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(54) **CORRUGATED STIFFENING DEVICES  
UTILIZING PEAKS AND VALLEYS AND  
METHODS OF MANUFACTURE**

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(71) Applicant: **ROHR, INC.**, Chula Vista, CA (US)

(72) Inventors: **JENNIFER DAVIS**, Carlsbad, CA (US); **NATHANIEL M. GRAY**, Stratham, NH (US)

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(73) Assignee: **ROHR, INC.**, Chula Vista, CA (US)

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(57)

**ABSTRACT**

**Related U.S. Application Data**

(62) Division of application No. 17/465,027, filed on Sep. 2, 2021, now Pat. No. 11,993,388.

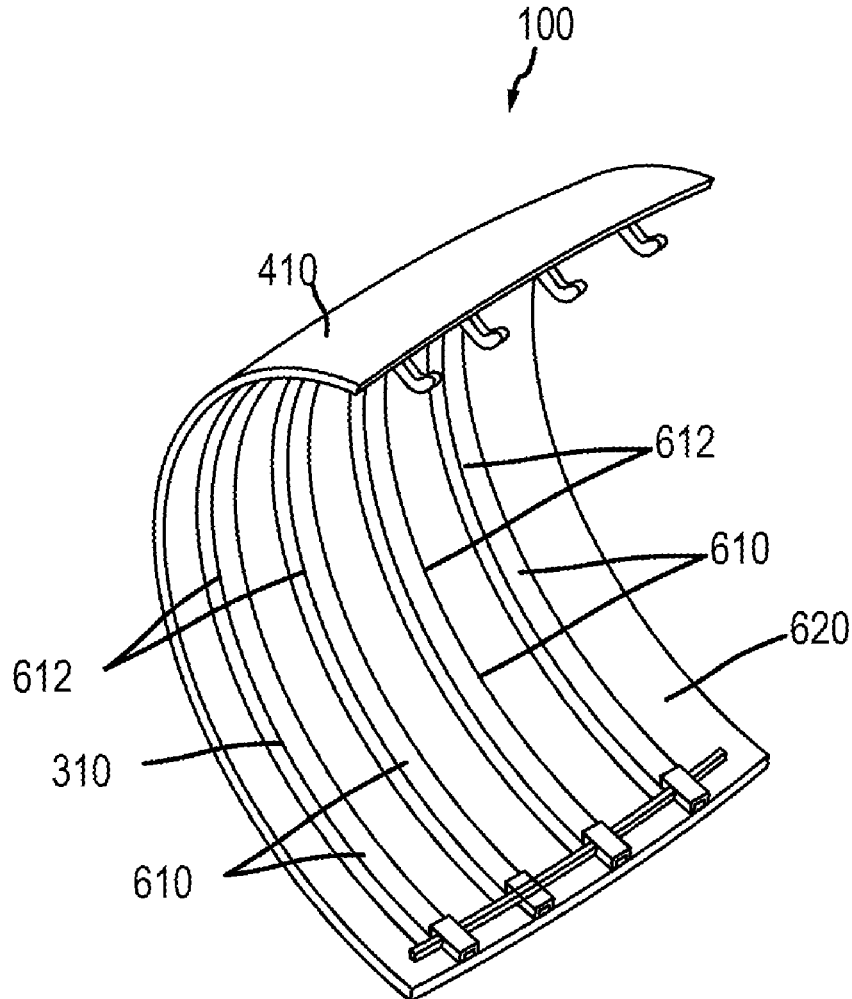
A method may comprise: laying up a first plurality of plies of material comprising thermoplastic resin and fiber to form an inner skin preform, the inner skin preform being a continuous sheet including alternating peaks and valleys; laying up a second plurality of plies of material comprising thermoplastic resin and fiber to form an outer skin preform; and joining the inner skin preform to the outer skin preform.

**Publication Classification**

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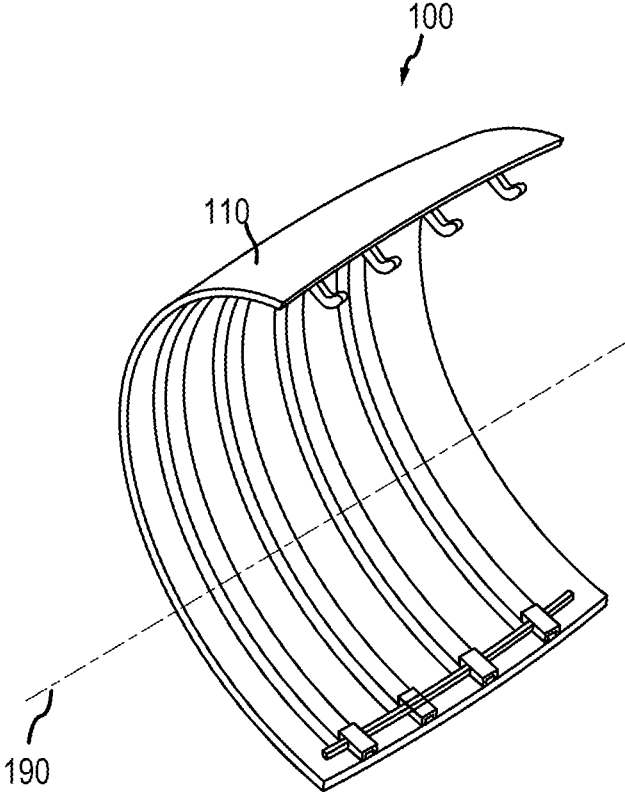


FIG. 1

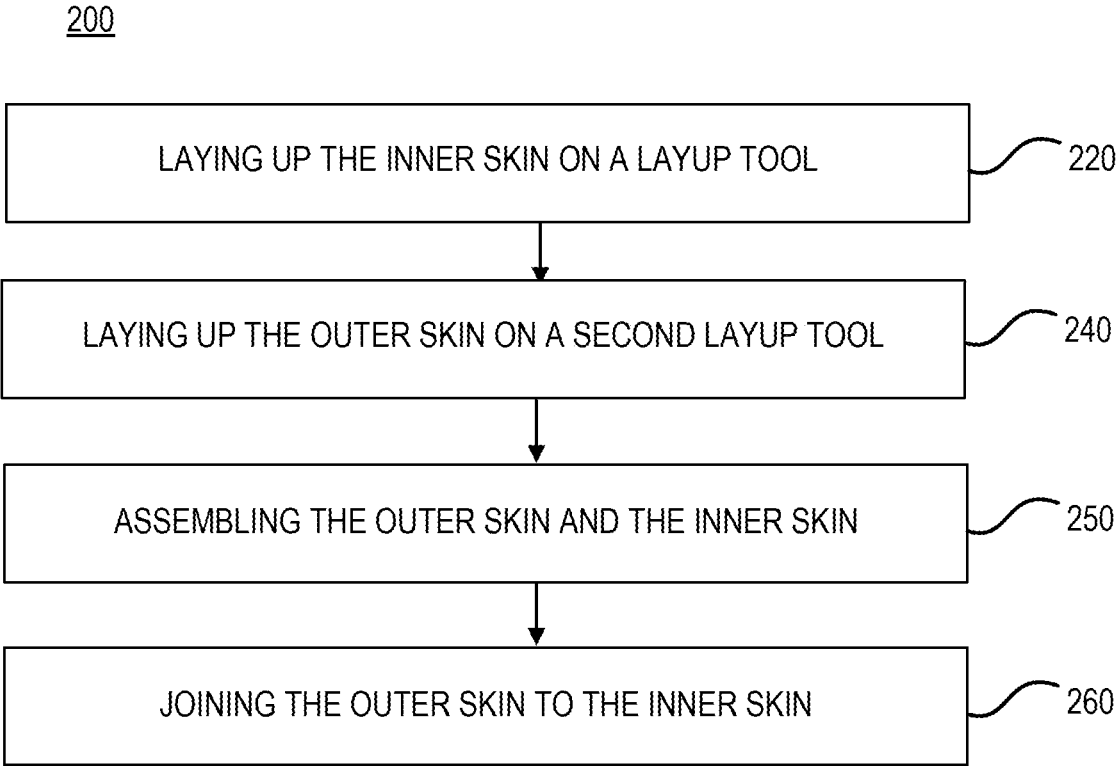


FIG. 2

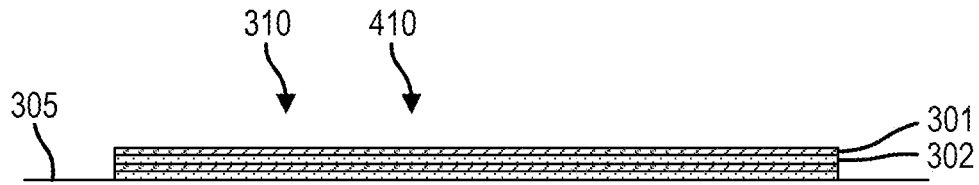


FIG. 3

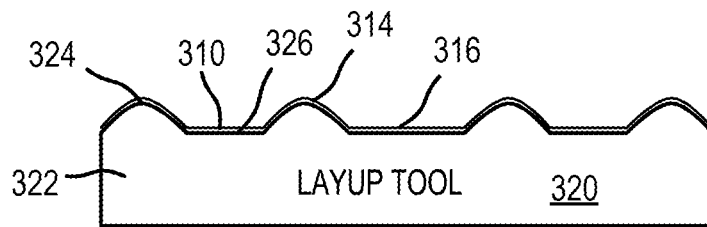


FIG. 4A

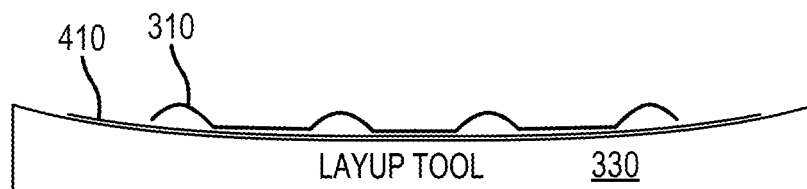


FIG. 4B

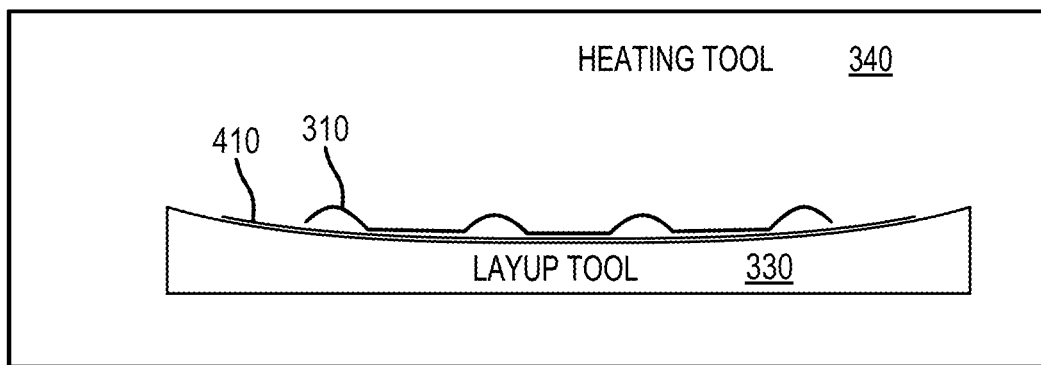


FIG. 4C

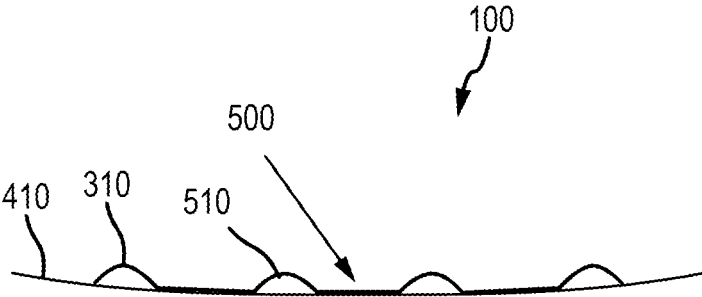


FIG. 5

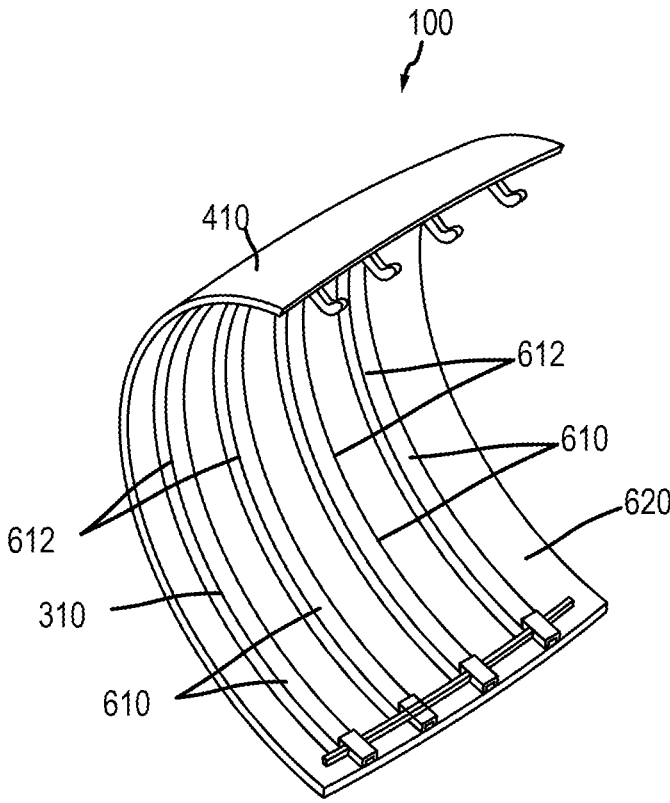


FIG. 6

## CORRUGATED STIFFENING DEVICES UTILIZING PEAKS AND VALLEYS AND METHODS OF MANUFACTURE

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a divisional of, claims priority to and the benefit of, U.S. application Ser. No. 17/465,027, filed Sep. 2, 2021 and titled “CORRUGATED STIFFENING DEVICES UTILIZING PEAKS AND VALLEYS AND METHODS OF MANUFACTURE” which is incorporated by reference herein in its entirety for all purposes.

### FIELD

[0002] The present disclosure relates generally to thermoplastics manufacturing, and more specifically to forming fiber-reinforced thermoplastic materials having a monolithic stiffening structure

### BACKGROUND

[0003] Various industries include components having multi-dimensional panels for various uses. For example, the aerospace industry utilizes nacelles for various applications for providing a protective housing around adjacent components as well as for providing an aerodynamic surface for reducing drag, among other applications. For example, a fan cowl is used for covering various components of a turbine engine and provides an aerodynamic surface for the turbine engine and related systems. A fan cowl outer skin preform is typically made from metal or carbon fiber thermoset composites in a skin and stringer or core stiffened architecture. A current method of forming skins and/or stiffeners includes laying up thermoset composite plies by hand, one at a time, to form a laminate structure, representing a time consuming process.

### SUMMARY

[0004] A method for forming a thermoplastic panel is disclosed herein. The method may comprise: laying up a first plurality of plies of material comprising thermoplastic resin and fiber to form an inner skin preform, the inner skin preform being a continuous sheet including alternating peaks and valleys; laying up a second plurality of plies of material comprising thermoplastic resin and fiber to form an outer skin preform; and bonding the inner skin preform to the outer skin preform.

[0005] In various embodiments, joining the inner skin preform to the outer skin preform includes heating the inner skin preform and the outer skin preform to a fusing temperature. The method may further comprise cooling the inner skin preform and the outer skin preform after consolidating the inner skin preform and the outer skin preform together via the joining. Joining the inner skin preform to the outer skin preform may form a stiffening structure that is monolithic with the thermoplastic panel. The first plurality of plies of material may be laid up in a hard female layup tool including a second set of alternating peaks and valleys, the second set of alternating peaks and valleys in accordance with the alternating peaks and valleys of the continuous sheet. The second plurality of plies of material may be laid up in a second layup tool having a second female mold

corresponding to an outer surface of the thermoplastic panel. The inner skin preform and the outer skin preform may be assembled prior to bonding.

[0006] A method of manufacturing a thermoplastic panel is disclosed herein. The method may comprise: assembling an inner skin preform and an outer skin preform, the inner skin preform having a first contour including alternating peaks and valleys, the valleys of the inner skin preform in contact with an inner surface of the outer skin preform; heating the inner skin preform and the outer skin preform; and consolidating the inner skin preform and the outer skin preform to form the thermoplastic panel.

[0007] In various embodiments, the outer skin preform includes an outer surface having a second contour, the second contour being defined in a longitudinal direction. The inner skin preform may define a stiffening structure of the thermoplastic panel. The alternating peaks and valleys may be defined in a longitudinal direction. The inner skin preform may be continuous. A peak in the alternating peaks and valleys may extend circumferentially along the inner surface of the outer skin preform. The valleys in the alternating peaks and valleys may be joined to the inner surface of the outer skin preform in response to the heating. The inner skin preform and the outer skin preform may both comprise a plurality of plies of material comprising thermoplastic resin and fiber. The method may further comprise laying up a first plurality of plies to form the inner skin preform and laying up a second plurality of plies to form the outer skin preform prior to assembly.

[0008] A stiffened example of a fan cowl panel is disclosed herein. The stiffened panel may comprise: an outer surface defining an arcuate shape, the outer surface being contoured in a longitudinal direction; an inner surface disposed radially inward from the outer surface; and a stiffening structure including a plurality of peaks extending radially inward from the inner surface, each peak in the plurality of peaks including an apex spaced apart and defining a gap from the inner surface.

[0009] In various embodiments, the outer surface, the inner surface and the stiffening structure form a monolithic component. Each peak in the plurality of peaks may define a hollow channel in a circumferential direction. The stiffening structure of the stiffened panel of the fan cowl may be continuous.

[0010] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated herein otherwise. These features and elements as well as the operation of the disclosed embodiments will become more apparent in light of the following description and accompanying drawings.

### BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The subject matter of the present disclosure is particularly pointed out and distinctly claimed in the concluding portion of the specification. A more complete understanding of the present disclosure, however, may best be obtained by referring to the detailed description and claims when considered in connection with the drawing figures, wherein like numerals denote like elements.

[0012] FIG. 1 illustrates a perspective view of a panel half, in accordance with various embodiments;

[0013] FIG. 2 provides a flow chart for a method for manufacturing a fiber-reinforced thermoplastic panel, in accordance with various embodiments;

[0014] FIG. 3 and FIG. 4A illustrate various steps of the manufacturing process of FIG. 2, in accordance with various embodiments; and

[0015] FIG. 4B illustrates various steps of the manufacturing process of FIG. 2, in accordance with various embodiments;

[0016] FIG. 4C illustrates various steps of the manufacturing process of FIG. 2, in accordance with various embodiments;

[0017] FIG. 5 illustrates a cross-sectional view of a panel half, in accordance with various embodiments; and

[0018] FIG. 6 illustrates a perspective view of a panel half, in accordance with various embodiments.

#### DETAILED DESCRIPTION

[0019] The detailed description of exemplary embodiments herein makes reference to the accompanying drawings, which show exemplary embodiments by way of illustration. While these exemplary embodiments are described in sufficient detail to enable those skilled in the art to practice the inventions, it should be understood that other embodiments may be realized and that logical changes and adaptations in design and construction may be made in accordance with this invention and the teachings herein. Thus, the detailed description herein is presented for purposes of illustration only and not for limitation. The scope of the invention is defined by the appended claims. For example, the steps recited in any of the method or process descriptions may be executed in any order and are not necessarily limited to the order presented. Furthermore, any reference to singular includes plural embodiments, and any reference to more than one component or step may include a singular embodiment or step. Also, any reference to attached, fixed, connected or the like may include permanent, removable, temporary, partial, full and/or any other possible attachment option. Additionally, any reference to without contact (or similar phrases) may also include reduced contact or minimal contact. Surface shading lines may be used throughout the figures to denote different parts but not necessarily to denote the same or different materials. In some cases, reference coordinates may be specific to each figure.

[0020] Throughout this specification, reference is made to “melting temperature” and “recrystallization temperature” in respect of thermoplastics. It is understood that the terms are defined as follows:

[0021] “Melting temperature” is the temperature range at which the plastic undergoes a phase change from a solid to liquid, upon heating.

[0022] “Recrystallization temperature” is the temperature at which the semi-crystalline or crystalline matrix begins to form crystals upon cooling from the molten amorphous state. The onset of re-crystallization from the molten state takes place over a temperature “window-range”, which is dependent on the rate of cooling and the final achievable degree of crystallinity of the polymer matrix.

[0023] Disclosed herein is a method for manufacturing a corrugated stiffened structure such as a fan cowl. The method may include laying up an inner skin preform on a first layup tool to form a stiffening structure for the fan cowl and laying up an outer skin preform on a second layup tool corresponding to a shape of the fan cowl. With the stiffening structure being fabricated as an inner skin preform, and the outer skin preform being fabricated from a similar process,

the inner skin preform and the outer skin preform may be assembled and consolidated directly after fabrication, greatly reducing a production time and simplifying the manufacturing process. The method disclosed herein may eliminate, or greatly reduce, addition processes during manufacturing, tooling costs, and capital expenditures for fan cowl manufacturing, in accordance with various embodiments. Additionally, in various embodiments, the method disclosed herein may minimize a value chain and improve an overall structure of the fan cowl.

[0024] In various embodiments, changing a shape of the stiffening structure as disclosed herein may facilitate the manufacturing process disclosed herein. Typical stiffening structures of fan cowls would be unable to accommodate the process disclosed herein due to a tight radii of the stiffener shape.

[0025] With reference to FIG. 1, a perspective view of a stiffened panel outer skin 100 is illustrated, in accordance with various embodiments. Stiffened panel 100 may comprise an outer skin preform 110. Outer skin preform 110 may comprise a semi-cylindrical geometry when viewed from the aft direction. Outer skin preform 110 may define a centerline axis 190. Stated differently, outer skin preform 110 may be bent around centerline axis 190.

[0026] Outer skin preform 110 may be contoured along the longitudinal direction. Stated differently, outer skin preform 110 may comprise a non-linear geometry (e.g., rounded) along the longitudinal direction.

[0027] Outer skin preform 110 may be made from a fiber-reinforced thermoplastic material. In various embodiments, the outer skin preform 110 comprises a continuous reinforcing fiber and a thermoplastic resin. The reinforcing fiber to be used for the outer skin preform 110 has no particular limitations with respect to the type thereof, and examples thereof include metal fibers, such as an aluminum fiber, a brass fiber, and a stainless steel fiber, carbon fibers (including graphite fibers), such as polyacrylonitrile (PAN)-based carbon fibers, rayon-based carbon fibers, lignin-based carbon fibers, and pitch-based carbon fibers, insulating fibers, such as glass fiber, organic fibers, such as aramid fibers, polyparaphenylene benzoxazole (PBO) fibers, polyphenylene sulfide fibers, polyester fibers, acrylic fibers, nylon fibers, and polyethylene fibers, and inorganic fibers, such as silicon carbide fibers and silicon nitride fibers. Fibers prepared by applying surface treatment to these fibers are also available. Examples of the surface treatment include treatment with a coupling agent, treatment with a sizing agent, treatment with a binder, and adhesion treatment with an additive in addition to deposition treatment with conductive metal.

[0028] In the disclosure, the thermoplastic resin to be used for the outer skin preform 110 may be either crystalline or amorphous.

[0029] Examples of the crystalline thermoplastic resin include polyester, polyolefin, polyoxymethylene (POM), polyamide (PA), polyarylene sulfide, polyketone (PK), polyetherketone (PEK), polyether ether ketone (PEEK), polyether ketone ketone (PEKK), polyvinylidene fluoride (PVDF), polytetrafluoroethylene (PTFE), polyaryletherketone (PAEK), polyether nitrile (PEN), fluororesin, and liquid crystal polymer (LCP). Examples of the polyester include polyethylene terephthalate (PET), polybutylene terephthalate (PBT), polytrimethylene terephthalate (PTT), polyethylene naphthalate (PEN), and liquid crystal polyester.

Examples of the polyolefin include polyethylene (PE), polypropylene (PP), and polybutylene. Examples of the polyarylene sulfide include polyphenylene sulfide (PPS). Examples of the fluororesin include polytetrafluoroethylene.

[0030] Examples of the amorphous thermoplastic resin include polystyrene, polycarbonate (PC), polymethyl methacrylate (PMMA), polyvinyl chloride (PVC), polyphenylene ether (PPE), polyimide (PI), polyamide imide (PAI), polyetherimide (PEI), polysulfone (PSU), polyether sulfone (PES), and polyarylate (PAR). The thermoplastic resin to be used for the outer skin preform **110** also may be phenoxy resin, polystyrene, polyolefin, polyurethane, polyester, polyamide, polybutadiene, polyisoprene, fluorine resin, acrylonitrile, and other thermoplastic elastomers, and copolymers and modified resin thereof.

[0031] With reference to FIG. 2, a method **200** for manufacturing a thermoplastic panel is provided, in accordance with various embodiments. Method **200** includes laying up the inner skin preform on a layup tool (step **220**). The layup tool may be a hard female layup tool as opposed to a mandrel or the like. The layup tool may include a stiffener shape having peaks and valleys as described further herein. In this regard, the stiffener for the thermoplastic panel (i.e., the inner skin preform) may comprise a continuous stiffener for the thermoplastic panel. In various embodiments, step **220** may include laying up the inner skin preform by hand, an advanced fiber placement process, or the like. The present disclosure is not limited in this regard.

[0032] The method **200** further includes laying up the outer skin preform on a second layup tool (step **240**). The second layup tool may correspond to a shape of the inner panel **100** from FIG. 1A. In this regard, the outer skin preform may define the outer skin preform **110** from FIG. 1A. The method **200** further includes assembling the outer skin preform and the inner skin preform (step **250**) and joining the inner skin preform to the outer skin preform (step **260**). In various embodiments, the joining of step **260** may be performed by placing the assembly of the inner skin preform and outer skin preform into a heated tool (i.e., a heated tool, heated oven) or welding apparatus. In various embodiments, in a heated tool, a pressure may be added to the outer skin preform and the inner skin preform in joining locations. Thus, consolidation between the outer skin preform and the inner skin preform may occur due to the pressure and cooling from the heated state, in accordance with various embodiments.

[0033] With combined reference to FIG. 3, the method may further comprise stacking plies of fiber sheets **301** and thermoplastic resin sheets **302** to a desired thickness to form a skin preform (e.g., inner skin preform **310** and outer skin preform **410**), prior to laying up in accordance with steps **220** and **240**. In various embodiments, and for ease of handling, the sheets may be stacked on a substantially planar surface **305** and layed up after stacking in the layup tool. In various embodiments, the sheets may be stacked on a layup tool **320** directly.

[0034] In various embodiments, the resin sheets **302** may be “tacked.” Various methods may be used to tack together the stack of sheets to hold the sheets in place with respect to each other without departing from the scope of the present disclosure, such as clamping and ultrasonic welding, among others. Furthermore, at least one resin sheet **302** between each adjacent pair of fiber sheets **301** and alternating between resin sheets **302** and fiber sheets **301** may be used

depending on the desired thickness of the fiber-reinforced thermoplastic panel (i.e., the outer skin preform) or stiffening structure (i.e., the inner skin preform). Furthermore, the thickness of the panel and stiffening structure may vary. In this regard, a first location of the panel may have a first number of plies and a second location of the panel may have a second number of plies, different from the first number of plies.

[0035] With combined reference to FIG. 2 and FIG. 4A, step **220** may include laying up the inner skin preform **310** on a layup tool **320** with equipment such as an automated fiber placement machine. In various embodiments, laying up the inner skin preform may be performed manually or automatically via a controller. The present disclosure is not limited in this regard. The layup tool **320** may comprise a hard female layup tool with a contour corresponding to a stiffening structure for the stiffened panel half **100** from FIG. 1A. In various embodiments, the layup tool **320** may facilitate a continuous inner skin preform **310** corresponding to a stiffening structure of the stiffened panel half **100** from FIG. 1A.

[0036] In various embodiments, the layup tool **320** comprises a female mold **322** including alternating peaks **324** and valleys **326**. The peaks **324** may be of any appropriate profile, but are at least generally convex relative to the adjacent valleys **326** and/or protrude relative to the adjacent valleys **324**. In this regard, the inner skin preform **310** may be pre-formed in the shape of the female mold **322** (i.e., inner skin preform **310** may comprise sheets **301**, **302** of FIG. 3 formed continuously as alternating peaks **314** and valleys **316**) to form a stiffening structure of the stiffened panel half **100**. In various embodiments, the valleys **316** may be configured to be bonded to the outer skin preform **410** in accordance with step **260** of FIG. 2 as described further herein.

[0037] With combined reference to FIGS. 2 and 4B, step **240** may include laying up the outer skin preform **410** on a second layup tool **330**. The second layup tool **330** may correspond to a shape of an outer surface of the stiffened panel half **100** from FIG. 1A. In various embodiments, the inner skin preform **310** may be assembled with the outer skin preform **410** on the second layup tool **330** in accordance with step **250** of method **200** (the valleys **326** of the inner skin preform **310** being disposed on or in closely-spaced relation to the inner surface of the outer skin preform **410**, and with the peaks **324** of the inner skin preform **310** projecting or protruding away from the inner surface of the outer skin preform **410**). In various embodiments, by fabricating the inner skin preform **310** as the stiffening structure and the outer skin preform **410** via the same process and using the same materials, the two shells may be assembled and consolidated (i.e., joined) in a significantly more efficient manner relative to typical stiffening structures for composite panels, in accordance with various embodiments.

[0038] With combined reference to FIGS. 2 and 4C, step **260** may further include disposing the assembly of the outer skin preform **410** and inner skin preform **310** from step **250** into a heating tool **340**. The heating tool **340** may be a heated oven or an autoclave. The heating tool **340** may be configured to heat and pressurize the locations being joined (i.e., apply localized heat to locations coinciding with the valleys **316** of the inner skin preform **310**). Additionally, the amorphous layers from the outer skin preform **410** and the inner skin preform **310** may be utilized as bonding layers. In this



regard, consolidation of the outer skin preform **410** and the inner skin preform **310** may be unsupported, in accordance with various embodiments.

[0039] In various embodiments, step **260** may further include heating, via one or more heating elements in the heating tool **340**, the inner skin preform **310** and the outer skin preform **410** to a bonding temperature. Heating elements in the heating tool **340** may comprise any suitable heating element including infrared heaters, resistive heating elements, or the like. Bonding locations of the inner skin preform **310** to the outer skin preform **410** may be locally heated to a sufficient bonding temperature such that the inner skin preform **310** becomes pliable for more easily joining the outer skin preform **410** to the inner skin preform **310**. In various embodiments, the term “bonding temperature” as used herein may refer to a range of temperatures which is greater than the recrystallization temperature (or glass transition temperature for amorphous thermoplastic resins) of the thermoplastic resin of inner skin preform **310** and outer skin preform **410**. The suitable pliable bonding temperature may vary depending on the particular thermoplastic material being used, as well as other factors, such as the thickness of the panel. In various embodiments, the bonding temperature is a temperature below the melting temperature, but not less than the recrystallization temperature (or glass transition temperature for amorphous thermoplastic resins) of the thermoplastic. In various embodiments, the bonding temperature is a temperature above the melting temperature of the thermoplastic.

[0040] In various embodiments, step **260** may include cooling the outer skin preform **410** and the inner skin preform **310** after consolidating and conforming the inner skin preform **310** to the outer skin preform **410** at the mating interfaces between the inner skin preform **310** and the outer skin preform **410** to a temperature below a recrystallization temperature of the thermoplastic resin (e.g., room temperature) to form the hardened skin **500** (as shown in FIG. 5). In various embodiments, the hardened skin **500** is a monolithic component (i.e., formed of a single piece) including the outer skin preform **410** of the stiffened panel half **110** from FIG. 1A and a stiffening structure **510** defined by the inner skin preform **310** being formed as the single piece via method **200** from FIG. 2.

[0041] Referring now to FIG. 6, a perspective view of the stiffened panel half **110** from FIG. 1A is illustrated, in accordance with various embodiments. The stiffened panel half **110** may be a fan cowl for a nacelle of a gas turbine engine. The stiffened panel half **110** is formed in accordance with method **200**. Thus, the stiffened panel half **110** includes the outer skin preform **410** and the inner skin preform **310** formed as a monolithic component (i.e., formed as a single piece). In various embodiments, the stiffened panel half **110** may be lighter relative to typical stiffened panel halves. In various embodiments, the stiffened panel half **110** includes a stiffening structure **610** including a plurality of peaks **612** extending radially inward from an inner surface **620**, each peak in the plurality of peaks **612** including an apex spaced apart and defining a gap from the inner surface **620**. In various embodiments, the inner surface **620** and the stiffening structure **610** are defined by the inner skin preform **310**.

[0042] Benefits, other advantages, and solutions to problems have been described herein with regard to specific embodiments. Furthermore, the connecting lines shown in the various figures contained herein are intended to represent

exemplary functional relationships and/or physical couplings between the various elements. It should be noted that many alternative or additional functional relationships or physical connections may be present in a practical system. However, the benefits, advantages, solutions to problems, and any elements that may cause any benefit, advantage, or solution to occur or become more pronounced are not to be construed as critical, required, or essential features or elements of the inventions. The scope of the inventions is accordingly to be limited by nothing other than the appended claims, in which reference to an element in the singular is not intended to mean “one and only one” unless explicitly so stated, but rather “one or more.” Moreover, where a phrase similar to “at least one of A, B, or C” is used in the claims, it is intended that the phrase be interpreted to mean that A alone may be present in an embodiment, B alone may be present in an embodiment, C alone may be present in an embodiment, or that any combination of the elements A, B and C may be present in a single embodiment; for example, A and B, A and C, B and C, or A and B and C. Different cross-hatching is used throughout the figures to denote different parts but not necessarily to denote the same or different materials.

Systems, methods, and apparatus are provided herein. In the detailed description herein, references to “one embodiment,” “an embodiment,” “an example embodiment,” etc., indicate that the embodiment described may include a particular feature, structure, or characteristic, but every embodiment may not necessarily include the particular feature, structure, or characteristic. Moreover, such phrases are not necessarily referring to the same embodiment. Further, when a particular feature, structure, or characteristic is described in connection with an embodiment, it is submitted that it is within the knowledge of one skilled in the art to affect such feature, structure, or characteristic in connection with other embodiments whether or not explicitly described. After reading the description, it will be apparent to one skilled in the relevant art(s) how to implement the disclosure in alternative embodiments. Furthermore, no element, component, or method step in the present disclosure is intended to be dedicated to the public regardless of whether the element, component, or method step is explicitly recited in the claims. No claim element is intended to invoke 35 U.S.C. 112(f) unless the element is expressly recited using the phrase “means for.” As used herein, the terms “comprises,” “comprising,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises a list of elements does not include only those elements but may include other elements not expressly listed or inherent to such process, method, article, or apparatus.

We claim:

1. A stiffened panel half of a fan cowl, comprising:
  - an outer surface defining an arcuate shape, the outer surface being contoured in a longitudinal direction;
  - an inner surface disposed radially inward from the outer surface; and
  - a stiffening structure including a plurality of peaks extending radially inward from the inner surface, each peak in the plurality of peaks including an apex spaced apart and defining a gap from the inner surface.
2. The stiffened panel half of claim 1, wherein the outer surface, the inner surface and the stiffening structure form a

monolithic component, and wherein each peak in the plurality of peaks defines a hollow channel in a circumferential direction.

3. The stiffened panel half of claim 1, wherein the stiffening structure of the stiffened panel half of the fan cowl is continuous.

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