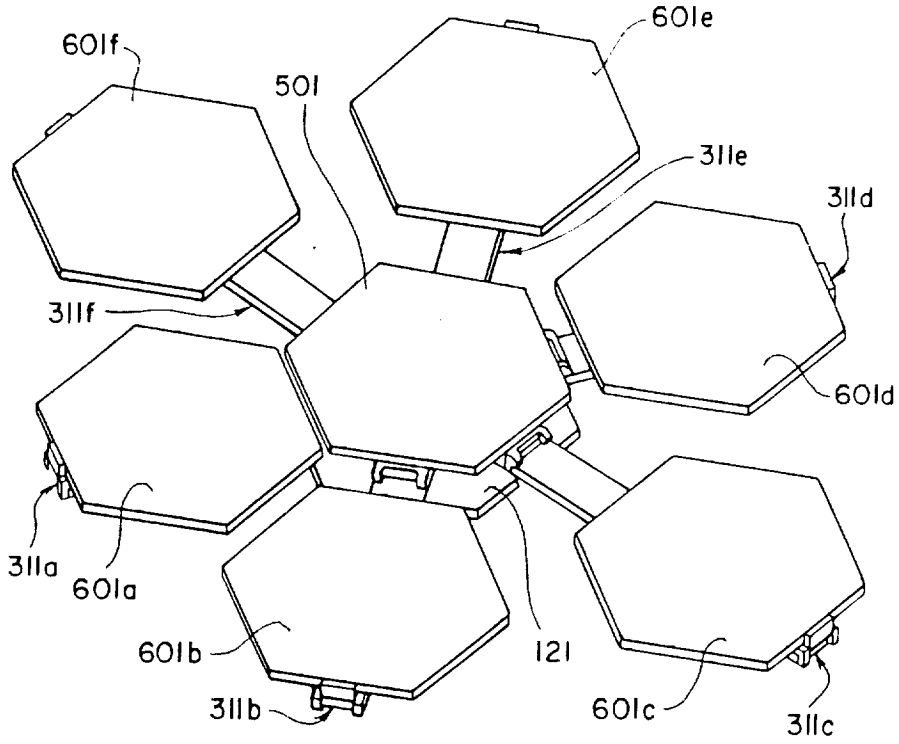

601f
501
601e
311e
311d
311f
601d
311a
601a
601b
121
311b
601c
311c

FIG. 3D

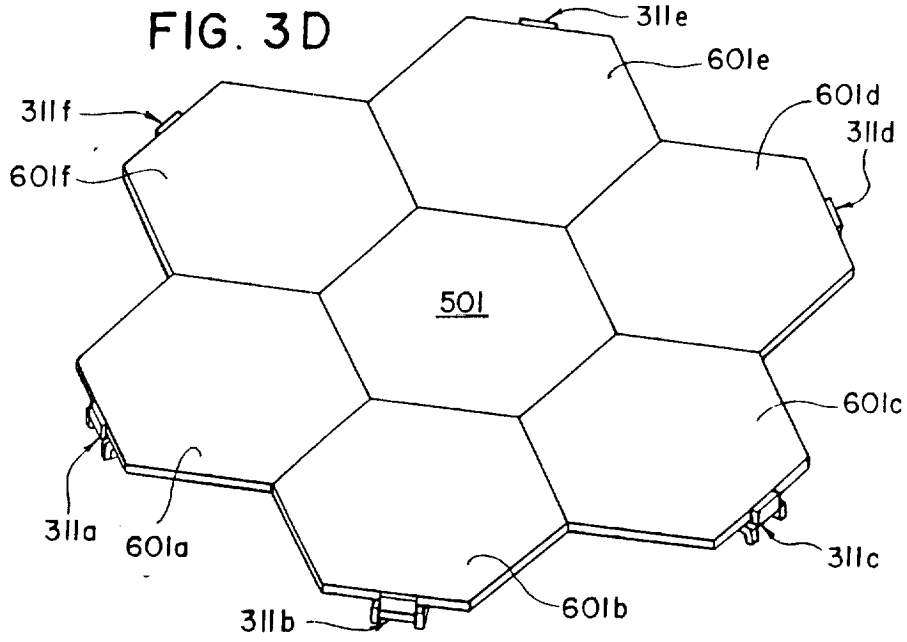

311e
601e
601d
311d
311f
601f
501
601c
311a
601a
311c
311b
601b

FIG. 4A

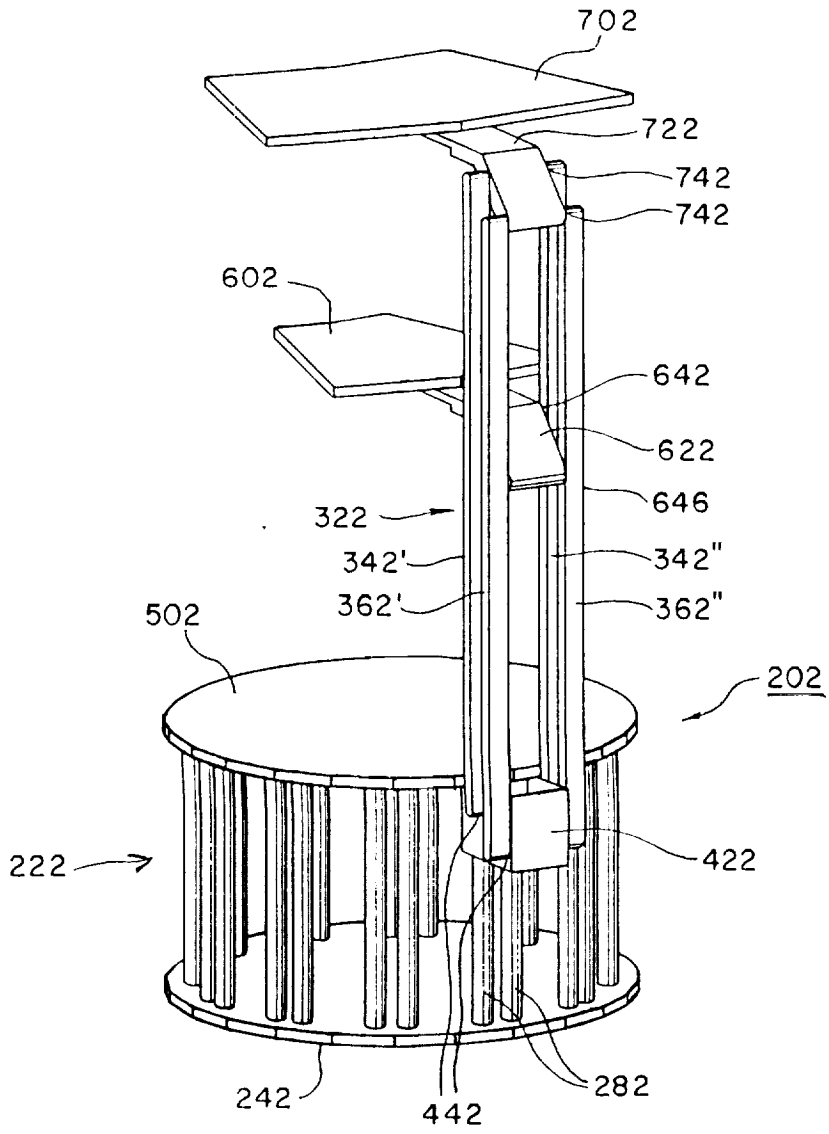

702
722
742
742
602
642
622
646
322
342'
342"
362'
362"
502
202
222
422
242
442
282

FIG. 4B

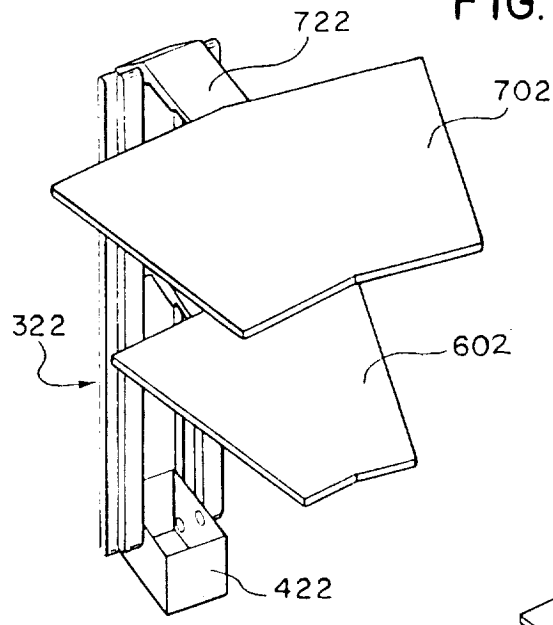


FIG. 4C

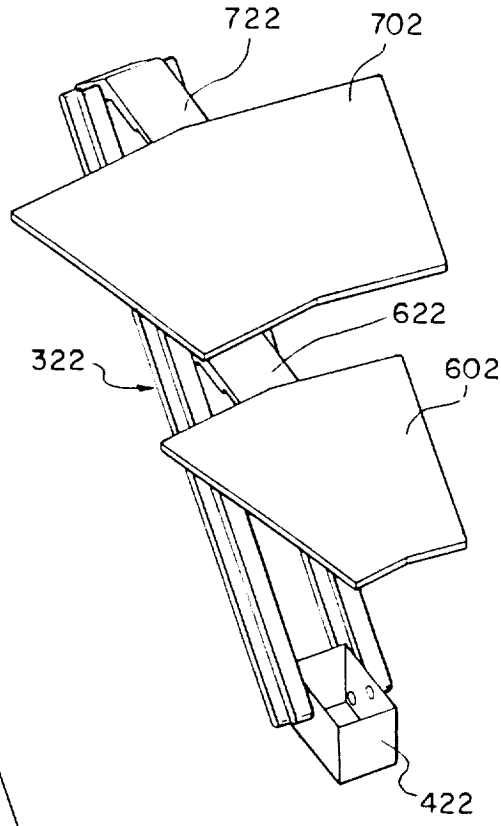


FIG. 4D

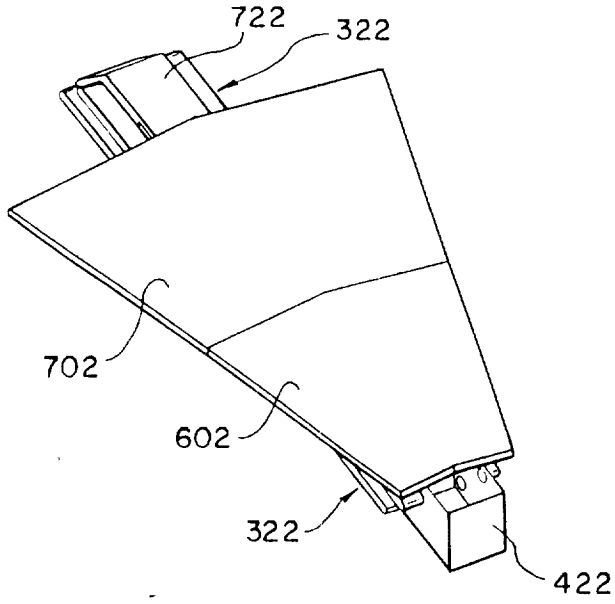


FIG. 5A

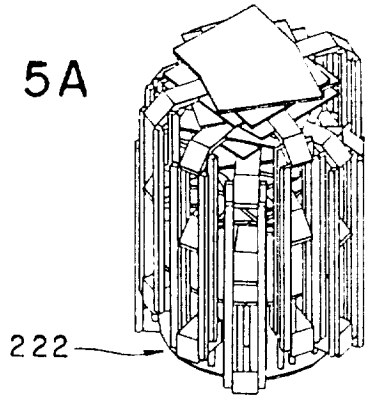


FIG. 5B

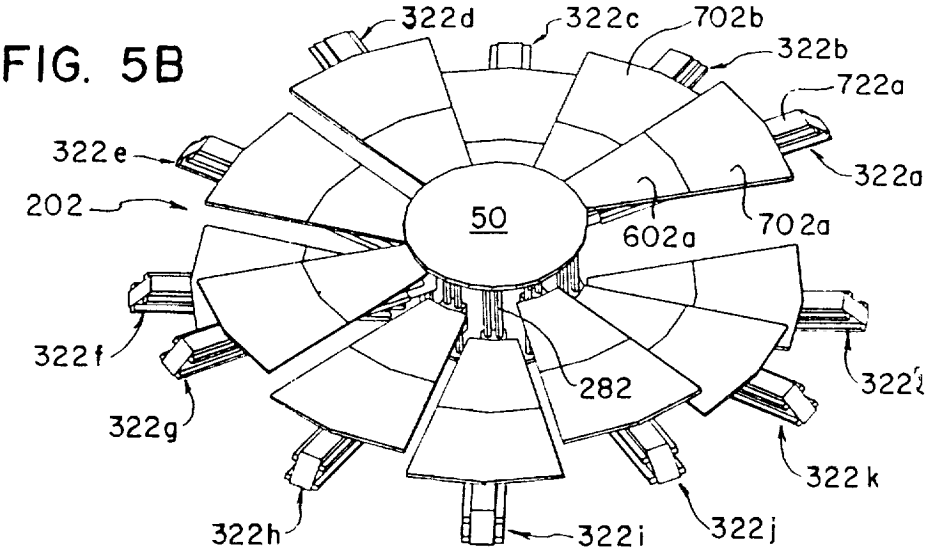


FIG. 5C

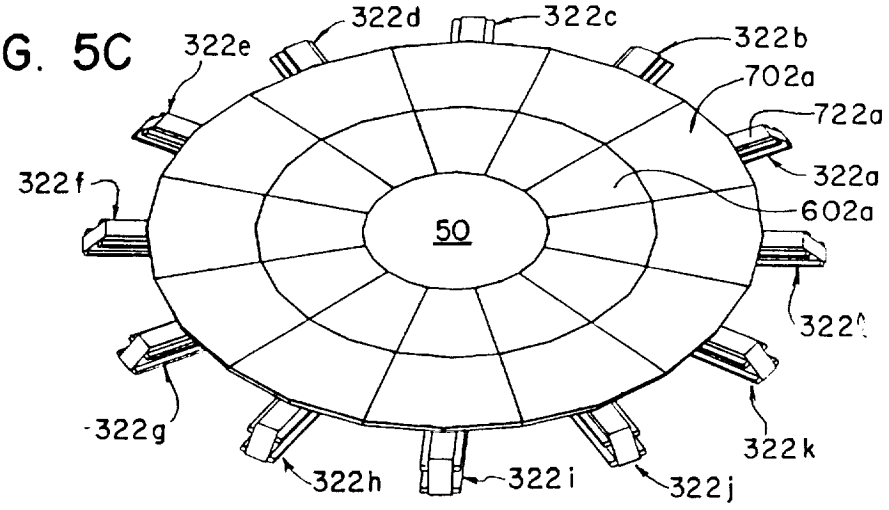


FIG. 6A

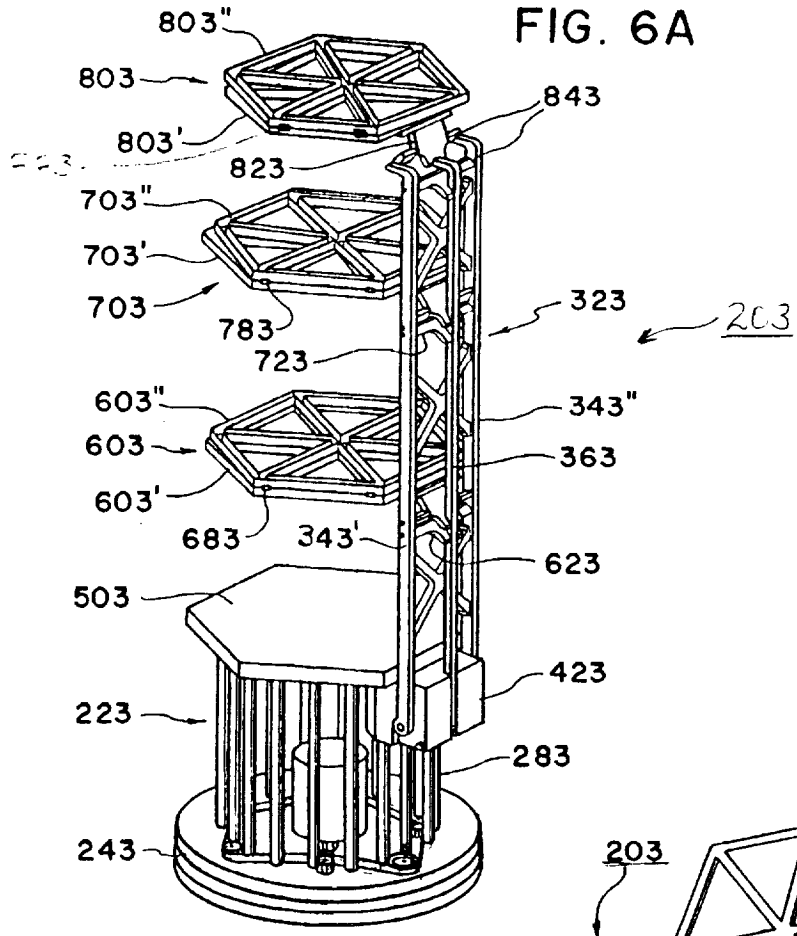

803"
803
803'
843
823
703"
703'
703
783
723
323
203
603"
603
603'
683
343'
343"
363
623
503
423
223
283
243

FIG. 6B

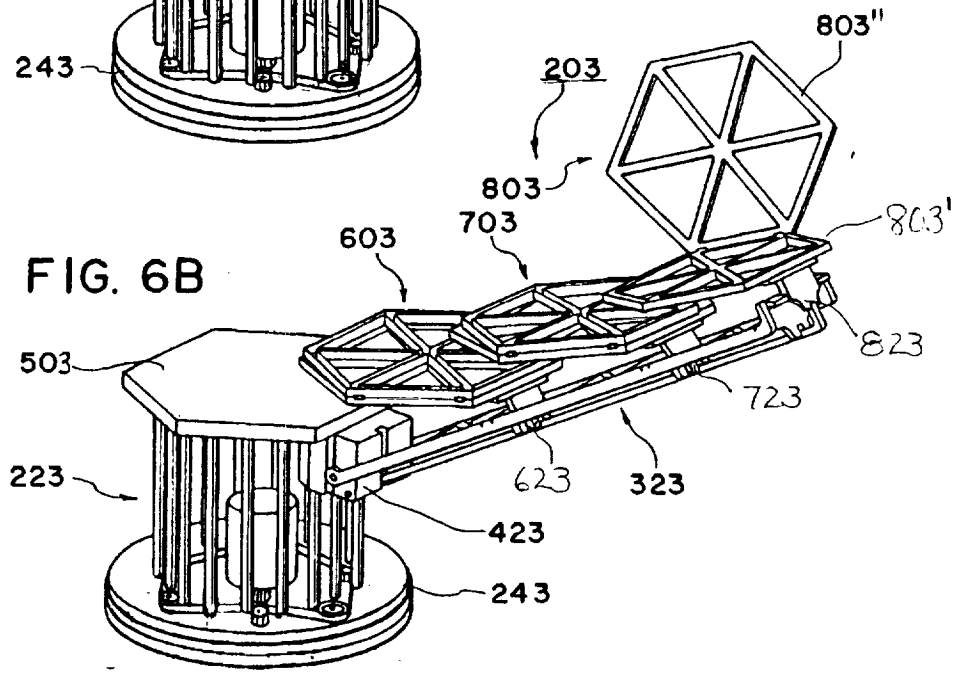

803"
203
803
703
603
803'
823
723
623
323
503
223
423
243

FIG. 7A

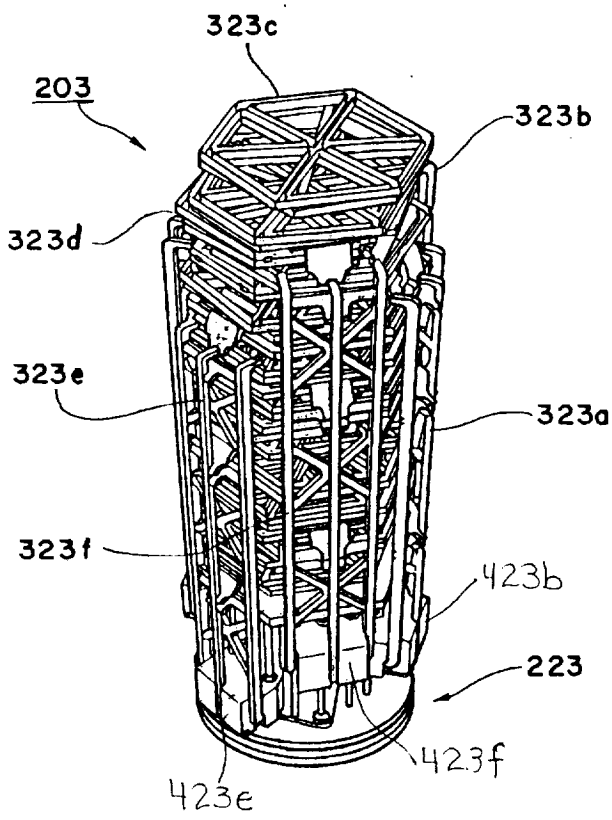


FIG. 7B

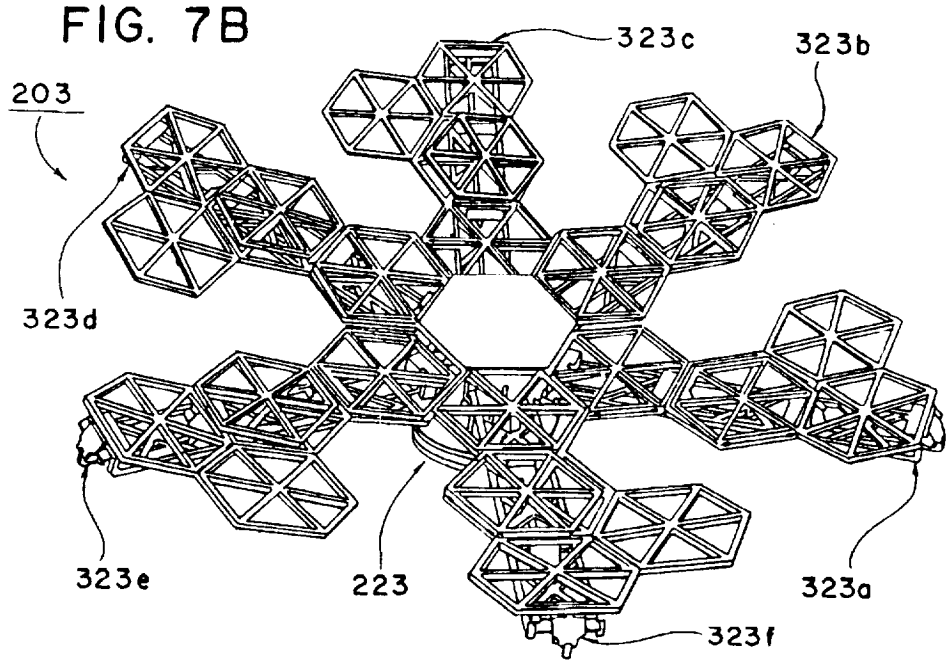

323c
323b
203
323d
323e
223
323a
323f

FIG. 7C

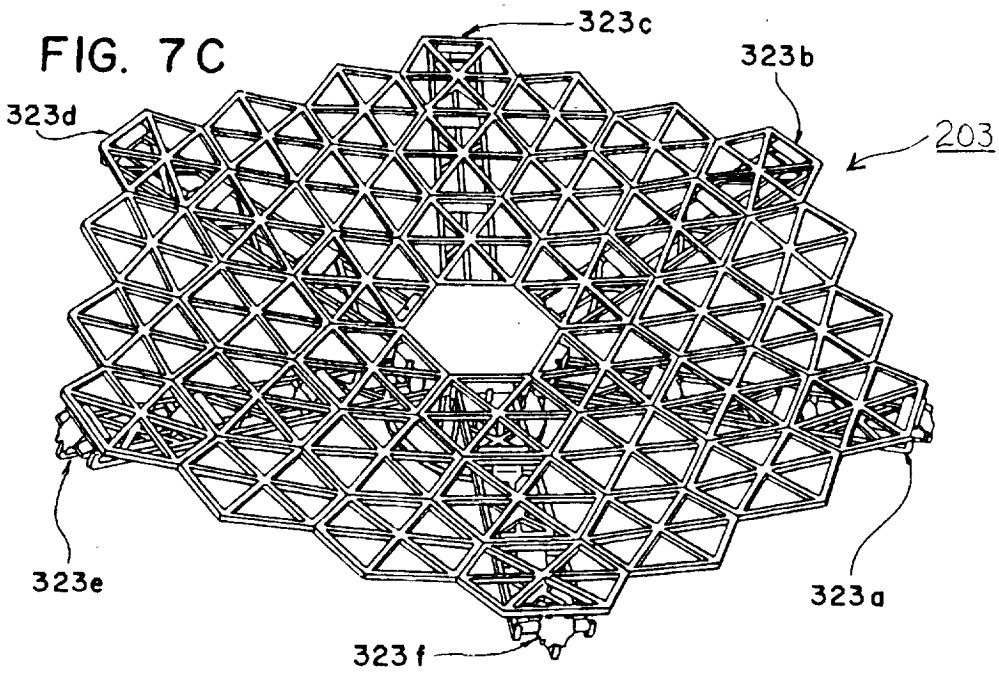

323c
323b
323d
203
323e
323a
323f

FIG. 8A

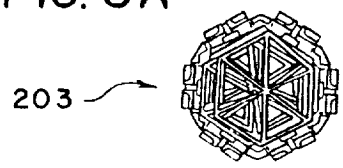


FIG. 8B

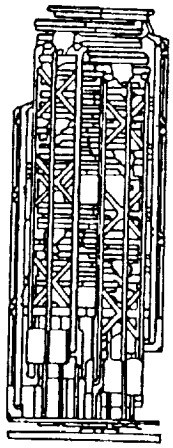


FIG. 8D

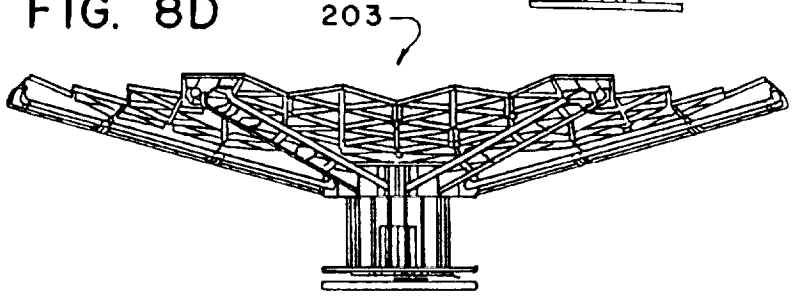


FIG. 8C

