HYPERBOLIC PARABOLOID ROOF STRUCTURE

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ABSTRACT
A roof structure for a hanger or the like in which first and second roof sections having the shapes of parts of respective first and second hyperbolic paraboloids, having common base lines are joined along a line lying on the locus of an arch common to the two paraboloids to form a roof having openings of predetermined height between spaced roof supports. Reinforcing girders around the edges of the roof are formed with triangular cross sections made up of hyperbolic paraboloid surfaces joined by vertical edges.

3 Claims, 9 Drawing Figures
HYPERBOLIC PARABOLOID ROOF STRUCTURE

This is a continuation of application Ser. No. 58,065, filed 7-24-70 now abandoned.

BACKGROUND OF THE INVENTION

There are many instances in the building construction art in which roofs covering a large area must be erected without the use of vertical supporting members such as columns located within the perimeter of the roof. A salient example of such a building is an aircraft hangar which must receive an aircraft having a wide wing span and having a high tail structure. Hangars of the prior art generally have been made of a boxlike construction in which the roof is of uniform height over the entire area to be covered. Complicated and expensive truss arrangements must be employed to support such a roof without the use of intermediate ground supports such as columns.

Not only are roof structures of this nature expensive to construct but structures incorporating them have a large amount of waste space in many applications such as aircraft hangars and the like. These problems have become greatly magnified with the advent of super-size aircraft which are either in existence or are in the planning and development stage.

Various geometric shapes have been proposed in the prior art for roof structures which will effectively cover a large area at a relatively low cost without the use of intermediate supports. Specifically, it has been proposed that the roof have the shape of a hyperbolic paraboloid, which may be described as a surface having parabolic contours when intersected with vertical planes at 45° to the grid lines and having hyperbolic contours when intersected by horizontal planes. Such a structure per se however, has not proved to be an ideal solution to the problem outlined above.

First, if the hyperbolic paraboloid roof is made large enough in area to accommodate a large modern aircraft, its shape renders it unsuitable for that purpose. That is, over a given area and for certain vertical exterior dimensions, the stress condition of the roof is so high that excessive deflection results. This condition could only be overcome by use of a curvature which, while it reduces the stress, results in excessive exterior vertical dimensions. Use of a plurality of hyperbolic paraboloid structures of limited area with intermediate supporting columns obviously defeats the intended purpose of the structure.

Secondly, a hyperbolic paraboloid is a structure which generally has great strength and rigidity except along the edges of the structure. The stiffness of the edges might be increased by increasing the curvature of the body but again, the permissible external vertical dimensions would be exceeded.

We have invented a hyperbolic paraboloid roof structure which effectively covers a large area without the use of intermediate vertical supports. Our structure effectively covers an extended area without incorporating inordinately great vertical dimensions. Our structure incorporates stiff edges without requiring excessive vertical dimensions and without adding an inordinate weight to the structure. Our roof permits an aircraft hangar to be constructed in such a way as most efficiently to use the available space while accommodating extremely large aircraft.

SUMMARY OF THE INVENTION

One object of our invention is to provide an improved roof structure for covering a large area without requiring the use of intermediate vertical supports within the perimeter of the area.

Another object of our invention is to provide a hyperbolic paraboloid roof structure especially adapted for use in an aircraft hangar.

A further object of our invention is to provide a hyperbolic paraboloid roof structure which effectively covers an extended area without requiring excessively great exterior vertical dimensions.

Still another object of our invention is to provide a hyperbolic paraboloid roof structure having stiff edges without excessive vertical dimensions.

Yet another object of our invention is to provide a hyperbolic paraboloid roof structure having edges which are reinforced without adding materially to the weight of the basic structure.

Other and further objects of our invention will appear from the following description.

In general our invention contemplates the provision of a hyperbolic paraboloid roof structure in which first and second roof sections shaped as portions of respective first and second hyperbolic paraboloids are joined along an arch which is common to the two paraboloids. Portions of other hyperbolic paraboloids together with the edge portions of the first and second paraboloids and vertical edges form reinforcing girders of hollow, generally triangular cross section extending around the edge of the structure.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings which form part of the instant specification and which are to be read in conjunction therewith and in which reference numerals are used to indicate like parts in the various views:

FIG. 1 is a side elevation of an aircraft hangar incorporating our hyperbolic paraboloid roof structure.

FIG. 2 is a front elevation of the hangar shown in FIG. 1 taken along the line 2—2 of FIG. 1.

FIG. 3 is a diagrammatic view illustrating the manner in which a roof section can be taken from a hyperbolic paraboloid.

FIG. 4 is a diagrammatic view of a first hyperbolic paraboloid on which one of our roof sections is based as viewed from the right front thereof.

FIG. 5 is a diagrammatic view of a second hyperbolic paraboloid on which a second section of our roof structure is based as viewed from the right front thereof.

FIG. 6 is a diagrammatic view illustrating a compound figure made up by joining the paraboloids of FIGS. 3 and 4 along an arch common to the two.

FIG. 7 is a diagrammatic view of another hyperbolic paraboloid from which we obtain one side of a reinforcing girder of our hyperbolic paraboloid roof structure.

FIG. 8 is a diagrammatic view illustrating the manner in which a structure derived from the paraboloid of FIG. 6 cooperates with a portion of the arrangement of FIG. 5 in forming a reinforcing girder.

FIG. 9 is a perspective view illustrating our finished hyperbolic paraboloid roof structure.
DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 3 we have illustrated a generalized form of hyperbolic paraboloid the equation of which is:

\[(x^2/a^2) - (y^2/b^2) = z\]

As is also known in the art this figure has the shape of a parabola in the \( y - z \) plane and has the shape of a hyperbola in the \( x - z \) plane. It can readily be demonstrated that roof sections covering various areas can be derived from the figure. For example, selecting points \( p_1 \) and \( p_2 \) on the curve in the \( x - z \) plane and projecting the points into a plane parallel to the \( x - y \) plane at the desired distance from the origin the selected section covers an area \( A_1 \), two corners of which are located on the parabola at the saddle and two corners of which are located in the plane of projection at distances \( h_1 \) and \( h_2 \) from the curve in the \( x - z \) plane. By way of example we have illustrated a second area \( A_2 \) covered by a different part of the figure at a different distance from the origin. This area has two corners at points on the parabola at the saddle and two other corners at distances \( h_3 \) and \( h_4 \) from points \( p_1 \) and \( p_2 \) on the curve in the \( x - z \) plane. It will be understood that in practice the area to be covered as well as minimum and maximum permissible heights are predetermined.

Referring now to FIG. 4 we have illustrated the manner in which a first roof section surface indicated generally by the reference character 10 may be formed with reference to a square grid indicated generally by the reference character 12 which may for example be 15 feet square to provide 255 squares defined by the intersecting lines of the grid. It will be appreciated, of course, that the area to be covered by the finished roof determines the area with reference to which the surface is derived. The surface of our roof, as has been pointed out hereinabove, is derived from a hyperbolic paraboloid. Such a surface contains two families of straight lines and has a saddle point at the origin. In generating the surface for the first section of our roof we select a portion of the hyperbolic paraboloid providing respective high points 14 and 16 at the corners 18 and 20 of the grid 12 and low points of zero elevation at the other corners 22 and 24 of the grid. The paraboloid surface has a hyperbolic curvature in planes passing through corners 18 and 20 and a parabolic contour in planes passing through corners 22 and 24. Moreover, the surface can be entirely made up of a plurality of straight lines 26. In effect, the entire 225 feet square with the 15 ft. grid is raised to conform to the high and low points resulting in the hyperbolic paraboloid surface. In practice the form work stringers need not be placed parallel to the straight lines 26 to form the surface, but may extend in any direction. We terminate the front portion of the roof along a radius 28 so that the portion of the surface to the left of that radius in FIG. 4 need not actually be constructed.

We also make our roof in at least two sections connected at an arch so as to eliminate excessive vertical dimensions. Thus the front section terminates along a paraboloidal arch 30 shown in FIG. 4 so that the portion of the surface to the right of that line in FIG. 3 need not be constructed. As to actual dimensions, in one example high point 14 has an elevation 108.6 ft. and the theoretical high point 16 has an elevation of 392 ft.

Referring now to FIG. 5 we generate another hyperbolic paraboloid surface indicated generally by the reference character 32 with reference to the same grid 12. Surface 32 is made up of a plurality of straight lines 34 but the form work stringers need not be laid parallel to these lines in constructing the rear section of the roof. The surface 32 contains an arch 36 which is identical with the arch 30. We connect the two sections along this arch so that we need not actually construct the portion of surface 32 to the left of the line 36 in FIG. 5. Surface 32 is so selected as to provide a desired high point 38 in the nose area of the hangar and a theoretical high point 40 at the other end of the surface with low points of zero at the corners 22 and 24 of the grid. In a particular example, we provide a high point 38 having an elevation of 66 ft. above the corner 20 and a theoretical high point 40 having an elevation of 210.6 ft. above the corner 18.

Referring now to FIG. 6 we have illustrated the manner in which the surfaces 10 and 32 can be joined along an arch 40 which is common to both arches 30 and 36 to form a composite structure. For purposes of clarity we have shown the portions of the surfaces which were not actually constructed by broken lines in this figure.

As has been pointed out hereinabove hyperbolic paraboloids generally have great strength and rigidity except along the edges thereof.

Referring now to FIGS. 7 to 9 we generate a portion 42 of an edge reinforcing beam structure from a third hyperbolic paraboloid surface indicated generally by the reference character 44 the unused portion of which is indicated in broken lines in the FIG. Surface 44 is provided with low points 46 and 48 above the corners 22 and 24 of the grid 12 by a distance for which, for example, 10 feet so as to keep the surface 44 above surface 10 along the front edge thereof and to cause it to intersect with it at about thirty feet for example, back from the front edge. The paraboloid from which the surface portion 42 is derived may have high points at 115 ft. and at 392.25 ft. above the corners 18 and 20 of the grid.

In an analogous manner we derive additional surfaces 50, 52, 54 and 56 for other edges of the composite roof structure. When that has been done flat surfaces 58 are provided around the edge between the outer edge of surface 10 and of surface 42 for example to provide a hollow reinforcing girder entirely around the edge of the roof structure. Abutments 60 and 62 may also be added to the structure. The roof section per se is now complete.

Referring now to FIGS. 1 and 2 in an actual installation of our hyperbolic paraboloid roof indicated generally by the reference character 64 including sections 10 and 32 in a hangar the roof is erected on a tie beam 66 and may be provided with wind columns 68. Section 10 forms the entrance of the hangar while the left hand portion of section 32 as viewed in FIG. 1 forms the nose area. Siding 70 across the upper portion of the front of section 10 is formed with an opening 72 for admitting the tail of an aircraft indicated in phantom at 74. Suitable doors and the like may be used to close the front of the hangar. Since the other portions of the hangar structure do not per se form part of our invention they will not be described in detail.
In constructing a roof in accordance with our invention, starting with given vertical dimensions for the front entrance, for the nose area and for the central arch, we first determine the surfaces of the sections 10 and 32. Next, the reinforcing form work stringers are laid parallel to the surfaces. These stringers run in various directions and intersect each other. Next, the building material such as for example as concrete is applied. So that said arch portions define a common arch therebetween. In the course of that operation the reinforcing beam surfaces such as 42 and the vertical surfaces which close the beams are applied until the roof is complete. It will then accommodate an aircraft 74 with a minimum of waste space.

It will be seen that we have accomplished the objects of our invention. We have provided a hyperbolic paraboloid roof structure which effectively covers a large area without the use of intermediate vertical supports. Our structure does not incorporate excessively great external vertical dimensions. We provide stiff edges while at the same time avoiding excessive vertical dimensions and avoiding excess weight.

It will be understood that certain features and sub-combinations are of utility and may be employed without reference to other features and subcombinations. This is contemplated by and is within the scope of our claims. It is further obvious that various changes may be made in details within the scope of our claims without departing from the spirit of our invention. It is, therefore, to be understood that our invention is not to be limited to the specific details shown and described.

Having thus described our invention, what I claim is:

1. A roof structure having hyperbolic paraboloid sections, said roof structure comprising:
   a first section cementitious having the shape of a predetermined part of a hyperbolic paraboloid generated with reference to a preselected grid, said first section having outer edge terminating outlying portions and an arch portion;
   a second section cementitious having the shape of a predetermined part of a hyperbolic paraboloid generated with reference to said preselected grid, said second section having outer edge terminating outlying portions and an arch portion that is substantially identical to the arch portion of said first section, the arch portion of said second section being positioned adjacent to the arch portion of said first section, so that said arch portions define a common arch therebetween;
   a third section having the shape of a predetermined part of a hyperbolic paraboloid, said third section having one portion positioned adjacent to predetermined outlying portions of said first section and having another portion positioned adjacent to predetermined outlying portions of said second section with said one portion of said third section outwardly terminating at outer edges spaced with respect to the outer edges of said first section and inwardly terminating at inward edges in contact with said first section inwardly of the outer edges thereof, and said another portion of said third section outwardly terminating at outer edges spaced with respect to the outer edges of said second section and inwardly terminating at inward edges in contact with said second section inwardly of the outer edges thereof; and
   joining means having one portion joining outer edges of said first and third sections and another portion joining outer edges of said second and third sections whereby a roof structure reinforcing member is formed about said outer edges of said roof structure.

2. The roof structure of claim 1, wherein outer edges of said first and second sections are spaced from one another a distance less than the distance between the outer and inner edges of said second section.

3. The roof structure of claim 1 wherein the outer edges of said first and second sections are in substantially vertical alignment so that said joining means is substantially vertically positioned.

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UNITED STATES PATENT OFFICE
CERTIFICATE OF CORRECTION

Patent No. 3,798,849 Dated October 28, 1974

Inventor(s) Dutton Biggs and Vernon Konkel

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 4, line 7, "need not" should read -- can --;
Column 5, line 5, "are" should read -- may be --;
Column 5, line 6, "to the surfaces" should read -- to the lines of the surface --;
Column 5, lines 6 to 7, cancel [These stringers run in various directions and intersect each other.]
Column 5, lines 8 to 10, cancel [So that said arch portions define a common arch therebetween.]
Column 5, line 37, "section cementitious" should read -- cementitious section --;
Column 5, line 42, "section cementitious" should read -- cementitious section --;
Column 6, line 32, "edged" should read -- edges --.

Signed and sealed this 14th day of January 1975.

(SEAL)
Attest:

McCoy M. Gibson Jr. C. Marshall Dann
Attesting Officer Commissioner of Patents