Sept. 3, 1968 C. K. L. GRANT 3,399,914

LATTICEWORK COMPONENTS

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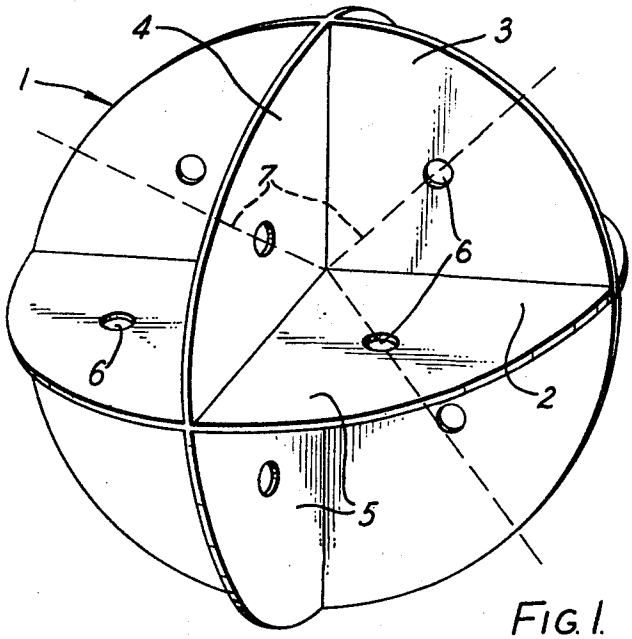


FIG. 1.

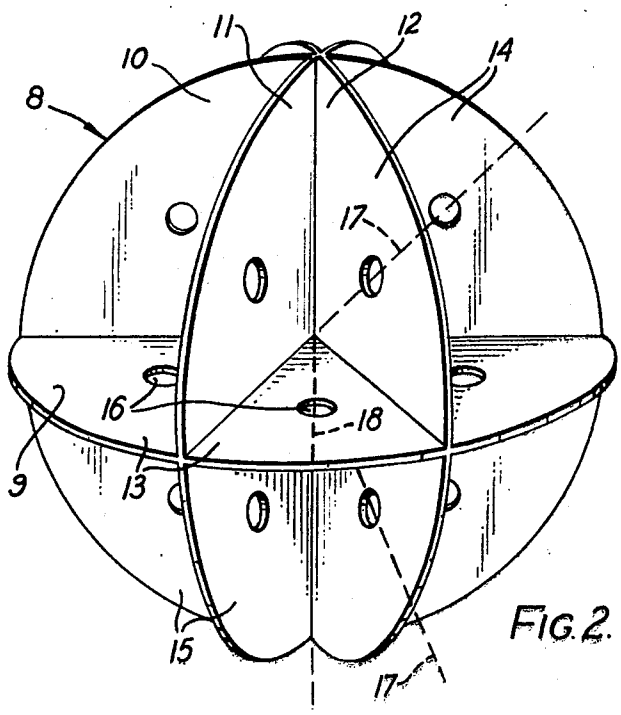


FIG. 2.

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FIG. 3.

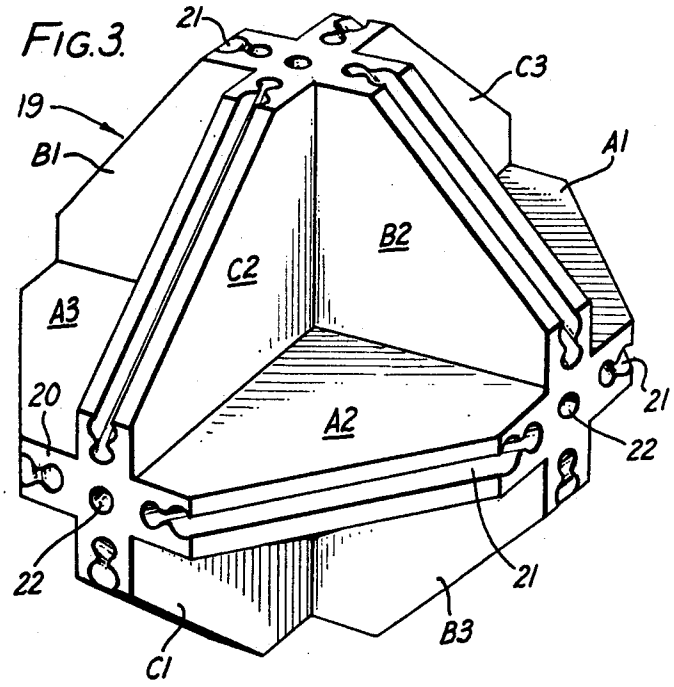
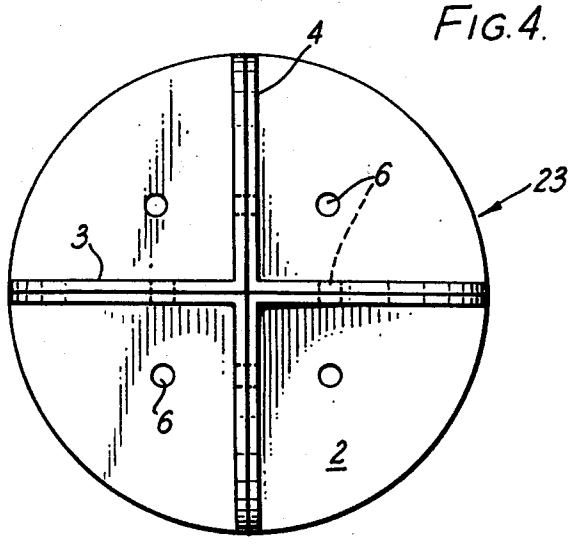


FIG. 4.



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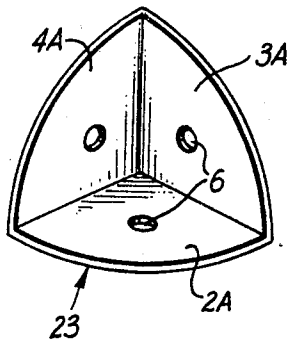
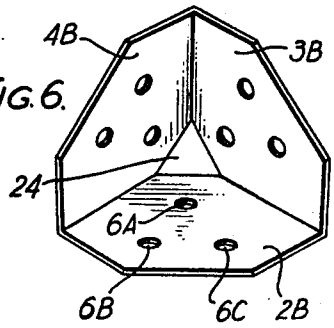


FIG. 5.

FIG. 6.



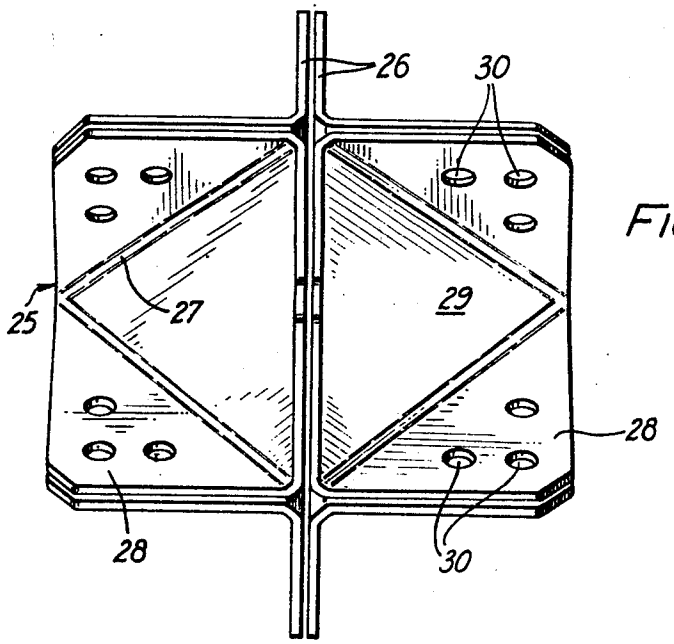


FIG. 7.

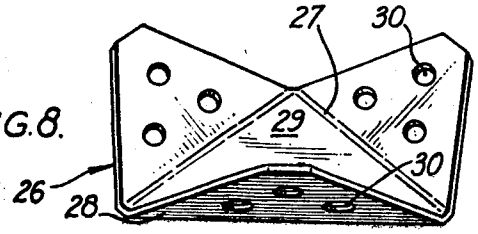


FIG. 8.

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LATTICEWORK COMPONENTS

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FIG. 9.

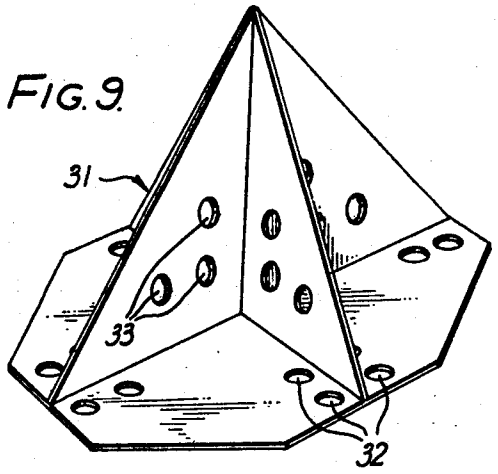
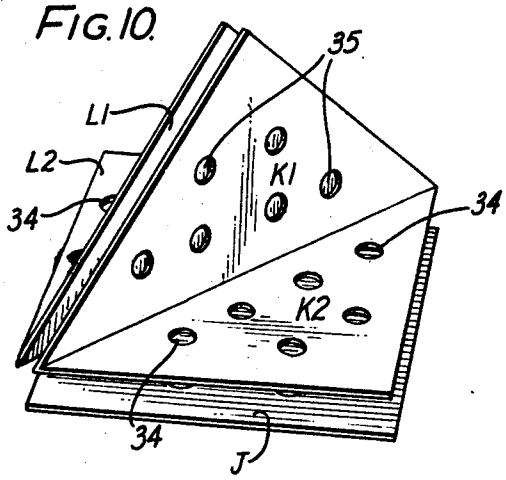


FIG. 10.



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3,399,914

LATTICEWORK COMPONENTS

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Filed Aug. 15, 1966, Ser. No. 572,585
Claims priority, application Great Britain, Aug. 19, 1965, 35,719/65
8 Claims. (Cl. 287—189.35)

ABSTRACT OF THE DISCLOSURE

A hub member for the interconnection of a plurality of struts at a junction point in a latticework structure, comprising several intersecting flat webs. The intersecting webs divide each other into a group of sectors or flange areas. A strut may be attached to each of these flange areas. One of the webs is oriented in a first (e.g., horizontal) plane, and the remaining webs are oriented in mutually equiangularly spaced planes which are normal to the first plane so that all of the planes meet at a common symmetrical center. The flange areas of the remaining webs are arranged along lines which branch out or radiate from the common center of the planes at angles less than or other than normal to the first plane.

This invention concerns improvements in or relating to components for lattice structures. It deals in particular with novel means for forming junctions in lattice structures, and above all in that type of lattice structure termed a space frame which is built up of struts intended to bear if possible only tensile and compressive stresses, the ends of these struts being interconnected with the ends of other struts diverging from junction points so arranged as to form and interconnect two or more planes of the space frame.

There are a wide variety of latticework structures which are theoretically possible, and those contemplated by contemporary architecture are formed primarily of either steel or, more often, aluminum struts, usually but not necessarily tubular. The invention is also of general application to latticework structures of all kinds, wherein the struts are formed not only of those and other metals but also of synthetic resin "plastics," fibreglass-reinforced synthetic resins, and indeed other structural materials capable of bearing both tensile and compressive stresses quite generally.

The main problem encountered in the construction of space-frames lies in the difficulty of producing a satisfactory junction between the ends of the several struts (usually at least 12) diverging therefrom. Direct welding together of the ends of the diverging struts is neither convenient nor economic in the construction of space frames and suffers also from the disadvantage that replacement of a defective strut becomes a matter of great difficulty. Probably the most practical and effective means devised till now for joining the ends of the struts diverging from a junction in a space frame has been a generally cylindrical hub member, provided with a number of serrated-edged slots or keyways which open radially inwards from the outer periphery of the cylindrical hub, and which extend parallel to the axis of the cylindrical hub from one end thereof to the other. Into these keyways there are fitted the ends of the struts, these being tubular members crimped at their ends in such a manner as to produce serrations thereon corresponding to the serrated edged slots and thus adapted to key into the keyway. After the crimped ends of the struts have been inserted into the keyways they are clamped and held against disengagement

therefrom by means of retaining cover discs which are fitted over the ends of the slots to each end of the cylindrical hub member by a bolt passing through an axial bore in the hub member and secured there. With this arrangement the junction can join the ends of struts diverging radially from the hub member in a plane normal to its axis and can also joint struts wherever they lie in an axial plane, simply by crimping the ends thereof in such a manner as to produce the serrated key pattern at a suitable angle.

In a space frame latticework structure all the struts diverging from a junction should ideally diverge from a single common point thereat in order that the compressive and tensile forces shall be transferred from one strut to the others at this junction without creation of any torsional or shear stresses. With the type of hub member mentioned above it is in some circumstances, very difficult to ensure this since the axial length thereof is limited by considerations of weight and cost. Similar considerations limit the radius and thus the number of slots which can be cut into the hub member around its periphery. It is for these practical reasons that in the known jointing arrangement only a limited number of keyways can normally be provided.

Another form of hub member which has been evolved comprises a spherical member from which protrude several tubular extensions. Struts in the form of tubular rods are secured to this hub member by placing their ends over the extensions and securing them with a bolt passing through the rod and extension. It is possible with this type of hub member to ensure that all the extensions have a common centre of divergence but it suffers from the extreme disadvantage that the volume of the sphere required to enable a sufficient number of extensions to be provided is so great that an aluminum hub member for use with 6" tubular rod struts would weigh something in the order of 200 lbs. Such a hub member is not only difficult to handle when assembling a space frame but also is very expensive as regards material used.

We have now discovered an improved form of hub member and jointing system which greatly alleviates the above disadvantages, is much more economical as regards weight and, therefore, cost, and can be easily used in constructing a latticework structure.

According to the invention, there is provided a hub member for interconnection of several struts at a junction point in a latticework structure, the hub member comprising a plurality of intersecting flat webs, a first set of said webs being located in a first plane and each having flange areas to which can be attached one end of the struts of the junction in one plane of the latticework structure, the others of said webs forming further sets in mutually equiangularly spaced further planes normal to said first plane such that said first plane passes through a line of symmetry of each said further planes and all the further planes meet at a line which lies on the axis of symmetry of said first plane, the said other webs having flange areas to which can be attached one end of the struts at the junction which join said one plane to another plane of the latticework structure.

Each set of webs can form a complete disc or other symmetrical planar member of different shape, e.g., square or diamond and one of the simpler forms of the invention will comprise one disc in the first plane of the hub member and two further discs which must of course be arranged at 90° to one another and be concentric with and normal to the first plane. Such a hub member allows for the attachment of four struts in one plane of the latticework structure, and four joining struts from both above and below which are connected at their other ends to two other planes of the latticework structure. A hub member having three further discs could have six struts

connected in the one plane of the latticework structure as well as six from both above and below. Such forms of hub member can have a weight (and yet adequate strength) of only 35 to 40 lbs. for connecting 6 inch tubular struts as compared with the 200 lbs. necessary for the conventional hub member hereinbefore described.

In another form of the hub member the first set of webs can form a complete disc or other symmetrical planar member and there can then be three further sets of webs each in the form of half the planar member formed by the first set of webs and each set at 120° to one another and joined at the axis of symmetry of the complete planar member. With such a hub member, three joining struts could be attached from both above and below and either three or six struts in the plane of the latticework structure could also be attached, in the latter case there being two flange areas for each web in the first set.

The flange areas on the webs can be adapted for attachment of a strut thereto by means of a hole passing therethrough in which a nut and bolt or rivet can be secured during assembly. Alternatively the ends of the struts can be welded in position onto the flanges. One particular form of attachment which allows for great ease in assembling and securing struts to the hub member is achieved by forming a straight ribbed and grooved recess in the edge of each web at the flange area such that the end of a strut which has been crimped into a complementary grooved and ribbed configuration can be slid into engagement with each recess. The struts can be securely fixed within the recesses, if necessary by means of a cap affixed (e.g., by a screw) over the end of the groove and where the ends of several recesses meet in the same general area, one cap should be sufficient for all of those.

The hub member according to the invention as hereinbefore defined can be formed of a number of discrete identical hub units wherein each hub unit comprises three webs, one from the first set and one from each of two of the further sets of webs. Since each hub unit is composed of three webs, but each web is duplicated, it follows that there must be two-thirds the number of hub units as there are webs when the complete hub member is formed by securing all the hub units together. The ends of struts can be very effectively attached to a hub member of this form by sandwiching each one between the two portions of a web, all three members then being secured together by means of, for instance, a rivet passing through all three. To form a hub member of the form comprising three identical planar members of square shape, eight identical hub units would be required, each unit being formed from three plates in the form of a right-angled isosceles triangle, the plates forming an integral structure with their right angled corners together and each plate being normal to the other two. A hub member of this construction can be made of aluminum in such a manner that the necessary strength is obtained but only 16 lbs. of material is used for a hub member for 6" diameter tubular struts.

It is particularly preferred that the hub units should be of a modified form to those just described. In this form the three webs are formed from a single sheet of material, a central portion of the sheet forming a connecting piece from which the webs are bent so as to be at the necessary angles to each other. Since this form of hub unit is made from the one sheet of material, no welding together of the webs is necessary which is a great advantage. The sheet of material used may be of any desired shape, but if the unit is made from a sheet in the form of an equilateral triangle and the three corners are bent up at angles of 125° to the connecting piece in the form of an equilateral triangle in the centre, a hub member constructed of eight of these units will have the general configuration of that comprising three complete planar members described hereinbefore.

It will be appreciated that the hub members positioned on the outermost or innermost plane of a latticework structure will have joining struts entering the junction from one side only. This invention therefore encompasses in its scope hub members which in fact have a complete set of webs for the plane of the latticework structure but only half the number of webs in each other set so that no further webs are present on one side of the first set of webs. Such hub members are particularly useful in the type of latticework structure termed a "space deck" which has only two planes of struts.

It should be noted that it is not intended to exclude from the scope of this invention a hub member in which any set of webs in a plane thereof are slightly modified so that they have no line or centre of symmetry. If one or more webs in a set differ slightly from the others then it will be appreciated that if the irregularity of the one or more webs is ignored (by theoretically adding to or subtracting from the shape of the irregular webs) symmetry will be restored.

The invention does of course extend to complete latticework structures or sections thereof when constructed using the hub members of this invention, where the ends of struts are secured to the flange portions thereof by bolting, welding, rivetting, etc. Although in some cases bolting or rivetting may be preferred, the hub members are particularly suited to welding because of the large area of contact between the flange areas and the edges of the ends of the strut members. If welding is used however, it will normally be more feasible to construct large sections of the structure at ground level and then bolt them in position.

In order that the invention may be fully understood, preferred embodiments thereof will now be described with reference to the accompanying drawings, in which:

FIGURE 1 is a perspective view of one embodiment of a space-frame hub member according to the invention;

FIGURE 2 is a perspective view of an alternative form of hub member to that shown in FIGURE 1;

FIGURE 3 is a hub member similar to that shown in FIGURE 1 but showing an alternative form of connecting means;

FIGURE 4 is a plan view of a modification of the hub member of FIGURE 1 showing how hub component units can be fitted together to form a composite hub member;

FIGURE 5 shows a hub unit of the hub member shown in FIGURE 4;

FIGURE 6 shows a modification of the hub unit of FIGURE 5;

FIGURE 7 is an alternative form of composite hub member to that shown in FIGURE 4;

FIGURE 8 shows a hub unit for use in the hub member of FIGURE 7;

FIGURE 9 is a hub member suitable for use in a particular form of space-deck; and

FIGURE 10 is a composite member for use in conjunction with the hub member of FIGURE 9 when constructing the space-deck.

Referring first to FIGURE 1, it will be seen that the hub member **1** is a simple integral casting having the form of three diametrically-intersecting disc-shaped plates **2**, **3**, **4**, the axis of intersection of any two plates (e.g., **3**, **4**) being normal to the plane of the other plate (e.g., **2**). Each disc-shaped plate is thus quartered by the other two plates into four right-angled sectors **5**, so that the hub member possesses a total of twelve flanges **5** each in the shape of a 90° sector, and each having an aperture **6** disposed along the median line **7** which bisects that sector-shaped flange **5**. To each such flange **5** there can be secured one end of a strut having the form of a tube whose end has been flattened and cut away at an angle of 45° to the strut axis on both sides so as to form a right-angled point to the strut adapted to fit onto one of the sector-shaped flanges **5** and apertured along the strut axis such that when the pointed end of the strut abuts against the

other two disc-shaped plates the aperture in the strut registers with the aperture **6** in the flange, and the strut and hub member can be secured together by a bolt or rivet fastened through the two apertures. The end of the strut can be bifurcated so that the two parts thereof can pass either side of the flange before fastening.

With the simple, but, effective, arrangement just described it will be seen that all the struts diverging from hub member **1** will enjoy a substantially common centre of divergence. Nevertheless, the struts can be readily assembled or disassembled, and they transmit compressive stresses to the hub member mainly via the abutment between the pointed end of the strut and the other disc-shaped plates, while tensile stresses are transmitted via the bolt or rivet which of course will be formed of material capable of withstanding the shear stresses thus imparted, which stresses are in any case minimized by the frictional engagement between the end of the strut and the flange to which it is secured.

What is perhaps of even greater significance is that the struts diverge in the optimum directions for the construction of a particularly preferred latticework structure; thus, there will be four struts lying in the plane of each of the disc-shaped plates, each of these four struts being each at right-angles to two of the others and diametrically opposite to the fourth, while the four struts in the planes of each of the other disc-shaped plates lie, like those plates, in planes normal to each other and normal to the first-mentioned plane. Thus there are four struts lying in what can be taken as a horizontal plane, four struts pointing upwards from the horizontal plane at an angle of 45° relative thereto, and another four struts pointing downwards at 45° therefrom, the upwardly and downwardly directed struts lying in vertical planes which bisect the 90° angles between the vertical planes in which opposed pairs of the horizontal struts lie. With this arrangement it is possible to build a latticework structure of the form wherein, in each plane a squared configuration is formed, by the struts joining the hub members, the hub members in one plane being disposed directly above the centre of the squares formed in the next, lower, plane.

Referring now to FIGURE 2 it will be seen that this shows a hub member **8** essentially similar to hub member **1** shown in FIGURE 1, but there are provided not three but four diametrically intersecting disc-shaped plates **9, 10, 11, 12** three of them **10, 11, 12** intersecting along a common diametrical axis but each inclined at an angle of 60° to each of the other two, the fourth plate **9** being normal to the axis of intersection of the other three and intersecting each of them through their centres of radius. Regarding the fourth-mentioned plate **9** as lying in a horizontal plane, it will be appreciated that there are provided six 60° sector flanges **13** in the horizontal plane, each apertured at points **16** along the median lines **18** bisecting the 60° sector-shaped flange, and six 90° sector flanges **14** above the horizontal plane as well as six more 90° sector flanges **15** below it, all these 90° sector flanges **14, 15** being apertured at points **16** along the median lines **17** bisecting those flanges. Accordingly this arrangement makes it feasible for a total of eighteen struts to diverge from the junction, six of these struts disposed at angles of 60°, lying in what can be taken as a horizontal plane, six struts pointing upwardly from that horizontal plane at an angle of 45° relative thereto and another six struts pointing downwardly at 45° therefrom, the upwardly and downwardly directed struts lying in vertical planes which bisect the 60° angles between the vertical planes in which opposed pairs of the horizontal struts lie.

With this arangement it is possible to build a latticework structure of the form wherein, in each plane a triangulated configuration is formed, by the struts joining the hub members, the hub members in one plane being disposed directly above the centre of the triangles formed in the next, lower, plane.

In FIGURE 3 there is shown a space-frame hub member **19** similar to that shown in FIGURE 1 but employing a different method of connections for the struts. Parts of the hub member **19** have been shown shaded merely to aid in consideration of the construction thereof. The hub member **1** comprises three square, plate-like members A, B, C each divided into quarter sections of which three for each disc can be seen and are subdesignated **1, 2, 3** after the letter representing the respective plate-like member. The corners of each square plate-like member A, B, C have been cut away so that at each point where four sectors, such as **A1, A2, B2, B3**, meet, a cross-shaped end **20** is formed.

Hub member **19** has, in each edge where struts are to be connected, a ribbed and grooved recess **21** into which a strut end (having a complementary grooved and ribbed configuration) can be slid. When four adjacent struts have been inserted they can be held in position at one end by means of a plate placed over cross-shaped end **20** and secured by a screw into hole **22**.

This type of hub member **19** is very useful in the construction of space frames, since the struts can easily and quickly be connected thereto.

In FIGURE 4 there is shown a modified embodiment of the hub member illustrated in FIGURE 1, which differs only inasmuch as notionally speaking, each of the three disc-shaped plate members **2, 3, 4** in FIGURE 1 has been divided in the plane of the disc into two separate but superimposed plates so that, in all, the complete hub member in FIGURE 4 consists of eight identical nuits **23** one of which is shown in FIGURE 5. From FIGURE 5 it will be apparent that the composite hub member can readily be assembled into a single unit merely by bolting or rivetting the components together via the apertures **6** at the time of bolting or rivetting the ends of struts in position.

FIGURE 6 shows how the unit for a hub member as shown in FIGURE 4 can be reduced in weight by forming the side panels **2B, 3B, 4B**, which will become the flanges **5** (FIGURE 1), when all the units are assembled, as triangular panels rather than as 90° segments of a circle, as are the panels **2A, 3A, 4A** in FIGURE 5. The panels **2B, 3B** and **4B** are further reduced in size at the centre **24** where a triangular section of material is removed and at the other two corners of the triangle so that they are of minimal weight, but are also large enough and strong enough to support the end of a strut at three points where holes **6A, 6B** and **6C** occur.

The strut for use with a hub member of the form shown in FIGURES 4 and 5 or modified as shown in FIGURE 6 will again be flattened so as to be inserted between the flanges of two hub member units and held thereby means of bolts or rivets passing through holes in the two flanges and the end of the strut sandwiched therebetween. The shape of the flattened end of the strut will of course have to be such that it can fit in the area provided by each flange.

Obviously a composite hub member of the form shown in FIGURE 4 can be formed to have the appearance of that shown in FIGURE 2. In this case of course twelve units will form the complete structure and will have the appearance of that shown in FIGURE 5 except that there will be an angle of 60° between panels **3A** and **4A** rather than 90°.

The hub member **19** of the form shown in FIGURE 3 could, if desired, be made from eight identical units each being three sectors integrally secured together to resemble sectors **A2, B2**, and **C2** cut down the centre of the groove **21** in each side. Such units could be secured together by welding or a nut and bolt passing through adjacent back-to-back sectors.

A further form of composite hub member of a configuration corresponding essentially to that of FIGURE 1 is shown in FIGURE 7. This shows a composite hub member **25** comprising eight identical units **26** of the form shown in FIGURE 8. Each unit **26** is formed initially

from a flat sheet of metal in the form of an equilateral triangle. The three corners of this equilateral triangle are bent up (on lines indicated at 27) until the three corners of flanges 28 are each at an angle of approximately 125° to the small base equilateral triangle 29 to form the unit shown in the side perspective view of FIGURE 8. When the sheet of metal to form unit 26 is initially cut out, three holes 30 are cut in each of the triangular flange portions 28.

Eight units of the form shown in FIGURE 8, when placed together in the required manner will form the complete hub member 25 for a space frame as shown in FIGURE 7. When a space-frame or other latticework structure is being constructed, the flattened ends of struts will be placed between the flanges 28 of two adjacent units 26 and secured therebetween by means of welding, nuts and bolts, rivets, etc. When struts are secured at all the flanges, a rigid and secure complete hub member 25 will have been formed. The units 26 shown in FIGURE 8 for forming the composite hub member 25 shown in FIGURE 7 have certain extra advantages when compared with that shown in FIGURE 5, namely that the former, while being of a very strong construction allows the weight to be cut down still further and the construction is such that the ends of struts secured therein do not have to be cut and tapered, but will easily be fitted merely by flattening the ends and forming holes therein. Also, it is possible to form each unit 26 without the need for welding or other securing as is necessary for connecting the three flanges 2A, 3A, 4A forming the unit 23 shown in FIGURE 5.

It will be appreciated that the twelve pairs of flanges 28 shown in FIGURE 7 are only at right angles to one another because the base triangles 29 of each unit 2 are all equilateral triangles. If it is desired that struts joining one plane to an adjacent plane should leave the hub member at angles other than 45° to the plane itself, then the hub member units 26 should be so formed that the base triangle is not equilateral but merely isosceles.

All the hub members so far described have been concerned with two particular forms of space frame. There are many others to which this invention is suited, but it will be appreciated that the form of hub member may need to differ for a different type of space frame. One type of space frame (termed a "space deck" because it has only two layers) which requires two different forms of hub member comprises a squared configuration of struts in one plane, (e.g., the lower plane) and another squared configuration of struts in the other, upper plane. The length of strut in the upper plane is equal to the diagonal of the squares in the lower plane and the struts in the upper plane are set diagonally to the lower squares with the upper hub members disposed above the centre of the lower squares.

FIGURE 9 shows a hub member 3 to which can be connected four struts in the upper plane of the space deck and four joining struts from the lower plane thereof. The planar struts are secured to hub member 31 via the four holes 32, while the joining struts are secured thereto via the three holes 33. If desired the hub member can be made with edge recesses similar to those shown in FIGURE 3, or be formed as four identical units which are bolted together back-to-back to sandwich the joining struts therebetween, planar struts being sandwiched between the hub member 31 and a lower plate of similar shape to the base of hub member 31. The particular construction of hub member 31 is necessary because the planar and joining struts enter the hub member in the same vertical planes.

A different form of hub member is required for the lower plane since there are only two joining struts to each hub member in a vertical plane which lies at 45° (or 135°) to the two vertical planes in which the planar struts lie. Such a form of hub member is shown in FIGURE 10 and comprises three square plates J, K, L, two of these being bent at their diagonals to form in each case, two integral triangular plates K1, K2 and L1, L2 respectively at right angles to each other. Planar struts will be secured between plate J and triangular portions K2, L2 by securing means passing through holes 34, while joining struts will be similarly secured between triangular plates K1, L1 by means of holes 35. Of course this hub member could be formed as a single member (as is that of FIGURE 9) and could then have recessed edges as the attachment means for the ends of struts.

I claim:

1. A hub member for interconnection of several struts at a junction point in a latticework structure, the hub member comprising a plurality of intersecting flat webs, a first set of said webs being located in a first plane, flange areas being present on the webs of said first set, to the external surfaces of which can be attached one end of the struts of the junction in one plane of the latticework structure, further sets in mutually equiangularly spaced further planes normal to said first plane being formed by the other of said webs to pass between flange areas on said first plane such that said first plane passes through a line of symmetry of each said further plane and all the further planes meet at a line which lies on the axis of symmetry of said first plane, flange areas being present on said other webs to the external surfaces of which can be attached one end of the struts at the junction which join said one plane to another plane of the latticework structure, the flange areas of said other webs being set on lines radiating from the common center of said planes at angles less than normal to said first plane.

2. A hub member as claimed in claim 1 wherein there are two or more flange areas on each web.

3. A hub member as claimed in claim 1 having a complete set of webs in said first plane but only half the number of webs in each other set so that no webs are present on the one side of said first set of webs.

4. A composite hub member for interconnection of several struts at a junction point in a latticework structure comprising a number of discrete identical hub units, formed from a single sheet of material which contains the three webs in each hub unit, a central portion of said sheet forming a connecting piece from which the webs are bent so as to be at the necessary angles to each other, the hub units being placed back to back to form a complete hub member which comprises a plurality of intersecting flat webs, a first set of said webs being located in a first plane, double layer flange areas being present on the webs of said first set, between the facing internal surfaces of which can be attached one end of the struts at the junction in one plane of the latticework structure, further sets in mutually equiangularly spaced further planes normal to said first plane being formed by the other of said webs to pass between flange areas on said first plane such that said first plane passes through a line of symmetry of each said further plane and all the further planes meet at a line which lies on the axis of symmetry of said first plane, double layer flange areas being present on said other webs, between the facing internal surfaces of which can be attached one end of the struts at the junction which join said one plane to another plane of the latticework structure, the flange areas at said other webs being set on lines radiating from the common center of said planes at angles less than normal to said first plane, one web from said first set and one web from each of two further sets of webs, forming each hub unit, there being two-thirds the number of hub units as there are webs in the complete hub member.

5. A hub member as claimed in claim 4 wherein there are two or more flange areas on each web.

6. A hub member for interconnection of several struts at a junction point in a latticework structure, the hub member comprising a plurality of intersecting flat webs, a first set of said webs being located in a first plane, flange areas being present on the webs of said first set, to the external surfaces of which can be attached one end of the

struts of the junction in one plane of the latticework structure, further sets in mutually equiangularly spaced further planes normal to said first plane being formed by the other of said webs to pass between flange areas on said first plane such that said first plane passes through a line of symmetry of each said further plane and all the further planes meet at a line which lies on the axis of symmetry of said first plane, flange areas being present on said other webs to the external surfaces of which can be attached one end of the struts at the junction which join said one plane to another plane of the latticework structure, the edge of each web at the flange area being shaped to form a straight ribbed and grooved recess, so that a strut end which has been grooved and ribbed in a complementary fashion can be slid in at one end of the groove.

7. A hub member as claimed in claim 6 having caps which can be affixed over the open ends of recesses in the webs.

8. Latticework structures or sections thereof incorporating at junction points therein, hub members of the form comprising a plurality of intersecting flat webs, a first set of said webs being located in a first plane, flange areas being present on the webs of said first set to the external surfaces of which can be attached one end of the struts of the junction in one plane of the latticework structure,

further sets in mutually equiangularly spaced further planes normal to said first plane being formed by the other of said webs to pass between flange areas on said first plane such that said first plane passes through a line of symmetry of each said further plane and all the further planes meet at a line which lies on the axis of symmetry of said first plane, flange areas being present on said other webs to the external surfaces of which can be attached one end of the struts at the junction which join said one plane to another plane of the latticework structure the flange areas at said other webs being set on lines radiating from the common center of said planes at angles less than normal to said first plane.

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