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(54) Title: PRECISION FOLDED STRUCTURAL AND AESTHETIC COMPONENT AND SHEET THEREFOR

(57) Abstract: A sheet material is provided for forming a precision folded structural and aesthetic component of a contoured three-dimension. The sheet material may include a forward-panel bend line separating a forward panel and a fold panel, the forward-panel bend line may be curved to impart contour on at least the fold panel upon bending of the sheet material about the forward-panel bend line, and a fold line extending along the fold panel, the fold line may be substantially straight to impart the contour of the fold panel to the upper panel upon bending of the sheet material about the fold line. The sheet material may include an upper panel, a first upper-panel-flange bend line separating a forward upper flange from a warp zone of the upper panel, the first upper-panel-flange bend line may be curved to impart a first contour on one or more of the first upper flange and the warp zone, a second upper-panel-flange bend line separating a second upper flange from the warp zone, the second upper-panel-flange bend line may be curved to impart a second contour on one or more of the second upper flange and the warp zone, and first and second curved warp zone bend lines separating the warp zone from a remainder of the upper panel, the first and second curved warp zone bend lines configured to localize bending along the bend line and substantially isolate warpage within the warp zone. A method of forming the same is also disclosed.



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**PRECISION FOLDED STRUCTURAL AND AESTHETIC
COMPONENT AND SHEET THEREFOR**

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 60/799,215 filed on May 9, 2006, the entire contents of which is incorporated herein by this reference.

[0002] This application also claims also priority to US Patent Application No. 60/799,217 filed on May 9, 2006, the entire contents of which is also incorporated herein by this reference.

BACKGROUND OF THE INVENTION**Field of the Invention**

[0003] The present invention relates, in general, to designing and precision bending of material sheets to form contoured three-dimensional structures having both structural and aesthetic components, and to methods for their use, and more particularly, to bent and warped structures and methods of forming the same.

Description of Related Art

[0004] Various methods are known for forming three-dimensional structures from two-dimensional sheet materials. For example, press brakes, stamping equipment and other cold-forming metal equipment have long been used to form sheet metal into three-dimensional objects.

[0005] More recently, the use of computer numerically controlled (CNC) devices have been used to treat sheet materials to facilitate bending about predetermined bend lines. For example, laser cutting, water jet cutting, stamping, punching, molding, casting, stereo lithography, roll forming, machining, chemical-milling, photo-etching and the like have been used to form slits or grooves in sheet materials along predetermined bend lines to facilitate and control bending along the bend lines.

[0006] Exemplar of the prior art is U.S. Patent No. 6,640,605 to Gitlin et al. which discloses a method of bending sheet material to form three-dimensional structures, including housings and casings, interior and exterior structures, and various covers and supports.

[0007] Such prior methods of bending sheet materials about predetermined bend lines are generally successful in forming three-dimensional objects but the three-dimensional shapes that may be produced by such methods are limited. For example, such methods are generally employed to form three dimensional objects having planar regions extending between adjacent bend lines, or curved regions extending between adjacent bend lines which generally follow the curvature of the adjacent bend lines. To date, however, laying out predetermined bend lines on sheet materials is generally not conducive to forming complex three-dimensional structures which have complexly-curved contoured areas bounded between adjacent bend lines.

[0008] For instance, early vehicles generally included a framework providing structural integrity, to which body panels and non-structural components were attached. Such general configuration allowed designers and manufactures to provide varying ornamentation to the attached components to provide an overall pleasing aesthetic appearance to the vehicle.

[0009] With the more recent advent of unibody construction, vehicles are often provided with a one-piece frame and body structure which includes both structural and non-structural aesthetic elements. Nonetheless, subassemblies attached to or within a unibody frame continued to include one or more structural members providing

structural integrity to the frame, and one or more ornamental panels attached to the structural member(s).

[0010] For example, instrument panel structures ("I/P structures") are structures that provide support for the steering column, the instrument cluster and other dashboard components, as well as provide a structural element to the vehicle and the mounting points for airbags and the like. Such I/P generally includes one or more skeletal or internal structural members that are attached to the unibody frame, generally adjacent the A-pillar, and may provide additional structural integrity to the frame. External ornamental members, for example, dashboard panels and the like, are attached to the internal structural members and provide the vehicle interior with a finished and pleasing appearance.

[0011] More recently, I/P structures having more complex geometries have been formed with hydroforming and other stamping processes. Nonetheless, such I/P structures are still generally intended as skeletal or internal structural members to which dashboard panels are attached. As such, the number of parts required to finish a dashboard of an automobile are relatively high, and the labor required to assemble the various components is not insignificant

[0012] What is needed is an improved method of forming contoured three-dimensional structures from sheet materials which overcomes the above and other disadvantages of known structures and methods.

BRIEF SUMMARY OF THE INVENTION

[0013] In summary, one aspect of the present invention is directed to a sheet material is provided for forming a contoured three-dimensional structure. The sheet material includes a forward-panel bend line separating a forward panel and a fold panel, which forward-panel bend line is curved to impart contour on at least the fold panel upon bending of the sheet material about the forward-panel bend line, and a fold line extending along the fold panel. The fold line may be substantially straight to impart the

contour of the fold panel to the upper panel upon bending of the sheet material about the fold line.

[0014] The sheet material may include a supplemental fold line separating the fold panel from a supplemental fold panel. The supplemental fold line may be substantially straight to impart the contour of the first fold panel to the second fold panel upon bending of the sheet material about the supplemental fold line, wherein the contour of the forward-panel bend line may be imparted to the upper panel via the fold panel and the second fold panel upon bending the fold line and the supplemental fold line.

[0015] The sheet material may include a forward-panel-flange bend line separating the forward panel and a forward-panel flange. The forward-panel-flange bend line may be curved to impart contour on one or more of the forward panel and the forward-panel flange upon bending of the sheet material about the forward-panel-flange bend line. The forward-flange bend line may be S-shaped thereby imparting both concave and convex contours on the forward panel.

[0016] The forward-panel bend line may be downwardly concave to impart an upwardly convex contour on at least a portion of the upper panel. A first distance between the forward-panel bend line and the first fold line may be different than a second distance between the first fold line and the second fold line whereby a forward edge of the upper panel defined by the second fold line may be spaced from the forward panel. The first distance may be shorter than the second distance thereby recessing the forward panel rearward from the forward edge.

[0017] The sheet material may include a first upper-panel-flange bend line separating a forward upper flange from a warp zone of the upper panel. The first upper-panel-flange bend line may be curved to impart a first contour on one or more of the first upper flange and the warp zone. A second upper-panel-flange bend line may separate a second upper flange from the warp zone. The second upper-panel-flange bend line may be curved to impart a second contour on one or more of the second upper flange and the warp zone. First and second curved warp zone bend lines may separate the warp zone

from a remainder of the upper panel. The first and second curved warp zone bend lines may be configured to localize bending along the bend line and substantially isolate warpage within the warp zone. Both the first and second warp zone bend lines may terminate at an intersection point. Both the first and second warp zone bend lines may have compound curvatures. Portions of the bend lines adjacent the intersection point may have smaller radii of curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

[0018] In one embodiment, at least one of the bend lines and the fold lines may be formed with a plurality of slits through the sheet of material. Adjacent slits may be positioned alternating on either side of the at least one of the bend lines or fold lines. At least one of the bend lines and the fold lines may be formed with a plurality of displacements. Adjacent displacements may be positioned alternating on either side of the at least one of the bend lines or fold lines.

[0019] Another aspect of the present invention is directed to three-dimensional structures including the sheet material described above. A further aspect of the present invention is directed to a method of forming a three-dimensional structure including the steps of providing the sheet material described above, bending the sheet of material along the forward-panel bend line, and bending the sheet of material along the fold line.

[0020] Still another aspect of the present invention is directed to a sheet material for forming a contoured three-dimensional structure including an upper panel, a first upper-panel-flange bend line separating a forward upper flange from a warp zone of the upper panel, the first upper-panel-flange bend line being curved to impart a first contour on one or more of the first upper flange and the warp zone, a second upper-panel-flange bend line separating a second upper flange from the warp zone, the second upper-panel-flange bend line being curved to impart a second contour on one or more of the second upper flange and the warp zone, and first and second curved warp zone bend lines separating the warp zone from a remainder of the upper panel. The first and second curved warp zone bend lines are configured to localize bending along the bend line and substantially isolate warpage within the warp zone.

[0021] The first upper-panel-flange bend line may be concave in a first direction and the second upper-panel-flange bend line may be concave in a second direction that is not parallel to the first, wherein the warp zone elastically deforms to accommodate the different contours of the first and second upper-panel-flange bend lines.

[0022] In one embodiment, both the first and second bend lines terminate at an intersection point. Both the first and second bend lines may have compound curvatures. Portions of the bend lines adjacent the intersection point may have smaller radii of curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

[0023] In one embodiment, at least one of the bend lines and the fold lines may be formed with a plurality of slits through the sheet of material. Adjacent slits may be positioned alternating on either of the at least one of the bend lines or fold lines. At least one of the bend lines and the fold lines may be formed with a plurality of displacements. Adjacent displacements may be positioned alternating on either side of the at least one of the bend lines or fold lines.

[0024] Another aspect of the present invention is directed to three-dimensional structures including the sheet material described above. A further aspect of the present invention is directed to a method of forming a three-dimensional structure including the steps of providing the sheet material described above, and bending the sheet of material along the first and second upper-panel bend lines. The first and second warp zone bend lines may allow warpage within the warp to accommodate the varying contour imparted by the first and second dashboard-flange bend lines.

[0025] Still a further aspect of the present invention is directed to a sheet material for forming a contoured three-dimensional dashboard, the dashboard, and methods of forming the dashboard. The sheet material may include a dash-panel-flange bend line separating a dash panel and a dash-panel flange, the dash-panel-flange bend line may be curved to impart contour on one or more of the dash panel and the dash-panel flange upon bending of the sheet material about the dash-panel-flange bend line, a dash-panel

bend line separating the dash panel and a first fold panel, the dash-panel bend line may be curved to impart contour on at least the first fold panel upon bending of the sheet material about the dash-panel bend line, a first fold line separating the first fold panel from a second fold panel, the first fold line may be substantially straight to impart the contour of the first fold panel upon the second fold panel upon bending of the sheet material about the first fold line, a second fold line separating the second fold panel from a dashboard panel, the second fold line may be substantially straight to impart the contour of the second fold panel to the dashboard panel upon bending of the sheet material about the second fold line, a first dashboard-flange bend line separating a forward dashboard flange from a warp zone of the dashboard panel, the first dashboard-flange bend line may be curved to impart a first contour on one or more of the first dashboard flange and the warp zone, a second dashboard-flange bend line separating a second dashboard flange from the warp zone, the second dashboard-flange bend line may be curved to impart a second contour on one or more of the second dashboard flange and the warp zone, and first and second curved warp zone bend lines separating the warp zone from a remainder of the dashboard panel, the first and second curved warp zone bend lines configured to localize bending along the bend line and substantially isolate warpage within the warp zone.

[0026] The dash-panel-flange bend line may be S-shaped thereby imparting both concave and convex contours on the dash panel. The dash-panel bend line may be downwardly concave to impart an upwardly convex contour on at least a portion of the dashboard panel. A first distance between the dash-panel bend line and the first fold line may be different to a second distance between the first fold line and the second fold line whereby a forward edge of the dashboard panel defined by the second fold line may be spaced from the dash panel. The first distance may be shorter than the second distance thereby recessing the dash panel beyond the forward edge.

[0027] In one embodiment, both the first and second bend lines terminate at an intersection point. Both the first and second bend lines may have compound curvatures. Portions of the bend lines adjacent the intersection point may have smaller radii of

curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

[0028] In another embodiment, the sheet material includes a dash panel delineated by a plurality of curved bend lines, each bend line being shaped and configured to impart a pre-selected contour on the dash panel upon bending of the sheet material about the curved bend lines, and a cross beam delineated by a plurality of straight bend lines being shaped and configured to form an upper beam web, and an upper beam flange, and a lower beam flange, wherein the cross-sectional shape of the cross beam is set by one or more caps provided on the sheet material.

[0029] The method of forming a dashboard may include providing the sheet material described above, bending the sheet of material along the dash-panel-flange bend line, bending the sheet of material along the dash-panel bend line, bending the sheet of material along the first and second fold lines, and bending the sheet of material along the first and second dashboard-flange bend lines, wherein the first and second warp zone bend lines allow warpage within the warp to accommodate the varying contour imparted by the first and second dashboard-flange bend lines.

[0030] Yet another aspect of the present invention is directed to a sheet material for forming a precision folded vehicle member having structural and aesthetic components. The sheet material may include a dash panel delineated by a plurality of curved bend lines, each bend line being shaped and configured to impart a pre-selected contour on the dash panel upon bending of the sheet material about the curved bend lines, and a cross beam delineated by a plurality of straight bend lines being shaped and configured to form an upper beam web, an upper beam flange, and a lower beam flange, wherein the cross-sectional shape of the cross beam is set by one or more caps provided on the sheet material.

[0031] The precision folded structural and aesthetic component having contoured three-dimensional structure, the sheet therefor, and the methods of forming same of the present invention have other features and advantages which will be apparent from or

are set forth in more detail in the accompanying drawings, which are incorporated herein, and the following Detailed Description of the Invention, which together serve to explain the principles of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0032] The present invention will become more fully understood from the detailed description given hereinbelow and the accompanying drawings which are given by way of illustration only, and thus are not limitative of the present invention, and wherein:

[0033] FIG. 1 is a plan view of an exemplary two-dimensional sheet material configured for bending into a contoured three-dimensional structure in accordance with the present invention;

[0034] FIG. 2 is an enlarged partial view of the two-dimensional sheet material of FIG. 1, taken along detail 2-2 of FIG. 1;

[0035] FIG. 3 is an upper front perspective view of the two-dimensional sheet of material of FIG. 1 after bending in accordance with the present invention;

[0036] FIG. 4 is another upper front perspective view of FIG. 3 after bending in accordance with the present invention;

[0037] FIG. 5 is a lower perspective view of FIG. 3;

[0038] FIG. 6 is a plan view of another exemplary two-dimensional sheet material configured for bending into a contoured three-dimensional structure in accordance with the present invention;

[0039] FIG. 7A is a plan view of a two-dimensional sheet material configured for precision folding to form of another exemplary embodiment of a vehicle structure in accordance with the present invention;

[0040] FIG. 7B is an enlarged detail of the sheet material of FIG. 7A taken within detail 7B-7B of FIG. 7A;

[0041] FIGS. 8A-8E is a series of perspective views illustrating the folding the sheet material along the bend lines of FIG. 7 in accordance with the present invention;

[0042] FIGS. 9A-9E are enlarged perspective views of FIGS. 8A-8E, respectively;

[0043] FIG. 10 is a further enlarged perspective view of the vehicle structure of FIGS. 8E and 9E, as viewed from the front right of the vehicle structure;

[0044] FIG. 11 is a further enlarged perspective view of the vehicle structure of FIGS. 8E and 9E, as viewed from the rear right of the vehicle structure;

[0045] FIG. 12 is a further enlarged perspective view of the vehicle structure of FIGS. 8E and 9E, as viewed from the front left of the vehicle structure;

[0046] FIG. 13 is yet a further enlarged perspective view of the vehicle structure of FIG. 12;

[0047] FIG. 14 is a further enlarged perspective view of the vehicle structure of FIGS. 8E and 9E, as viewed from the bottom of the vehicle structure; and

[0048] FIG. 15 is partial perspective view of the vehicle structure of FIGS. 8E and 9E as mounted on a vehicle.

DETAILED DESCRIPTION OF THE INVENTION

[0049] Reference will now be made in detail to various embodiments of the present invention(s), examples of which are illustrated in the accompanying drawings and described below. While the invention(s) will be described in conjunction with exemplary embodiments, it will be understood that present description is not intended to limit the invention(s) to those exemplary embodiments. On the contrary, the

invention(s) is/are intended to cover not only the exemplary embodiments, but also various alternatives, modifications, equivalents and other embodiments, which may be included within the spirit and scope of the invention as defined by the appended claims.

[0050] Generally, the present invention provides for forming contoured three-dimensional structures from two-dimensional sheet materials. In particular, flat two-dimensional sheet materials are configured for bending along predetermined bend lines to form three-dimensional structures having complexly curved regions which may enhance both structural features and aesthetic features of the structure.

[0051] For the purposes of the present invention, “two-dimensional sheet materials” refers to sheet materials which are globally flat such that they may be stacked upon one another, but which may have various locally stamped, punched, and/or other features which may be cosmetic or structural.

[0052] Generally, the sheet materials include one or more bend lines or fold lines, which are configured to facilitate bending along a predetermined path, such that a contour corresponding to a curvature of the bend line is imparted upon a portion of the sheet material upon bending the sheet material along the bend line. The contour may be imparted upon an adjacent portion of the sheet material, or transferred to a remote portion of the sheet material, as will become evident below. Alternatively, or in addition, contours corresponding to the curvatures of multiple bend lines are imparted upon a warp zone delineated by intersecting bend or fold lines, in which warpage is confined and accommodates the various contours. Preferably, the warpage is confined within the warp zone and creasing is prohibited. The sheet materials of the present invention also include straight bend lines which facilitate the formation of structural elements, and in the illustrated embodiment, a hollow cross beam.

[0053] For the purposes of the present invention, a “bend line” is a predetermined path about which the sheet material is bent resulting in plastic deformation along the bend line thereby forming a three-dimensional shape. A “fold line” is a bend line in which portions of the sheet material on either side of the bend line are bent to substantially lay

over one another. One will appreciate that the sheet material may also experience some degree of elastic deformation along the bend line in addition to plastic deformation.

[0054] One will appreciate that various means may be used to form the bend lines of the present invention to facilitate bending along the bend lines. For example, the precision bending technology of Industrial Origami may be used to design and/or provide the bend lines of the present invention, which technology is described in U.S. Patent Nos. 6,481,259 for *Method For Precision Bending Of A Sheet Of Material And Slit Sheet Therefor* and 6,877,349 for *Method For Precision Bending Of Sheet Of Materials, Slit Sheets Fabrication Process*, as well as in the following U.S. Patent Application Publication Nos. 2003/0037586 *Method For Precision Bending Of Sheet Of Materials, Slit Sheets Fabrication Process*, 2004/0134250 for *Techniques For Designing And Manufacturing Precision-Folded, High Strength, Fatigue-Resistant Structures And Sheet Therefor*, 2004/0206152 for *Sheet Material With Bend Controlling Displacements And Method For Forming The Same*, 2005/0005670 for *Method Of Designing Fold Lines In Sheet Material*, 2005/0061049 for *Process Of Forming Bend-Controlling Structures In A Sheet Of Material, The Resulting Sheet And Die Sets Therefor*, 2005/0064138 for *Method For Precision Bending Of Sheet Of Materials, Slit Sheets Fabrication Process*, 2005/0097937 for *Sheet Material With Bend Controlling Grooves Defining A Continuous Web Across A Bend Line And Method For Forming The Same*, 2005/0126110 for *Techniques For Designing And Manufacturing Precision-Folded, High Strength, Fatigue-Resistant Structures And Sheet Therefor*, 2005/0257589 for *Sheet Material With Bend Controlling Displacements And Method For Forming The Same*, 2006/0021413 for *Fatigue-Resistance Sheet Slitting Method And Resulting Sheet*, 2006/0053857 for *Tool System For Bending Sheet Materials And Method Of Using Same*, and 2006/0075798 for *Sheet Material With Bend Controlling Displacements And Method For Forming The Same*, the entire content of which patents and applications is incorporated herein by this reference.

[0055] Turning now to the drawings, wherein like components are designated by like reference numerals throughout the various figures, attention is directed to FIG.1 which

illustrates a flat sheet material 30 that is configured to form a three-dimensional structure. In the illustrated embodiment, the sheet material is configured to form a three-dimensional structure 32 in the form of a dashboard assembly shown in FIG. 3. In the illustrated embodiment, the dashboard is configured and dimensioned for use in an automobile. However, the dashboard may be configured for use with other types of vehicles, industrial controls or other machine assemblies. One will appreciate, however, that the sheet material may be configured to form a multitude of three-dimensional structures including, but not limited to, mechanical structural elements, vehicular body panels, other vehicular structure and the like. Suitable materials for the sheet material include, but are not limited to thin and thick gauge sheet metals such as sheet steel, sheet stainless, sheet aluminum and other metals and alloys, plastics, and other ductile materials. One will also appreciate that the sheet materials may be unpainted, pre-painted, and/or laminated with coatings and/or other structural and/or non-structural materials such as films, foams, meshes, and/or other suitable materials.

[0056] In the illustrated embodiment, sheet material 30 includes a dash-panel-flange bend line 35 which separates a forward panel in the form of an instrument or dash panel 37 and a dash-panel flange 39, as shown in FIG. 1. The dash-panel-flange bend line 35 is generally configured to localize elastic deformation during bending along a predetermined path, as are the below mentioned bend lines and fold lines. For example, the dash-panel-flange bend line 35 may be in the form of events 40 disposed on either side of bend line 35 in order to facilitate and precisely control bending along the bend line 35, which events 40 are more clearly shown in FIG. 2. Events 40 may be in the form of slits, grooves, displacements and other suitable means described in the above-mentioned patents and applications of Industrial Origami, the entire content of which is incorporated herein by this reference.

[0057] Although the bend lines will be discussed in terms of “dash-panel-flange bend line” and other specific terms set forth below, and although the regions of the sheet material adjacent the bend lines will be discussed in terms of “dash panel”, “dash-panel flange”, and other specific terms set forth below, these terms are generally relative in that they are used to describe and set forth their general orientation to one another and

their respective bend line. As such, the terms should not be considered specifically limiting and instead should be considered as setting forth spatial orientations of the bend lines and relevant portions of the sheet material.

[0058] In some aspects, the dash-panel flange is similar to conventional flanges in that it may provide structural integrity to the dash panel, namely by stiffening what may otherwise be a fairly flexible sheet of material. In accordance with the present invention, however, the dash-panel-flange bend line is configured to impart a contour to one or both of the dash panel and the dash panel flange. The dash-panel-flange bend line may have an “S”-shaped curvature which will impart a corresponding contour on both the dash panel and the dash-panel flange upon bending of the sheet material about the dash-panel-flange bend line. One will appreciate that the dash-panel-flange bend line may have other curved shapes including, but not limited to, convex, concave, and wavy shapes, so as to impart contour on either or both of the adjacent dash panel or the dash-panel flange. One will further appreciate that the bend line may be straight in the event that no contour is desired for either the dash panel or the dash-panel flange.

[0059] With reference to FIG. 1, sheet material 30 also includes a dash-panel bend line 42 that separates a dash panel 37 and a first fold panel 44. The dash-panel bend line 42 is curved to impart contour to the first fold panel 44 upon bending of the sheet material about the dash-panel bend line 42 in a manner similar to that of dash-panel-flange bend line 35 described above. In the illustrated embodiment, dash-panel bend line 42 is downwardly concave such that it imparts an upwardly convex contour on the first fold panel 44 upon bending as shown in FIGS. 4 and 5. One will appreciate that, depending upon the curvature of the dash-panel bend line 42, and the relative angle that dash panel 37 is bent relative to first fold panel 44, the curvature of the dash-panel bend line 42 may be imparted to one or both of the dash panel 37 and the first fold panel 44. As best seen in FIG. 5 dash panel 37 is outwardly concave. One will also appreciate that the curvature of the dash-panel bend line may also vary in accordance with the present invention in that it may be upwardly concave, wavy, and/or otherwise curved.

[0060] Referring again to FIG. 1, sheet material 30 also includes a first fold line 46 separating first fold panel 44 from a supplemental or second fold panel 47. In this embodiment, the first fold line 46 is substantially straight in order to impart the contour of the first fold panel 44, which corresponds to the curvature of dash panel bend line 42, to the second fold panel 47 upon bending of the sheet material about the first fold line 46. As the first fold line 46 is substantially straight, and as the second fold panel 47 is substantially folded to lie over the first fold panel 44, first fold line 46 will impart substantially the contour of the first fold panel 44 to second fold panel 47, as shown in FIG. 5. A supplemental or second fold line 49 separates the second fold panel 47 from a dashboard panel 51. The second fold line 49 is also substantially straight in order to impart substantially the contour of the second fold panel 47 to the dashboard panel 51 upon bending of the sheet material about the second fold line 49, as shown in FIG. 5.

[0061] In the illustrated embodiment, a first distance D1 between dash-panel bend line 42 to first fold line 46 is different from an a second distance D2 between the first fold line 46 and second fold line 49, as shown in FIG. 1. Such configuration causes a forward edge 53 of the dashboard panel 51 defined by second fold line 49 to be spaced from the dash panel 37 as shown in FIG. 5. As shown in FIG. 1, the first distance D1 is shorter than the second distance D2 thereby recessing the dash panel 37 beyond the forward edge 53 as shown in FIGS. 3-5.

[0062] In another embodiment of the present invention, the dimensional sheet material 30a is similar to sheet material 30 described above but includes fold lines having curved sections as shown in FIG. 6. Like reference numerals have been used to describe like components of sheet materials 30 and 30a.

[0063] In this embodiment, a downwardly curved dash-panel bend line 42a separates dash panel 37a and a first fold panel 44a in a manner similar to that discussed above. In this embodiment, a contoured first fold line 46a separates first fold panel 44a from a second fold panel 47a, and includes a curved central portion 46a' intermediate two straight portions. Fold-line apertures 70 separate the curved and straight portions of the first fold line 46a and thereby prohibit any creasing which may occur in the transition

zone between the curved and straight portions. Similarly, a contoured second fold line 49a separates the second fold panel 47a from the dashboard panel 51a, and includes a curved central portion 49a' intermediate two straight portions. The fold-line apertures 70 may extend to and separate the curved and straight portions of the second fold line 49a, and thus prohibit creasing which may occur in the transition zone between the curved and straight portions.

[0064] In operation and use, sheet material 30a is used in substantially the same manner as of sheet material 30 discussed above.

[0065] Turning now to another aspect of the present invention, complex or compound contours corresponding to the curvatures of multiple bend lines can be imparted to a warp zone, and the resulting warpage due to the complex or compound contours may be confined within the warp zone, as the warp zone is delineated by intersecting bend or fold lines. With reference to FIG. 1, sheet material 30 includes a first dashboard-flange bend line 54 which separates a forward dashboard flange 56 from a warp zone 58 of dashboard panel 51. The first dashboard-flange bend line 54 is curved to impart a first contour on the warp zone 58. Similarly, a second dashboard-flange bend line 60 separates a second dashboard flange 61 from the warp zone 58, which bend line 60 is also curved to impart a second contour on the warp zone 58. One will appreciate that either or both of the dashboard-flange bend lines may impart contour on either the flanges or the warp zone 58, or if desired, on both a respective flange and the warp zone 58.

[0066] First and second curved warp zone bend lines 63 and 65 delineate and separate warp zone 58 from a remainder 67 of the dashboard panel 51. The first and second curved warp zone bend lines 63 and 65 are configured to localize bending affected by bending the dashboard-flange bend lines along the warp zone bend lines. As such, the warp zone bend lines 63 and 65 substantially isolate warpage within the warp zone 58. Both the first and second warp zone bend lines 63 and 65 terminate at an intersection point 68. Also, both the first and second warp zone bend lines 63 and 65 have compound curvatures. Preferably, which portions 63' and 65' of the warp zone bend

lines 63 and 65 adjacent the intersection point 68 have smaller radii of curvature than portions further out. Such decreased radii of curvature may prohibit creasing within the warp zone 58 adjacent the intersection point 68. In the illustrated embodiment, the radii of curvature of both portions extend in the same direction (e.g., both portions 63' and 65' are both concave downwardly). Such same-direction concavity may similarly prohibit creasing within the warp zone 58 adjacent the intersection point 68.

[0067] In operation and use, the sheet materials are preferably preformed with the bend lines and fold lines, that is, the sheet materials may be provided with events 40, shipped flat, and bent on site at the desired destination. The sheet materials may be bent sequentially along each individual line, or simultaneously about two or more bend lines.

[0068] In another illustrated embodiment as shown in FIGS. 7-15, attention is directed to FIG. 7A which illustrates a flat sheet material 130 that is configured to form a three-dimensional structure 132 in the form of an instrument panel structure (I/P structure) shown in FIG. 8E. In the illustrated embodiment, the I/P structure is configured and dimensioned for use in an automobile, however, one will appreciate, however, that the sheet material may be configured to form a multitude of three-dimensional structures including, but not limited to, mechanical structural and aesthetic elements, vehicular structure and the like.

[0069] In the illustrated exemplary embodiment, the sheet material includes a number of straight bend lines 133 and warp zone bend lines 135. The warp zone bend lines 135 are generally configured to localize elastic deformation during bending along a predetermined path, as are the below mentioned warp zone bend lines and fold lines. For example, the warp zone bend lines 135 may be in the form of events 137 disposed on either side of the warp zone bend line in order to facilitate and precisely control bending along the warp zone bend line, which events 137 are more clearly shown in FIG. 7B. Events 137 may be in the form of slits, grooves, displacements and other suitable means described in the above-mentioned patents and applications of Industrial Origami, the entire content of which is incorporated herein by this reference.

[0070] Generally, the straight bend lines 133 are provided to form an instrument panel crossbeam 139 as shown in FIG. 11, which extends the length of the vehicle dashboard and is dimensioned and configured for attachment to the vehicle adjacent the A-pillars, as is discussed in greater detail below. Warp zone bend lines 135 are provided to form a right lower dash panel 161. The primary purpose of the crossbeam 139 is to provide structural integrity to the I/P structure as well as the vehicle, while the primary purpose of the dash panel is to provide body panels having a pleasing contour to add to the aesthetic appearance of the interior. By folding the sheet material along the bend lines in the order illustrated in FIGS. 8A-8E, the two dimensional sheet material forms the three-dimensional I/P structure of the present invention.

[0071] With reference to FIGS. 9A and 9B, left and right tunnel flanges 142 and 144 are bent with respect to left and right tunnel flange folds 146 and 147, which in turn are bent with respect to a forward console flange 149, and which in turn is bent with respect to a bottom beam flange 151 to provide the intermediate structure shown in FIG. 9B. The tunnel flanges and associated flanges are dimensioned and configured to cooperate with a drive train tunnel in an otherwise well-known manner.

[0072] With reference to FIGS. 9B and 9C, the bottom beam flange 151 is bent with respect to an upper beam flange 153, which in turn is bent with respect to a bottom beam web 154, which in turn is bent with respect to a lower beam flange 156 to provide the intermediate structure shown in FIG. 9C. Thus far, straight bends have been formed which is forming in part a box beam which will traverse the vehicles interior between the A-pillars of the vehicle.

[0073] With reference to FIGS. 9C and 9D, the lower beam flange 156 is bent with respect to an upper dash panel 158. Also, left and right lower dash panels 160 and 161 are bent with respect to the upper dash panel 158, which also causes the left lower dash panel 160 to bend with respect to the right lower dash panel 161. While such action also forms in part the box beam, such action also creates complexly contoured curvatures, as will be discussed in greater detail below.

[0074] With reference to FIGS. 9D and 9E, left and right beam flaps 163 and 165 are bent with respect to the lower dash panels 160 and 161, as is the central console flap 167. Each of the flaps includes flap fastener apertures 168 which will ultimately align with beam fastener apertures 170 as shown in FIG. 1. In order to promote structural integrity and to assist alignment, the left and right beam flaps 163 and 165 are provided with left and right caps 172 and 174 which each have a profile that corresponds with the cross-sectional profile of the box beam on either end of the I/P structure. For example, FIG 11 illustrates how the profile of the right cap 174 indexes or provides the cross-sectional shape of right end of the box beam, while FIG. 12 illustrates the manner in which the profile of the left cap 172 indexes or provides the cross-sectional shape of the left end of the box beam. In many aspects the box beam of the present invention is similar to those discussed in detail in, and thus has the same advantages as those discussed in detail in, the above-mentioned patents and applications, the entire contents of which is incorporated herein by this reference.

[0075] In accordance with another aspect of the present invention, the I/P structure is also configured to impart a wide-flange contour upper and lower dash panels as shown in FIG. 7A. In particular, complex or compound contours corresponding to the curvatures of multiple curved warp zone bend lines 135 are imparted to contour zones, in which the left lower dash panel 160 forms a gently sweeping contour generally following the contour of the warp zone bend line 135 separating the left lower dash panel 160 from the upper dash panel 158 and the right lower dash panel 161. In contrast, the right lower dash panel 161 is bounded by intersecting warp zone bend lines 135 and thus warps to accommodate the various contours imparted thereon. The warpage of right lower dash panel 161 is largely confined as the right lower dash panel 161 is delineated by intersecting warp zone bend lines 135.

[0076] Turning now to the remaining figures, FIG. 10 illustrates the right front view of the folded I/P structure and thus shows the curvature of the left lower dash panel 160 and the complex curvature of the right lower dash panel 161. The lower dash panels 160 and 161 are provided with trim apertures 175 and 177 which allow trim to be fastened to the I/P structure. For example, leather trim may be affixed to the I/P

structure utilizing these apertures. The left lower dash panel 160 further includes indicia 179 and corresponding openings for various switches and other vehicular controls. In the illustrated embodiment, the indicia is etched or routed directly in the sheet material providing an opportunity to backlight the indicia and to avoid the need for addition parts bearing such indicia.

[0077] With reference to FIGS. 11 and 12, the cross beam is provided with left and right openings 181 and 182 to facilitate attachment to a vehicle unibody frame. For example, bolts 184 may extend from a vehicle unibody mount 186 adjacent the A-pillar 188 of the vehicle, as shown in FIG. 15.

[0078] For convenience in explanation and accurate definition in the appended claims, the terms “left” or “right”, “up” or “upper”, “down” or “lower”, “inside” and “outside” are used to describe features of the present invention with reference to the positions of such features as displayed in the figures.

[0079] In many respects the modifications of the various figures resemble those of preceding modifications and the same reference numerals followed by subscripts “a” designate corresponding parts.

[0080] The foregoing descriptions of specific exemplary embodiments of the present invention have been presented for purposes of illustration and description. They are not intended to be exhaustive or to limit the invention to the precise forms disclosed, and obviously many modifications and variations are possible in light of the above teachings. The exemplary embodiments were chosen and described in order to explain certain principles of the invention and their practical application, to thereby enable others skilled in the art to make and utilize various exemplary embodiments of the present invention, as well as various alternatives and modifications thereof. It is intended that the scope of the invention be defined by the Claims appended hereto and their equivalents.

WHAT IS CLAIMED IS:

1. A sheet material for forming a contoured three-dimensional structure, the sheet material comprising:

a forward-panel bend line separating a forward panel and a fold panel, the forward-panel bend line being curved to impart a pre-selected contour on at least the fold panel upon bending of the sheet material about the forward-panel bend line; and

a fold line extending along the fold panel, the fold line being shaped to impart the pre-selected contour of the fold panel to the upper panel upon bending of the sheet material about the fold line.

2. A sheet material according to claim 1, wherein the fold line is substantially straight.

3. A sheet material according to claim 1, further comprising a supplemental fold line separating the fold panel from a supplemental fold panel, the supplemental fold line being substantially straight to impart the contour of the first fold panel to the second fold panel upon bending of the sheet material about the supplemental fold line,

wherein the contour of the forward-panel bend line is imparted to the upper panel via the fold panel and the second fold panel upon bending the fold line and the supplemental fold line.

4. A sheet material according to claim 1, further comprising a forward-panel-flange bend line separating the forward panel and a forward-panel flange, the forward-panel-flange bend line being curved to impart contour on one or more of the forward panel and the forward-panel flange upon bending of the sheet material about the forward-panel-flange bend line.

5. A sheet material according to claim 3, wherein the forward-flange bend line is S-shaped thereby imparting both concave and convex contour on the forward panel.

6. A sheet material according to claim 1, wherein the forward-panel bend line is downwardly concave to impart an upwardly convex contour on at least a portion of the upper panel.
7. A sheet material according to claim 1, wherein a first distance between the forward-panel bend line to the first fold panel is different than a second distance between the first fold line and the second fold line whereby a forward edge of the upper panel defined by the second fold line is spaced from the forward panel.
8. A sheet material according to claim 7, wherein the first distance is shorter than the second distance thereby recessing the forward panel beyond the forward edge.
9. A sheet material according to claim 1, further comprising a first upper-panel-flange bend line separating a forward upper flange from a warp zone of the upper panel, the first upper-panel-flange bend line being curved to impart a first contour on one or more of the first upper flange and the warp zone; a second upper-panel-flange bend line separating a second upper flange from the warp zone, the second upper-panel-flange bend line being curved to impart a second contour on one or more of the second upper flange and the warp zone; and first and second curved warp zone bend lines separating the warp zone from a remainder of the upper panel, the first and second curved warp zone bend lines configured to localize bending along the bend line and substantially isolate warpage within the warp zone.
10. A sheet material according to claim 9, wherein both the first and second warp zone bend lines terminate at an intersection point; and both the first and second warp zone bend lines have compound curvatures, in which portions of the bend lines adjacent the intersection point have smaller radii of

curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

11. A sheet material according to claim 1, wherein
at least one of said bend lines and said fold lines is formed with a plurality of slits through the sheet of material, adjacent slits are positioned alternating on either said of said at least one of said bend lines of fold lines.

12. A sheet material according to claim 1, wherein
at least one of said bend lines and said fold lines is formed with a plurality of displacements, wherein adjacent displacements are positioned alternating on either side of said at least one of said bend lines or fold lines.

13. A three-dimensional structure comprising the sheet material according to claim 1.

14. A method of forming a three-dimensional structure comprising:
providing the sheet material according to claim 1;
bending the sheet of material along the forward-panel bend line; and
bending the sheet of material along the fold line.

15. A sheet material for forming a contoured three-dimensional structure,
the sheet material comprising:

an upper panel;

a first upper-panel-flange bend line separating a forward upper flange from a warp zone of the upper panel, the first upper-panel-flange bend line being curved to impart a first contour on one or more of the first upper flange and the warp zone;

a second upper-panel-flange bend line separating a second upper flange from the warp zone, the second upper-panel-flange bend line being curved to impart a second contour on one or more of the second upper flange and the warp zone; and

first and second curved warp zone bend lines separating the warp zone from a remainder of the upper panel, the first and second curved warp zone bend lines

configured to localize bending along the bend line and substantially isolate warpage within the warp zone.

16. A sheet material according to claim 15, wherein the first upper-panel-flange bend line is downwardly concave in a first direction and the second upper-panel-flange bend line is downwardly concave in a second direction that is not parallel to the first, wherein the warp zone elastically deforms to accommodate the different contours of the first and second upper-panel-flange bend lines.

17. A sheet material according to claim 15, wherein both the first and second bend lines terminate at an intersection point; and both the first and second bend lines have compound curvatures, in which portions of the bend lines adjacent the intersection point have smaller radii of curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

18. A sheet material according to claim 15, wherein at least one of said bend lines and said fold lines is formed with a plurality of slits through the sheet of material.

19. A sheet material according to claim 18, wherein adjacent slits are positioned alternating on either said of said at least one of said bend lines of fold lines.

20. A sheet material according to claim 15, wherein at least one of said bend lines and said fold lines is formed with a plurality of displacements, wherein adjacent displacements are positioned alternating on either side of said at least one of said bend lines or fold lines.

21. A three-dimensional structure comprising the sheet material according to claim 15.

22. A method of forming a dashboard comprising:
providing the sheet material according to claim 15;
bending the sheet of material along the first and second upper-panel bend lines,
wherein the first and second warp zone bend lines allow warpage within the warp to
accommodate the varying contour imparted by the first and second dashboard-flange
bend lines.

23. A sheet material for forming a contoured three-dimensional dashboard,
the sheet material comprising:

- a dash-panel-flange bend line separating a dash panel and a dash-panel flange,
the dash-panel-flange bend line being curved to impart contour on one or more of the
dash panel and the dash-panel flange upon bending of the sheet material about the
dash-panel-flange bend line;

- a dash-panel bend line separating the dash panel and a first fold panel, the
dash-panel bend line being curved to impart contour on at least the first fold panel upon
bending of the sheet material about the dash-panel bend line;

- a first fold line separating the first fold panel from a second fold panel, the first
fold line being substantially straight to impart the contour of the first fold panel upon
the second fold panel upon bending of the sheet material about the first fold line;

- a second fold line separating the second fold panel from a dashboard panel, the
second fold line being substantially straight to impart the contour of the second fold
panel to the dashboard panel upon bending of the sheet material about the second fold
line;

- a first dashboard-flange bend line separating a forward dashboard flange from a
warp zone of the dashboard panel, the first dashboard-flange bend line being curved to
impart a first contour on one or more of the first dashboard flange and the warp zone;

- a second dashboard-flange bend line separating a second dashboard flange from
the warp zone, the second dashboard-flange bend line being curved to impart a second
contour on one or more of the second dashboard flange and the warp zone; and

- first and second curved warp zone bend lines separating the warp zone from a
remainder of the dashboard panel, the first and second curved warp zone bend lines

configured to localize bending along the bend line and substantially isolate warpage within the warp zone.

24. A sheet material according to claim 23, wherein the dash-panel-flange bend line is S-shaped thereby imparting both concave and convex contour on dash panel.

25. A sheet material according to claim 23, wherein the dash-panel bend line is downwardly concave to impart an upwardly convex contour on at least a portion of the dashboard panel.

26. A sheet material according to claim 23, wherein a first distance between the dash-panel bend line to the first fold line is different than a second distance between the first fold line and the second fold line whereby a forward edge of the dashboard panel defined by the second fold line is spaced from the dash panel.

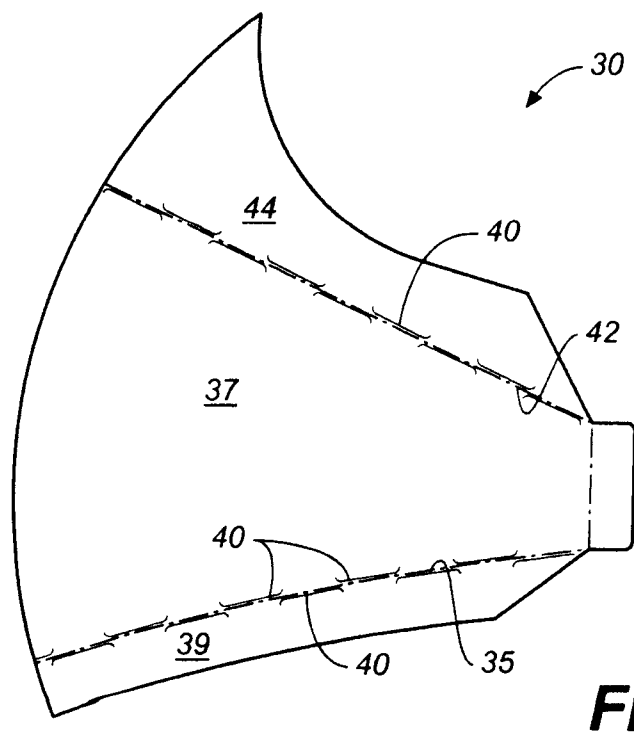
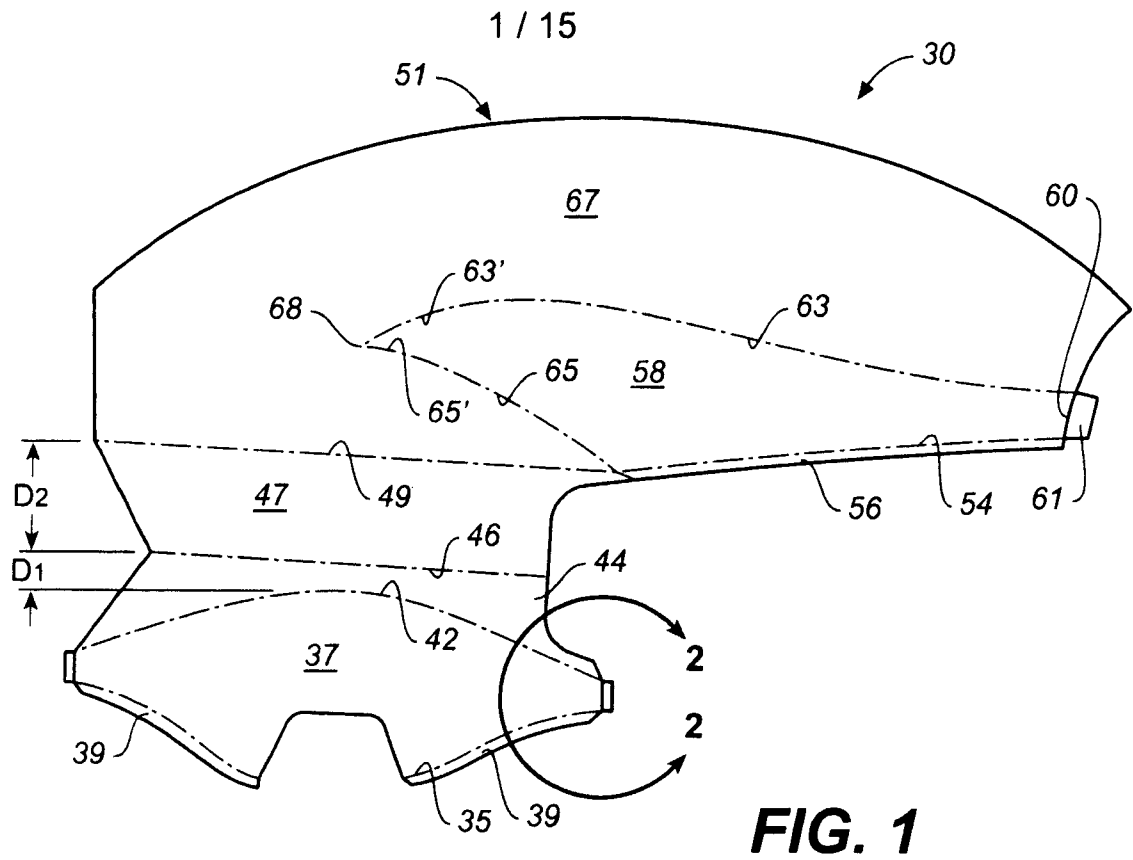
27. A sheet material according to claim 26, wherein the first distance is shorter than the second distance thereby recessing the dash panel beyond the forward edge.

28. A sheet material according to claim 23, wherein both the first and second bend lines terminate at an intersection point; and both the first and second bend lines have compound curvatures, in which portions of the bend lines adjacent the intersection point have smaller radii of curvature thereby prohibiting creasing within the warp zone adjacent the intersection point.

29. A dashboard comprising the sheet material according to claim 23.

30. A method of forming a dashboard comprising:
providing the sheet material according to claim 23;
bending the sheet of material along the dash-panel-flange bend line;

bending the sheet of material along the dash-panel bend line;
bending the sheet of material along the first and second fold lines; and
bending the sheet of material along the first and second dashboard-flange bend lines, wherein the first and second warp zone bend lines allow warpage within the warp to accommodate the varying contour imparted by the first and second dashboard-flange bend lines.



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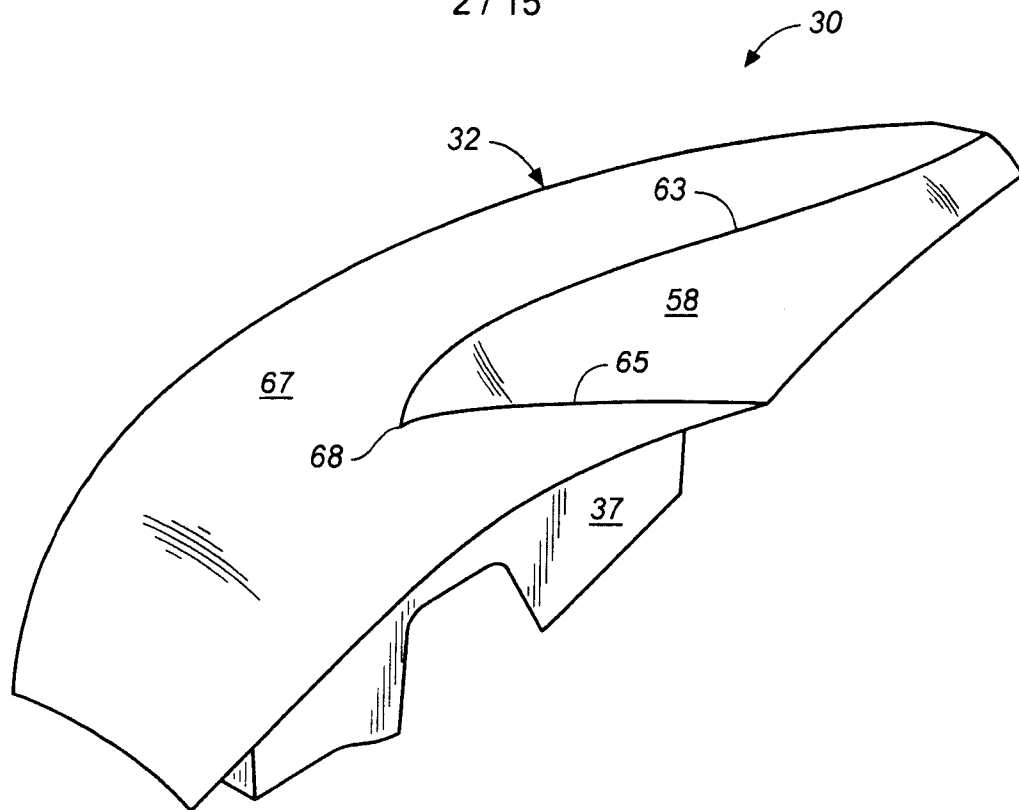


FIG. 3

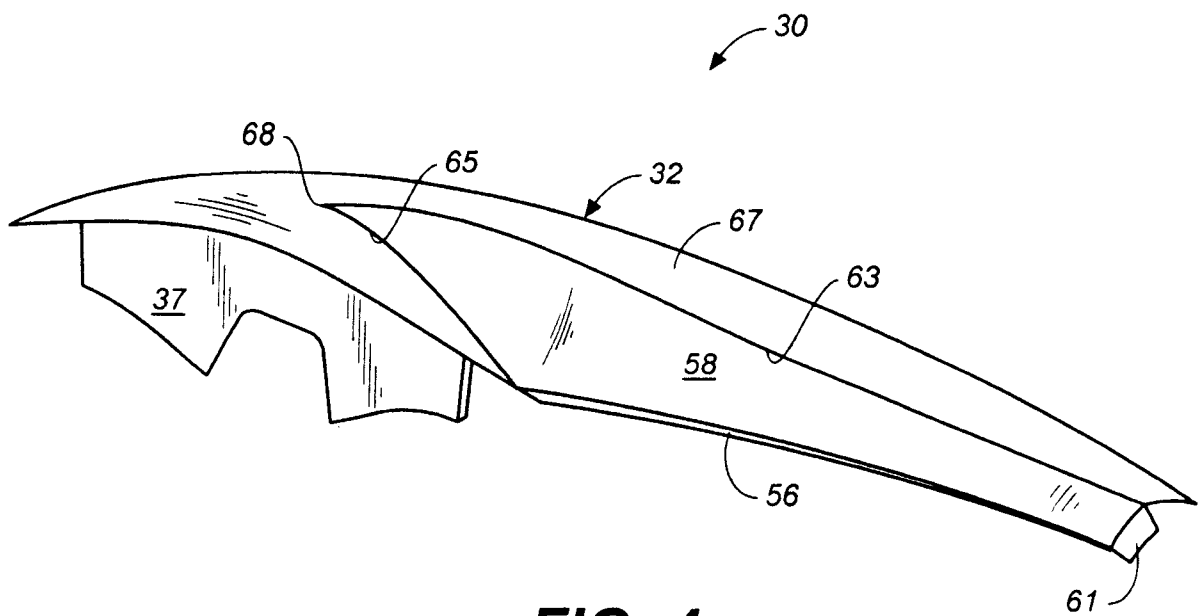
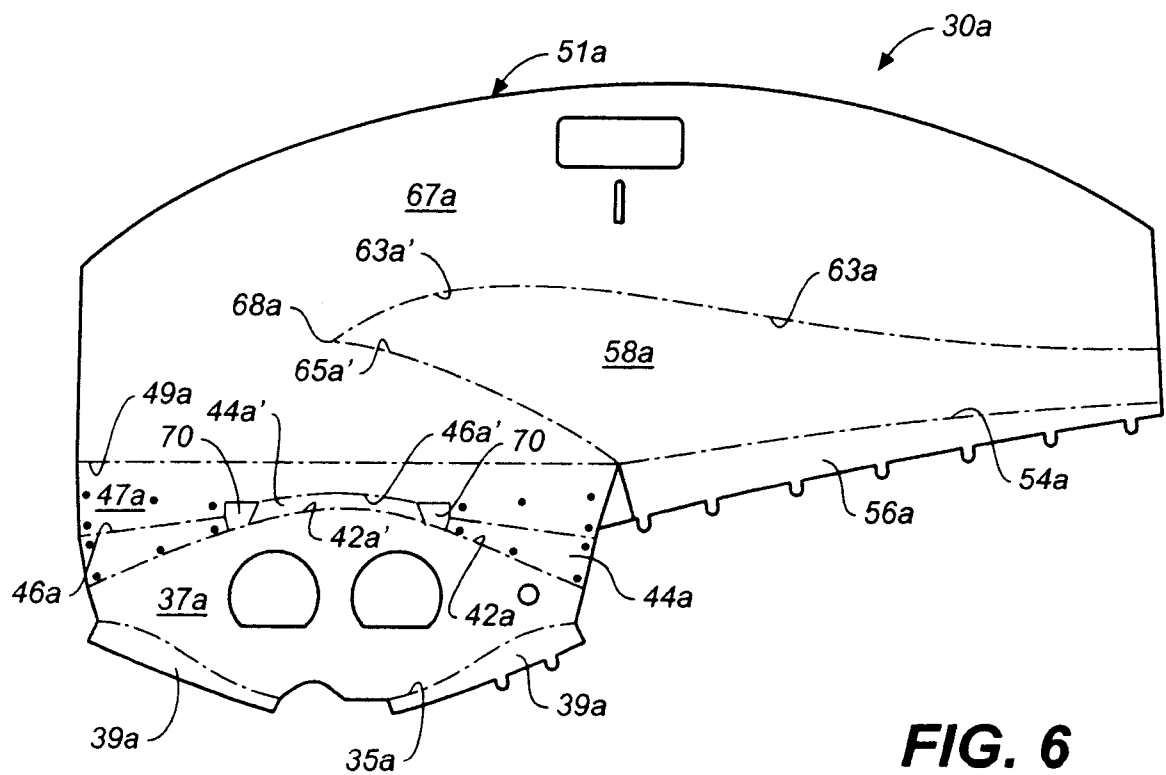
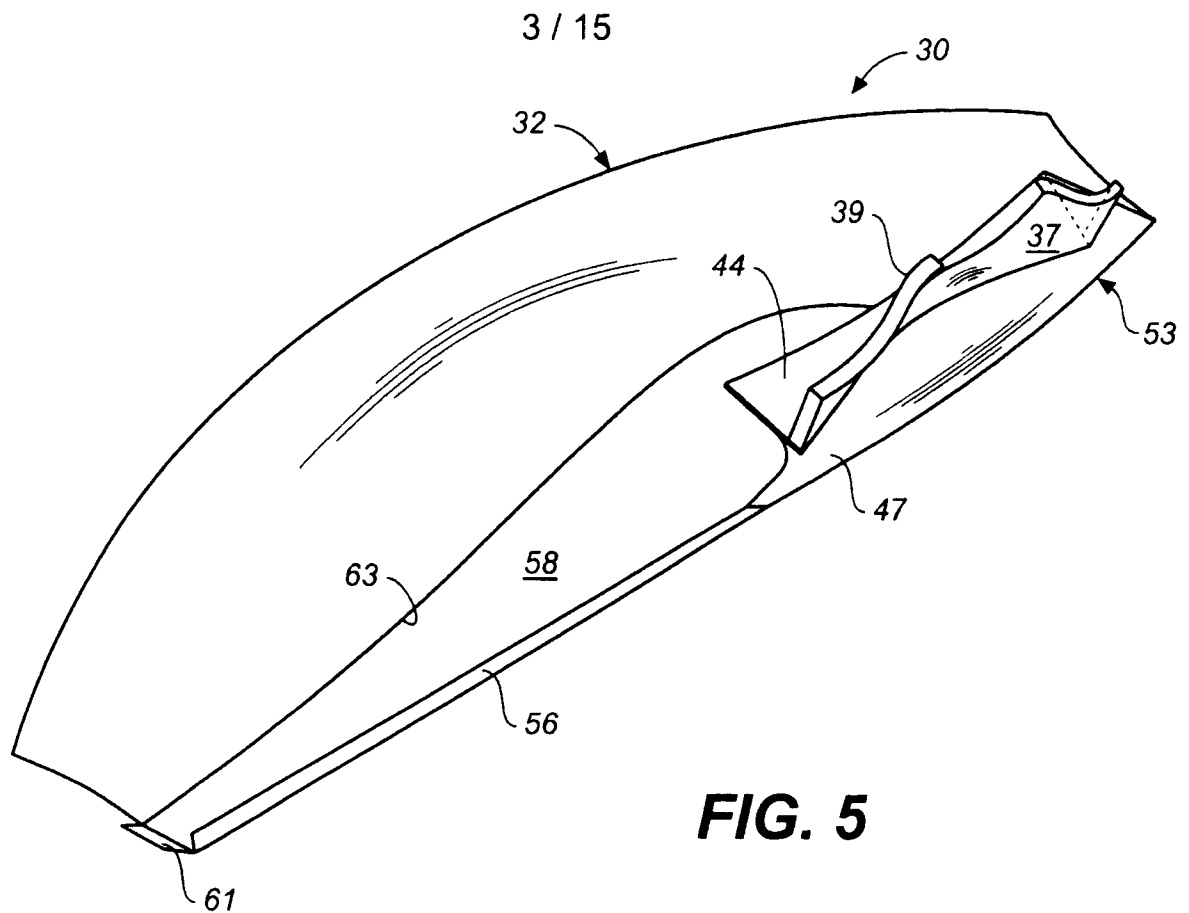
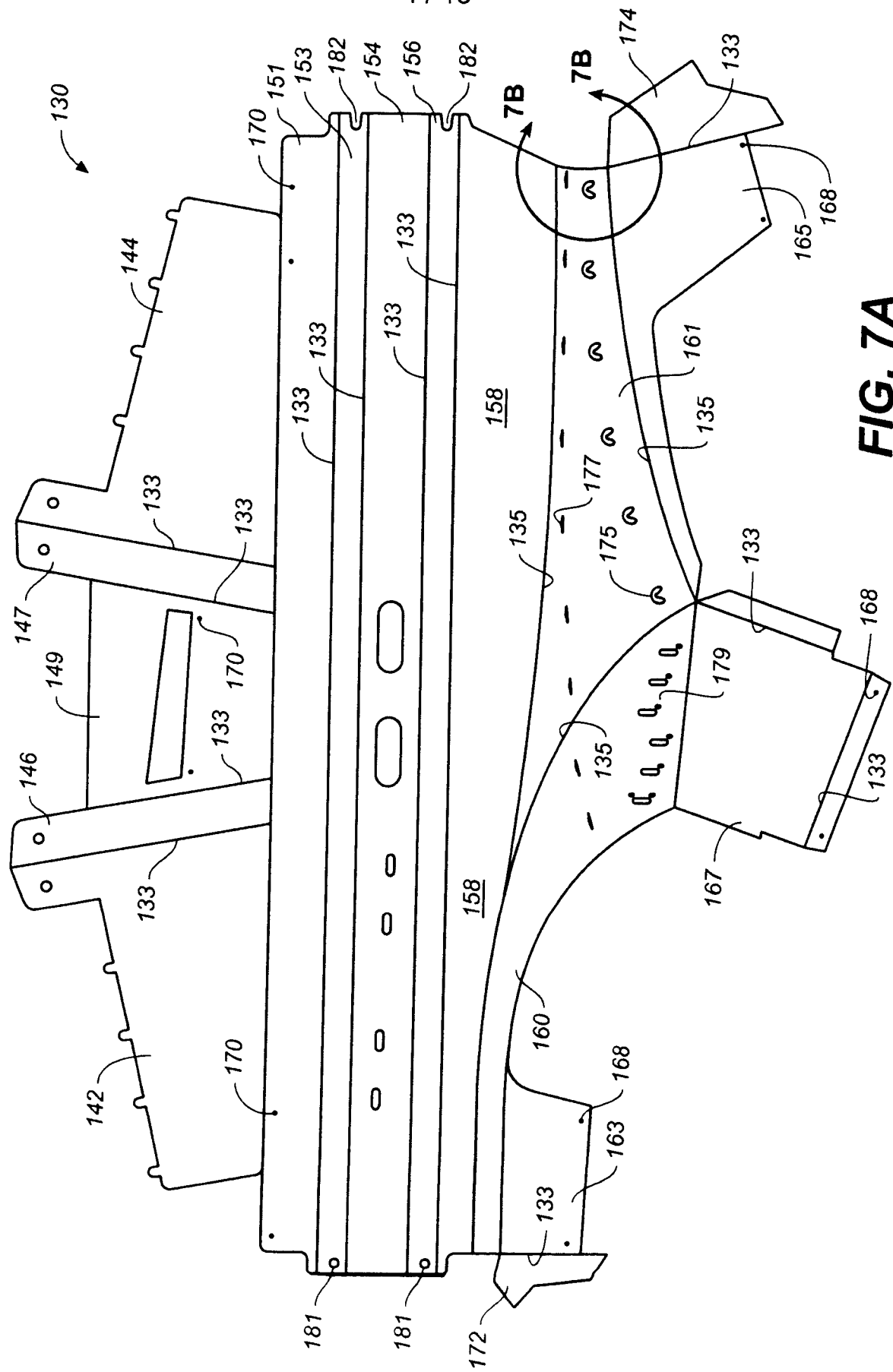


FIG. 4





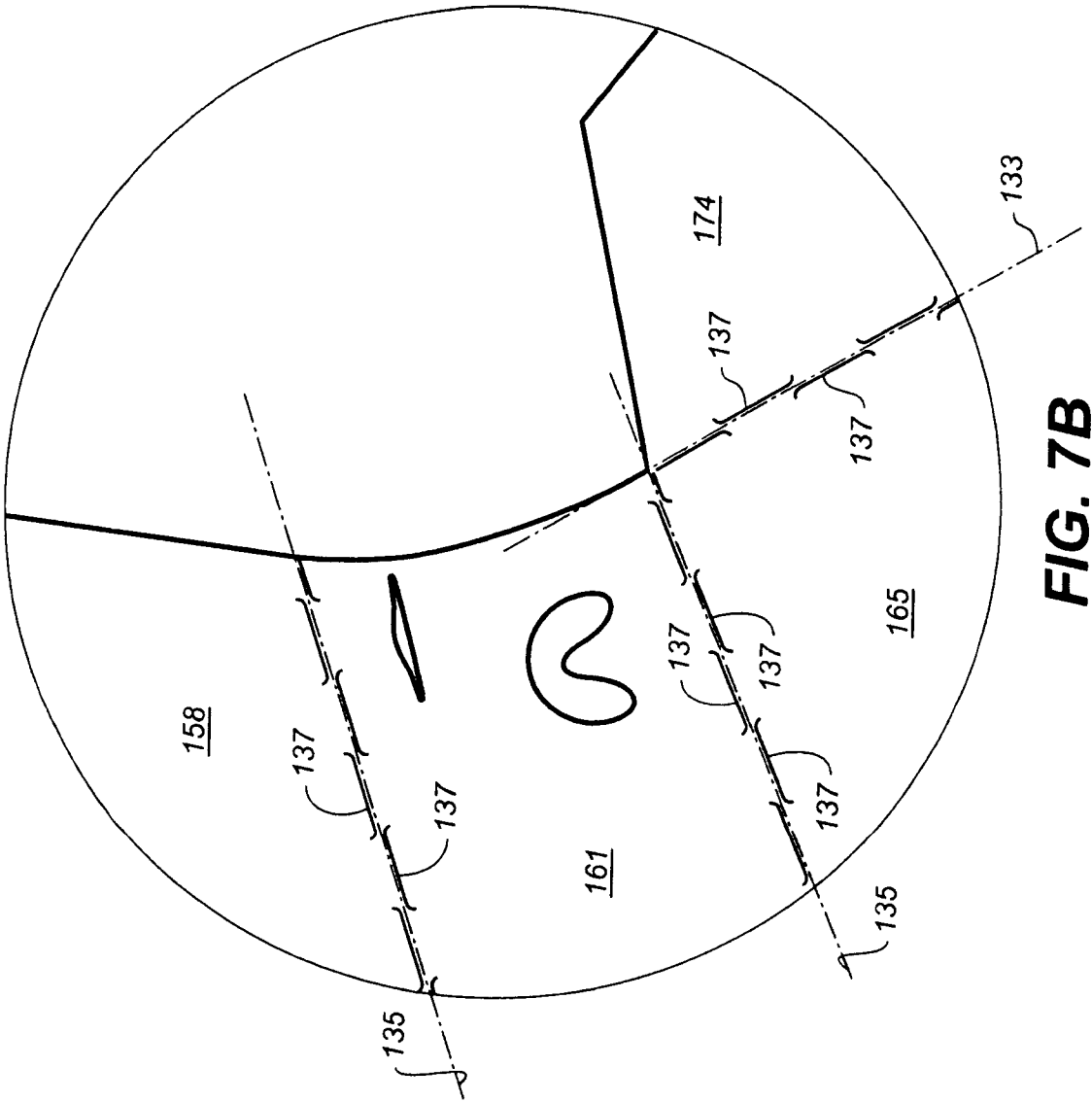


FIG. 7B

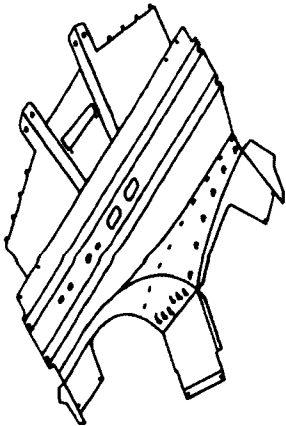


FIG. 8A

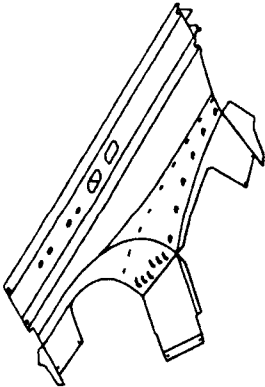


FIG. 8B

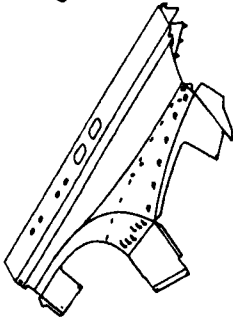


FIG. 8C

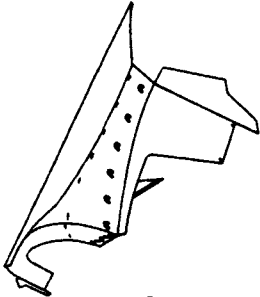


FIG. 8D

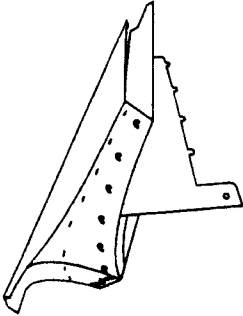


FIG. 8E

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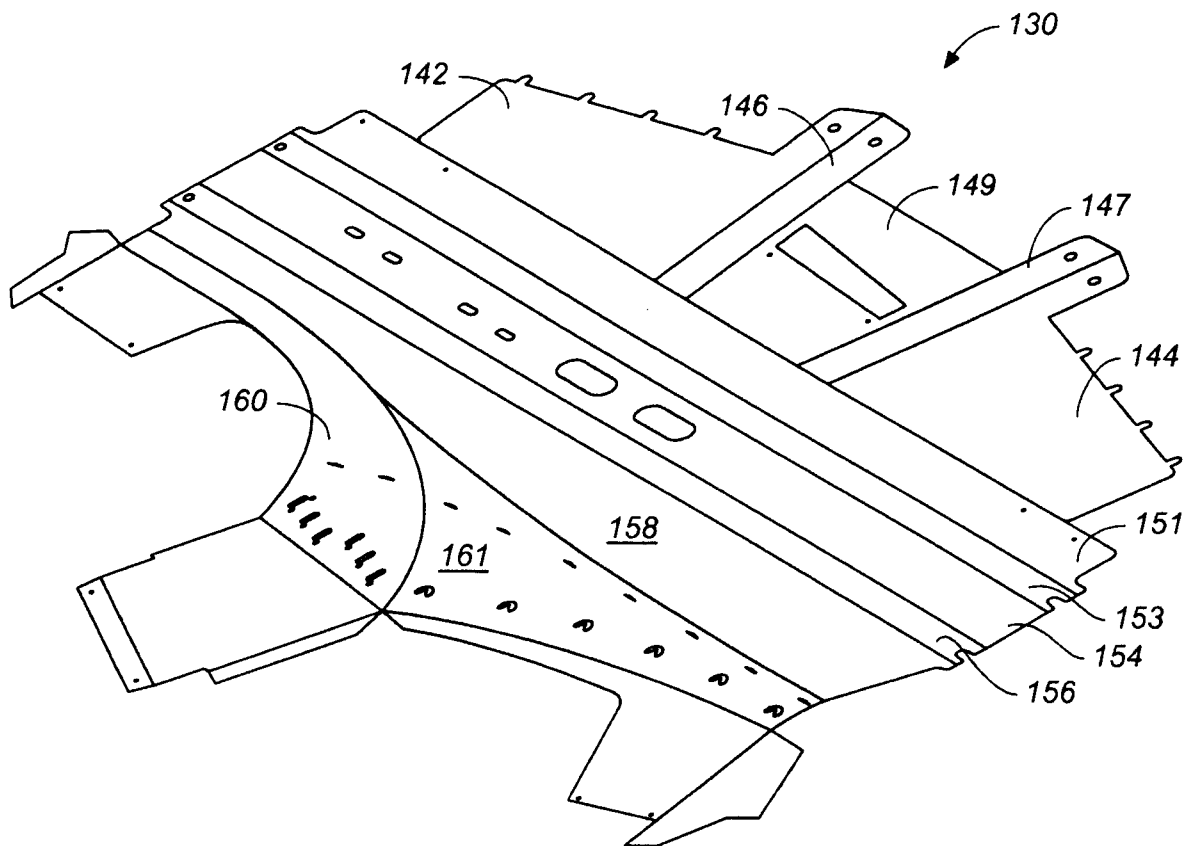
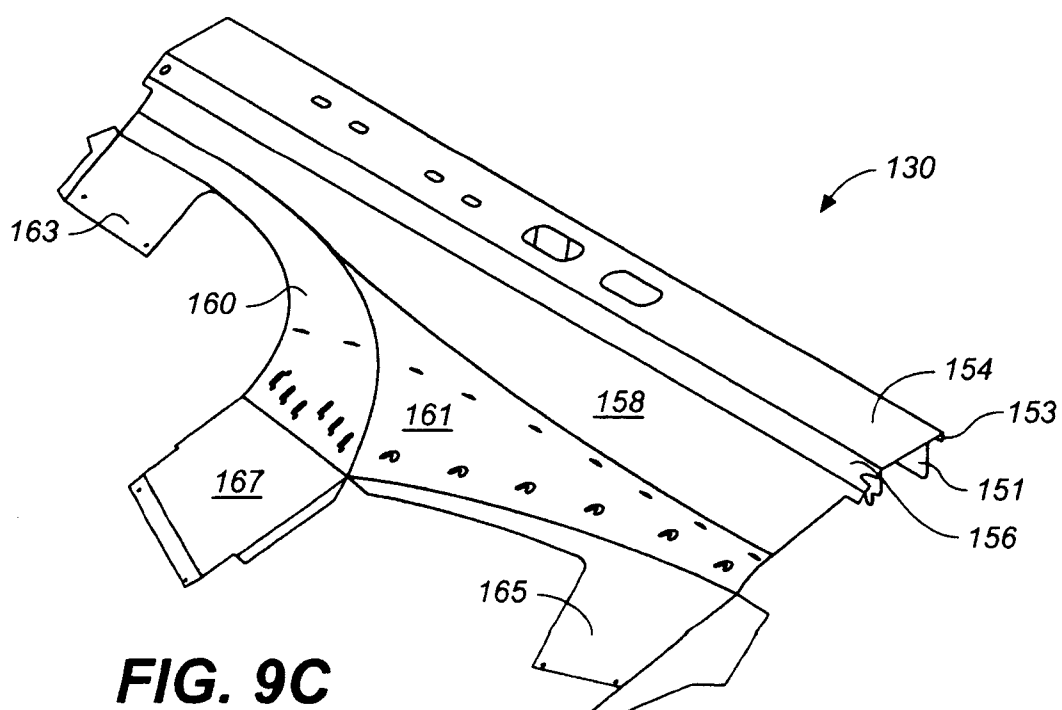
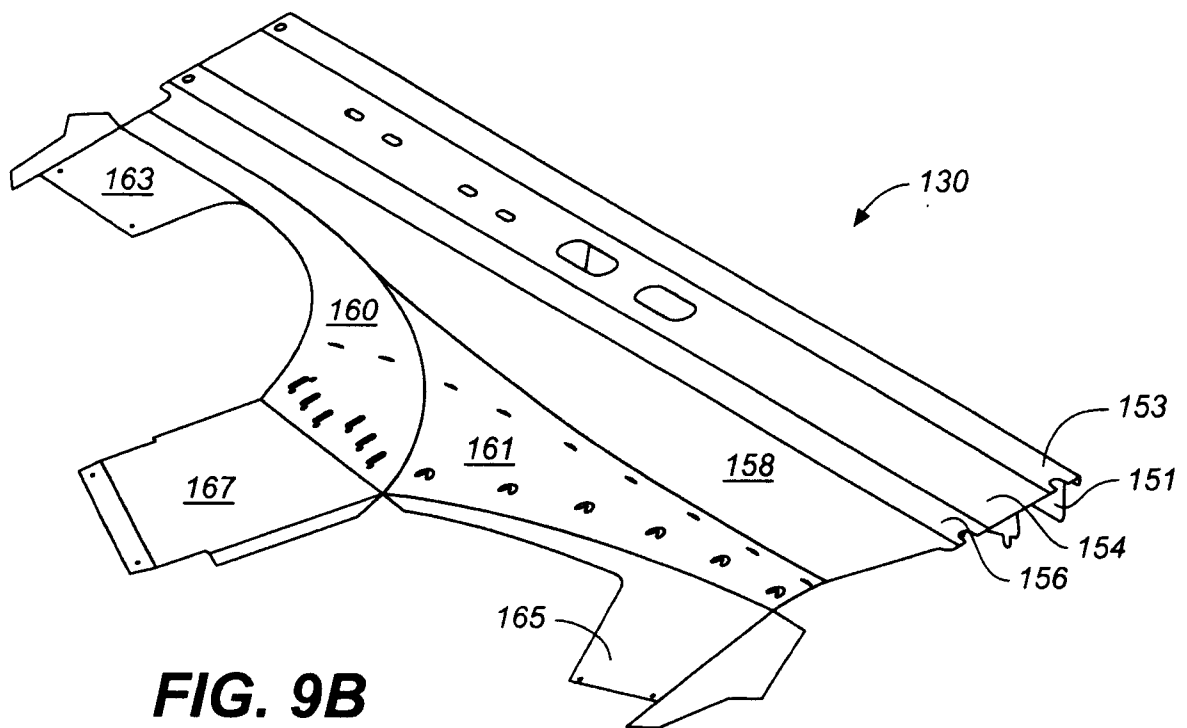


FIG. 9A

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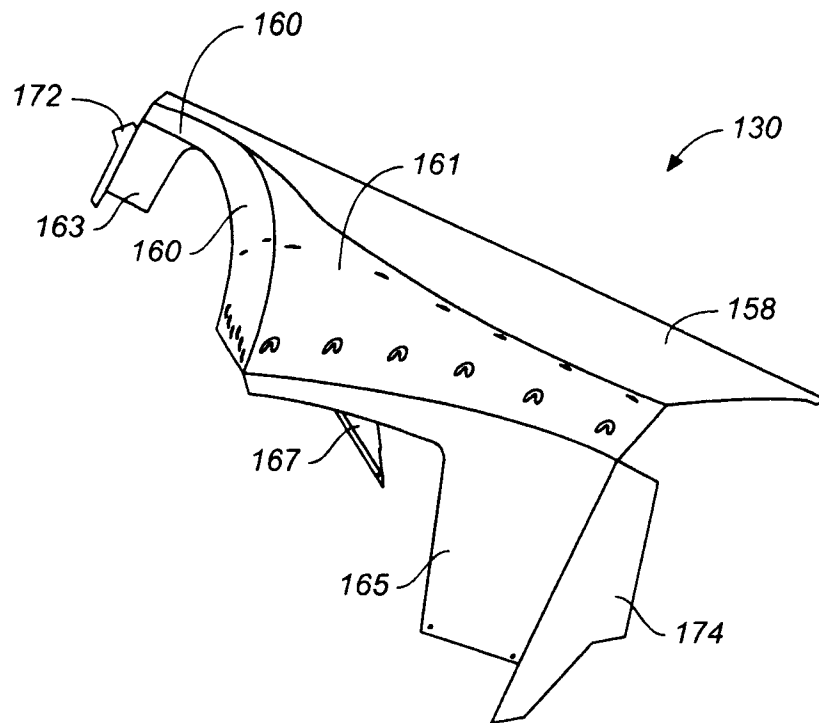


FIG. 9D

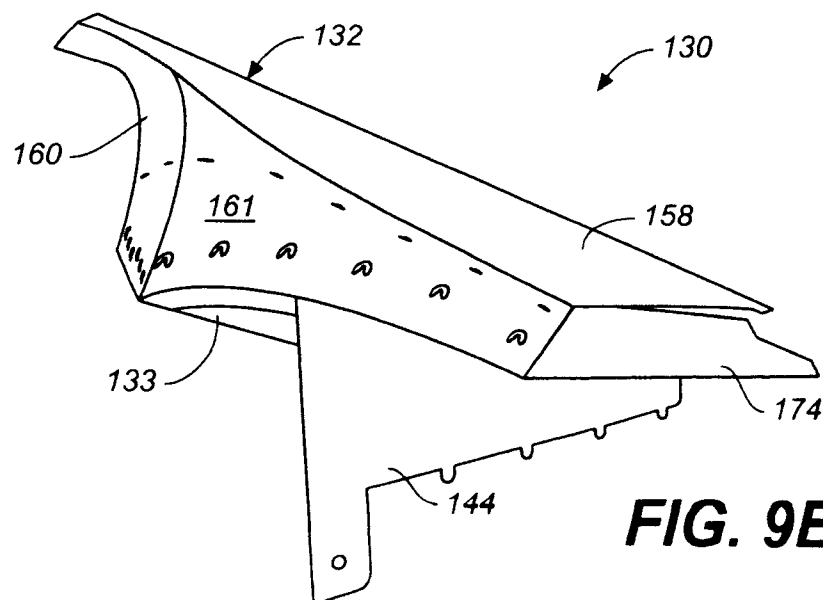


FIG. 9E

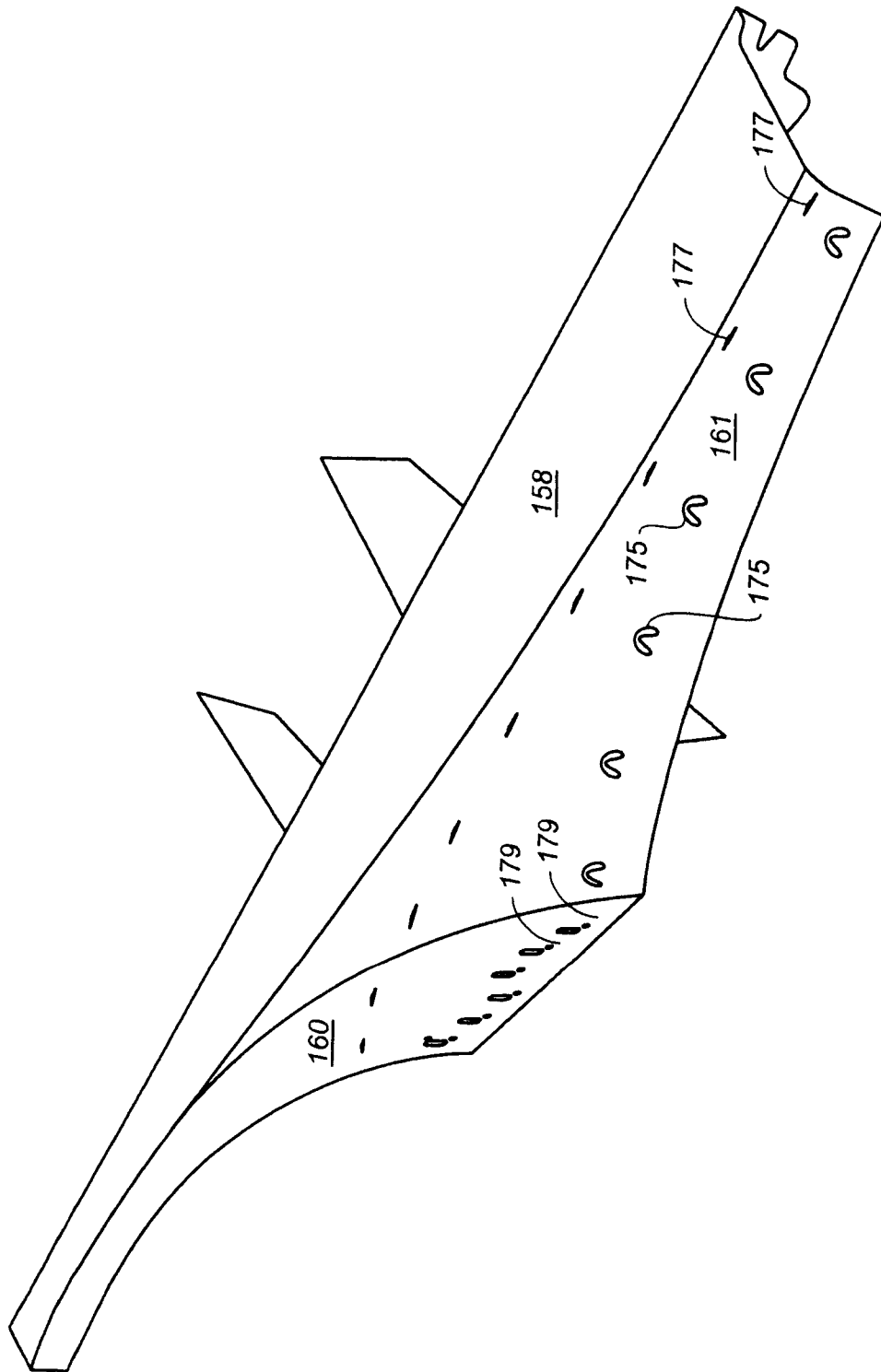


FIG. 10

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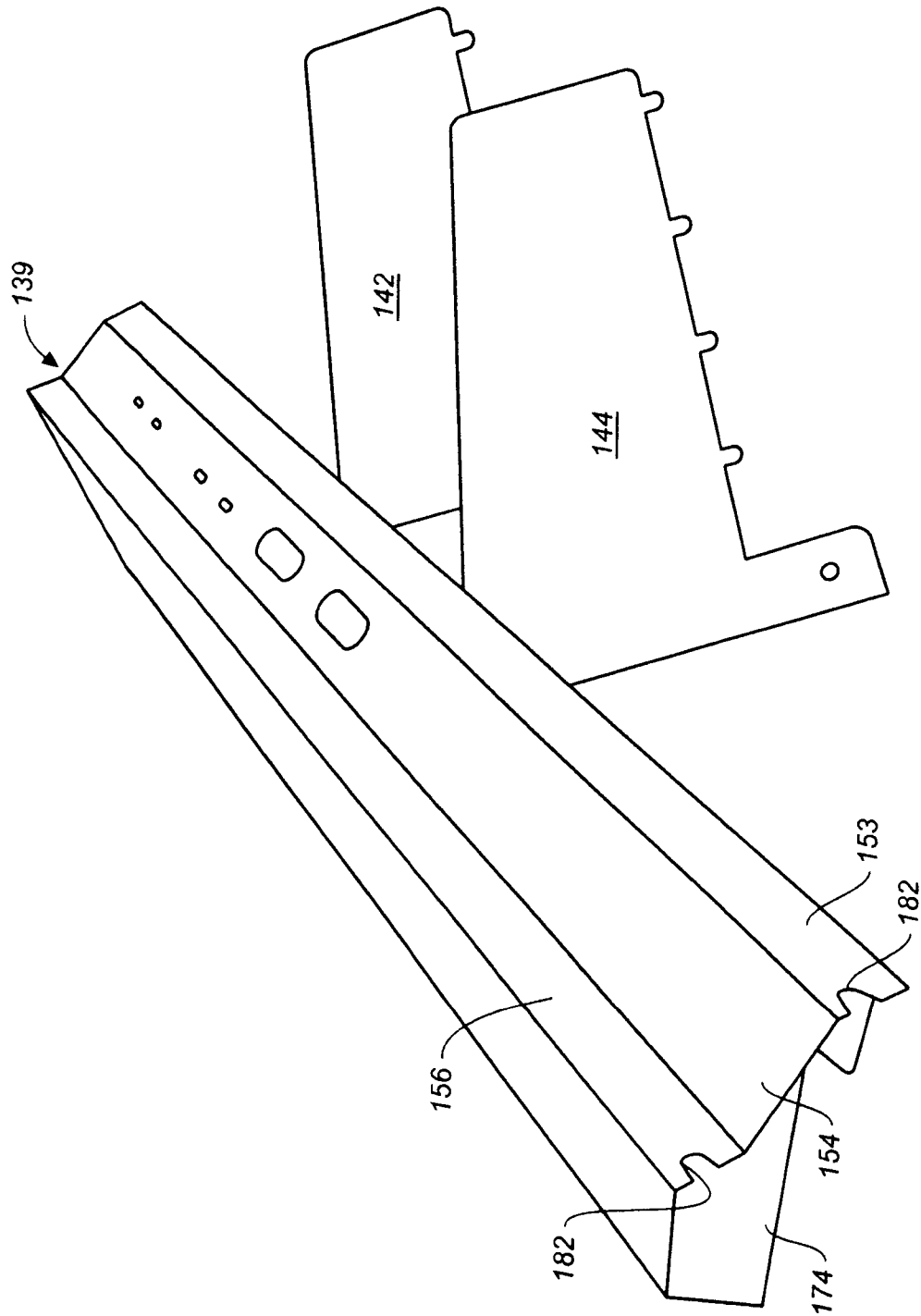


FIG. 11

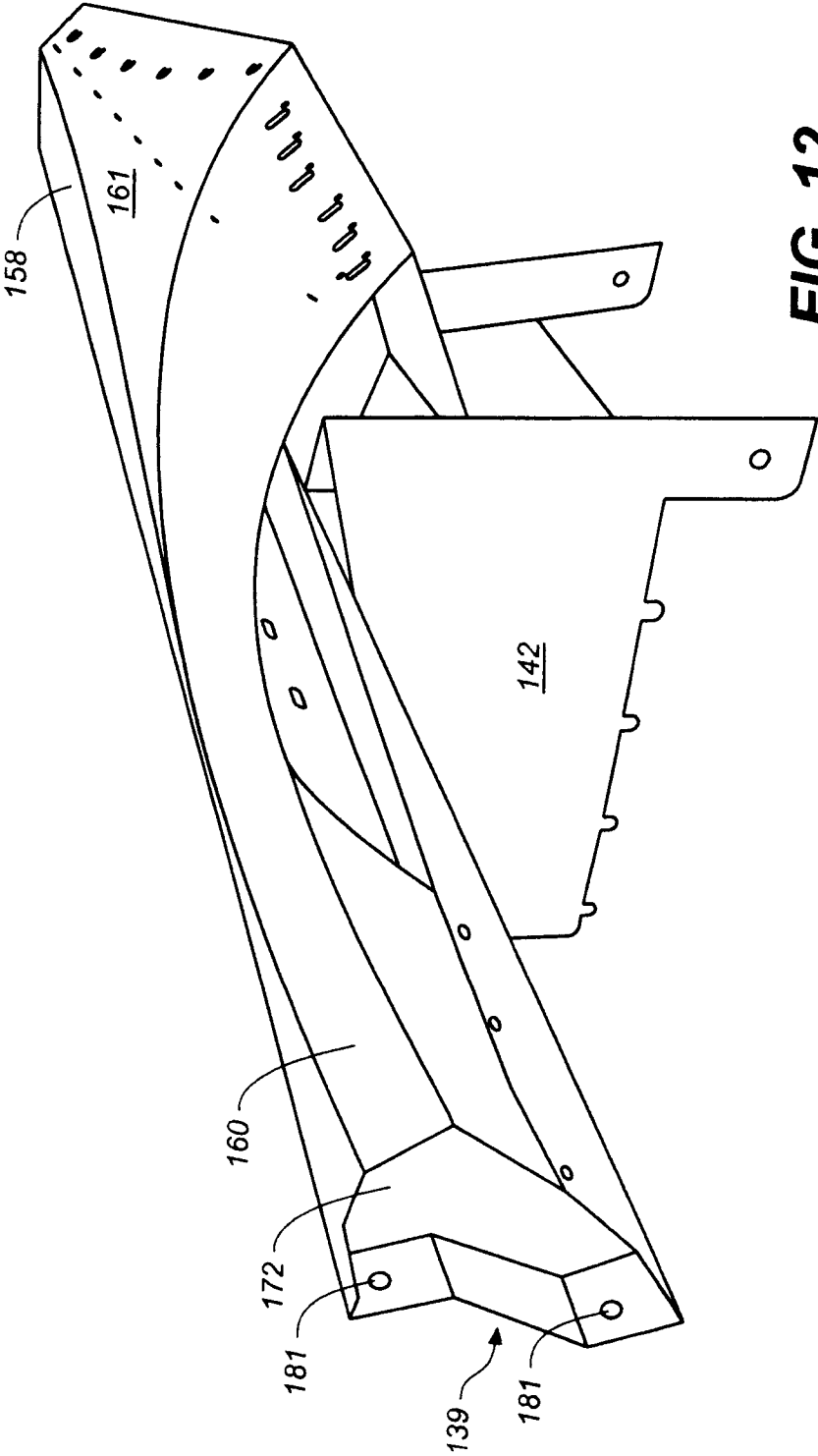


FIG. 12

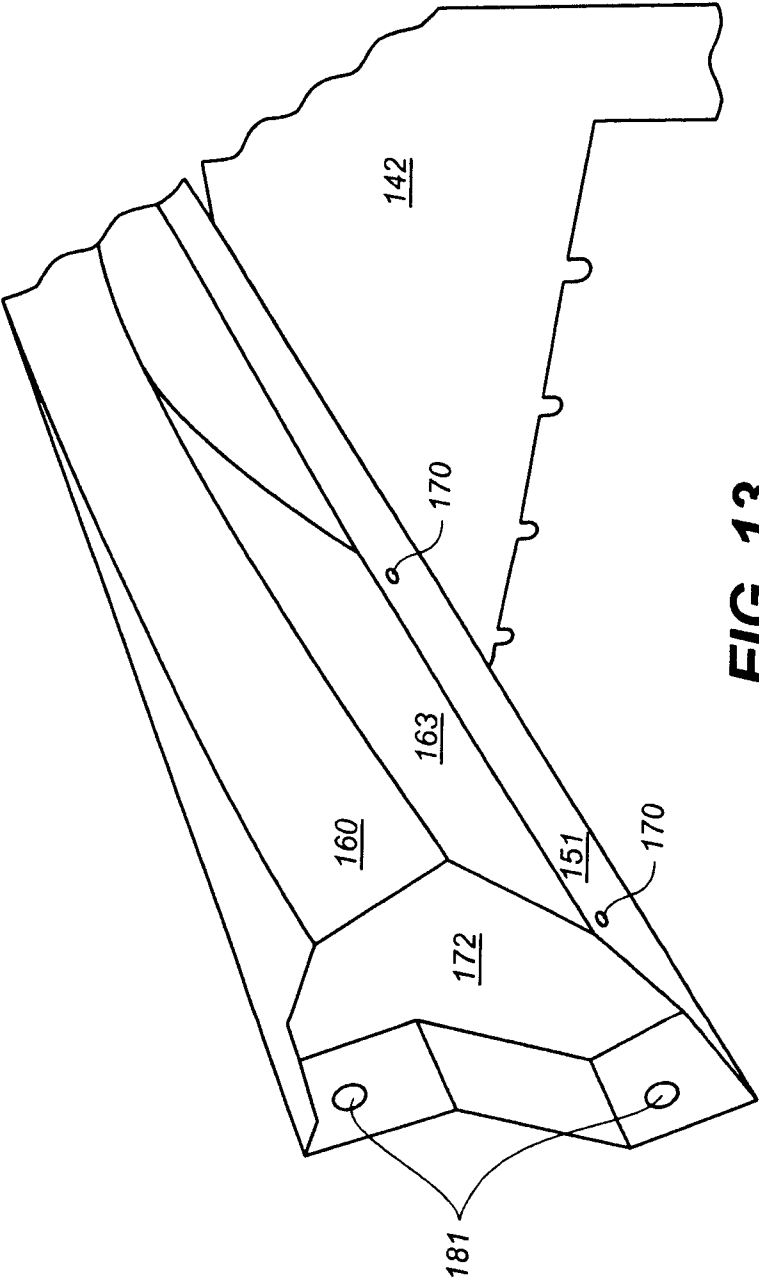


FIG. 13

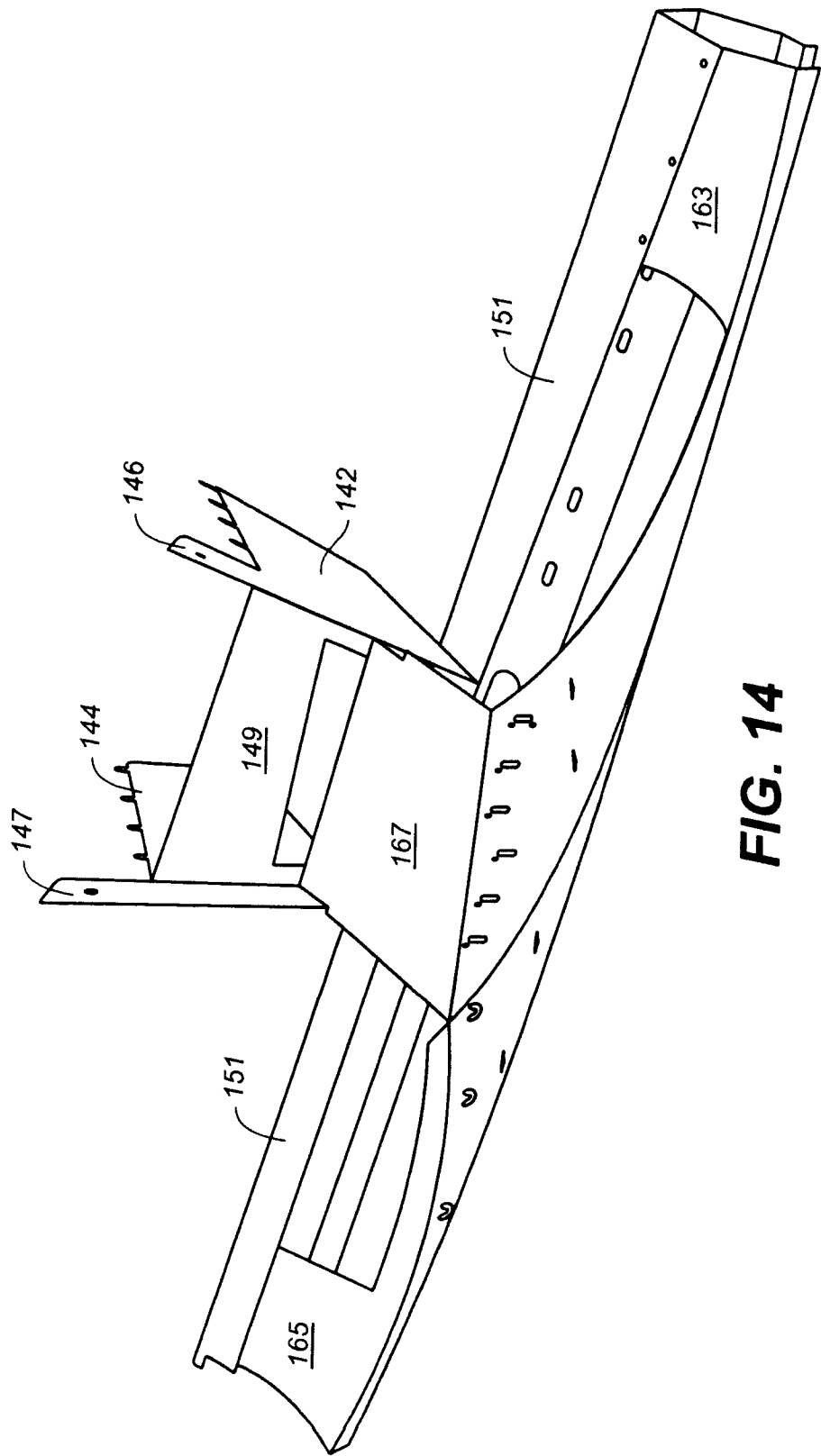


FIG. 14

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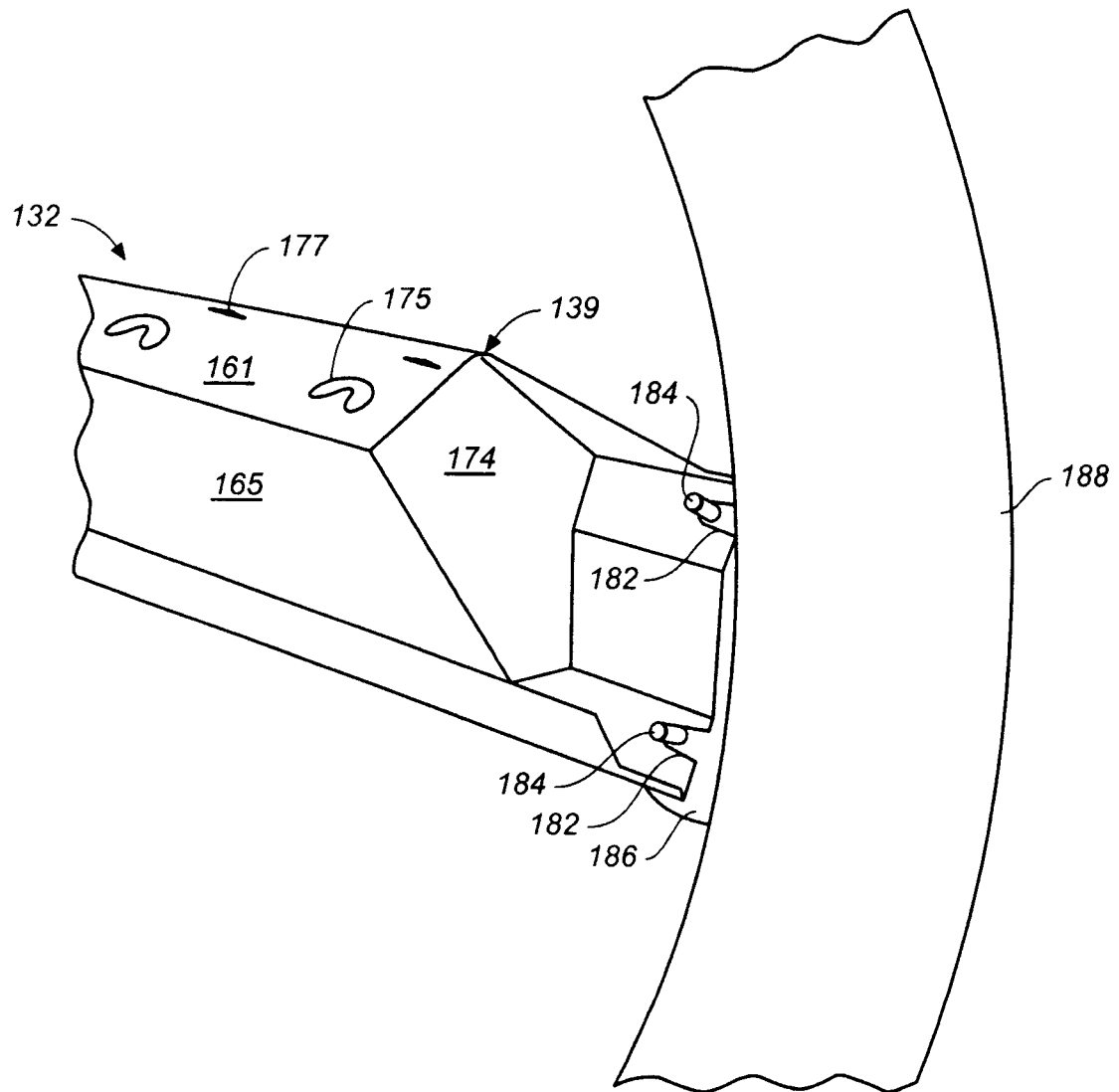


FIG. 15