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(71) Applicant (for all designated States except US): **THE BOEING COMPANY** [US/US]; 100 North Riverside Plaza, Chicago, IL 60606 (US).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **TALWAR, Rajesh** [US/US]; 861 Bluespring Lane, Frontenac, MI 63131 (US). **MARTIN, Ricky, L.** [US/US]; 139 Timberidge Drive, St. Peters, MO 63376 (US). **OGONOWSKI, James, M.** [US/US]; 14493 Britannia Drive, Chesterfield, MI 63017 (US).

(74) Agents: **RAFTER, John, R.** et al.; The Boeing Company, 15460 Laguna Canyon Road, MC 1650-7006, Irvine, CA 92618 (US).

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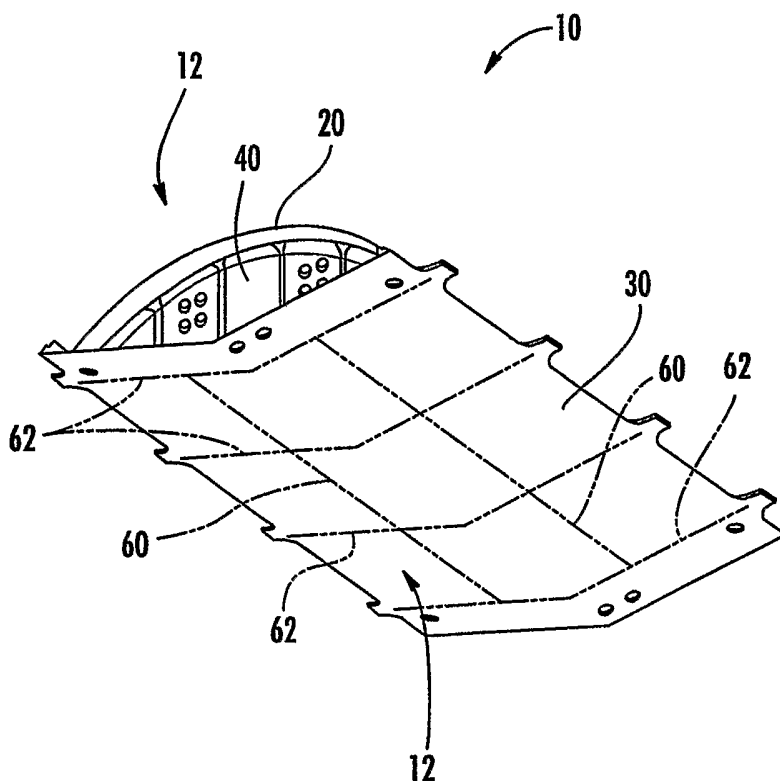
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(54) Title: **FRICION STIR WELDING OF JOINTS WITH SHIMS**



(57) Abstract: A method of friction stir welding joints with shims and an associated structural assembly is provided. The structural assembly includes one or more skin members that are disposed and friction stir welded to a substructure. A shim is disposed in a space defined by the other members of the assembly, e.g., between adjacent skin members or between a skin member and the substructure. The shim can be friction stir welded to the other members. That is, the adjacent skin members can be connected via the shim, and/or the skin members can be connected to the substructure via the shim. In some cases, the skin members and the substructure are relatively stiff, and the shim substantially fills the space to reduce flexing of the members during the friction stir welding operation.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

FRICTION STIR WELDING OF JOINTS WITH SHIMS

BACKGROUND OF THE INVENTION

1) Field of the Invention

The present invention relates to the joining of structural members and, more particularly,
5 relates to friction stir welding of joints including at least one shim disposed between structural members.

2) Description of Related Art

Aerospace structural assemblies, such as wings for aircraft, typically include outer
flexible sheets, or skins, that are supported in a desired contour to define the outer surface of the
10 structure. According to one conventional method of manufacturing such structures, a number of
stringers are connected to the skins to stiffen the skins and facilitate connection of the skins to an
underlying support framework of the structure. The stringers, which are typically long angles,
channels, or other types of beams, can be connected to the skins by riveting or welding while the
skins are supported in a generally flat configuration. Thereafter, the stringers and the skins can
15 be adjusted to the desired configuration, and the stringers are connected to spars or other
members of the support framework.

In some applications, however, it is desirable to have skins that are relatively stiff. The
stiffness of the skins prevents the skins from being readily flexed to the desired configuration
during assembly. Therefore, the skins are formed to the desired contour. For example, the skins
20 can be bent or stretched, or each skin can be formed of multiple portions that are connected in
the desired configuration. Nevertheless, even small differences between the configuration of the
formed skins and the underlying support structure can complicate the assembly or reduce the
quality of the finished structure. For example, the stiffness of the skins can prevent or
complicate the adjustment of the skins to accurately conform to the support framework. Small
25 gaps or mismatches can result between the skin and the framework and/or between the different
portions of the skin that are connected to the support framework. Such gaps are typically filled
with putty or caulk, but the strength, durability, and/or corrosion resistance of the connections
can be affected.

Therefore, there exists a need for an improved method for forming structural assemblies,
30 especially aerospace structural assemblies that include outer contoured skins. The method

should be capable of reducing the gaps between the members of the structure and improving the quality of the connections formed therebetween.

BRIEF SUMMARY OF THE INVENTION

5 The present invention provides a method of friction stir welding skin members and substructures and a structural assembly formed by such welding operations. For example, the structural assembly can be welded with a shim disposed in a space defined between a skin member and the substructure or between two adjacent skin members, to thereby friction stir weld the members of the assembly via the shim. Thus, the shim facilitates the formation of a desired
10 contour of the assembly, and is further capable of improving the quality of the joints formed between the multiple members of the assembly.

 According to one embodiment of the present invention, the substructure and one or more skin members are disposed to define a space, e.g., between adjacent skin members or between the substructure and one of the skin members. For example, the skin and the substructure can be
15 provided as rigid members, either or both of which can define simple or complex geometric contours, such as the shape of an airfoil or other aerospace structure. The shim, which can have a nonuniform thickness or width to correspond to the dimensions of the space, is disposed in the space. Thereafter, the skin is friction stir welded, i.e., to form an elongate weld joint between members of the skin via the shim and/or between the skin and the substructure via the shim. In
20 some cases, skin members can be welded to opposite sides of the substructure so that the substructure extends between the first and second skins on the opposite sides.

 According to another embodiment of the present invention, there is provided a friction stir welded structural assembly that includes a substructure defining an outer contour, one or more skin members disposed on the substructure at the outer contour of the substructure, and at
25 least one shim disposed between the skin members or between the skin member and the substructure. At least one friction stir weld joint connects the shim to the adjacent skin member(s) and or the substructure. The skin members and substructures can be rigid members, which can be formed of aluminum or other materials, and each can define a simple or complex geometric configuration. Further, skin members can be welded to opposite sides of the
30 substructure. For example, the outer contour of the substructure and, hence, the assembly, can define an airfoil or other aerospace shape.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

5 Figure 1 is a perspective view illustrating a structural assembly according to one embodiment of the present invention;

Figure 2 is an expanded perspective view illustrating the structure assembly of Figure 1 in an unassembled configuration;

Figure 3 is a section view illustrating the structural assembly of Figure 1 in a partially assembled configuration with a shim disposed between the skin and substructure;

10 Figure 4 is a section view illustrating the structural assembly of Figure 1 as seen along line 4-4 of Figure 3 with a friction stir welding tool configured for joining the skin to the substructure via the skin;

Figure 5 is a plan view illustrating the structural assembly of Figure 4;

15 Figure 5A is an enlarged section view illustrating the friction stir weld formed in the structural assembly of Figure 4, as seen along line 5A-5A of Figure 5;

Figure 6 is a perspective view illustrating a structural assembly according to another embodiment of the present invention;

Figure 7A is a plan view illustrating the structural assembly of Figure 6 before the skin members have been friction stir welded;

20 Figure 7B is a plan view illustrating the structural assembly of Figure 7A during friction stir welding of the skin members;

Figure 8 is a section view illustrating a structural assembly according to another embodiment of the present invention; and

25 Figure 8A is an enlarged section view illustrating a portion of the structural assembly of Figure 8, as indicated in Figure 8.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown.

30 Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

Referring now to the figures and, in particular, Figure 1, there is shown a structural assembly **10** according to one embodiment of the present invention. As illustrated in Figure 1, the structural assembly **10** is an aerospace structural assembly and, more particularly, an airfoil that defines a contoured outer surface **12** such that the assembly **10** is adapted for use as a wing of an aircraft. The structural assemblies according to other embodiments of the present invention can be otherwise configured, and the assemblies can be used in a variety of applications including, but not limited to, aerospace, marine, and terrestrial vehicles and structures.

The structural assembly **10** includes a number of connected structural members, i.e., one or more skins **20, 30** disposed on a substructure **40**. The members **20, 30, 40** can define various configurations according to the desired use of the structural assembly **10**, the materials from which the assembly **10** is to be built, the method of constructing the assembly **10**, and other design criteria. As illustrated in Figure 2, the substructure **40** includes two keels **42** extending in a longitudinal direction of the assembly **10**. The keels **42** are connected by two center frames **44** extending therebetween and two bulkheads **46** connected to the longitudinal ends of the keels **42**. The bulkheads **46** define a profile of the assembly **10**, and a corresponding shape is defined by each of the center frames **44** in conjunction with outer frames **48** connected to the keels **42** opposite the center frames **44**. The frames **44, 48** and bulkheads **46** are connected to the keels **42** by flanges **50** and bolts **52**, though other connections can alternatively be used, such as weld joints, including friction stir weld joints.

The substructure **40** provides a rigid support framework for the structural assembly **10**. By the term "substructure," it is meant that the keels **42** and frames **44, 48** are entirely or substantially covered by the skins **20, 30** disposed thereon. Typically, the substructure **40** defines first and second opposite sides for receiving the skins **20, 30**. That is, the substructure **40** provides a stiff support that extends from the first skin **20** on the first side of the assembly **10** to the second skin **30** on the second side of the assembly **10**. In combination, the first and second sides substantially define the shape of the assembly **10**. For example, as shown in Figure 1, the assembly **10** can be an airfoil or other aerodynamic shape for aerospace applications, the profile of which is substantially defined by the underlying substructure **40**.

Similarly, the skins **20, 30** of the assembly **10** can also define a desired contour according to the application in which the assembly **10** is to be used. In some cases, each skin **20, 30** can include portions that are flat, curved, or otherwise contoured. Further, each skin **20, 30** can be formed of multiple skin portions or member that are connected to one another before or after being connected to the substructure **40**. For example, as illustrated in Figure 2, the second skin

30 is formed of two skin members **32, 34**. The first member **32** is flat, and the second member **34** defines an angle or bend **36**. The members **32, 34** are joined by a friction stir butt weld **38**, though in other embodiments the members **32, 34** can be joined by other weld joints or by connectors such as rivets, bolts, and the like. In any case, the portions **32, 34** can be connected to form the skin **30**, such that the skin **30** is a substantially rigid member when it is subsequently attached to the substructure **40**.

Alternatively, the first skin **20** is a single curved member. In particular, the first skin **20** defines a simple curve, i.e., a contour defined by a curve extending about a single axis. In other embodiments of the present invention, the skins **20, 30** and the corresponding outer contour of the substructure **10** can define a complex curve. For example, as shown in Figure 6, each of the skins **20, 30**, which together define the outer surface **12** of the assembly **10**, is curved about multiple axes to define complex three-dimensionally curved contours.

The first and second skins **20, 30** are welded to the substructure **40**. In this regard, Figure 1 illustrates longitudinal and transverse weld joints **60, 62** extending through the second skin **30** to join the second skin **30** to the keels **42**, frames **44, 48**, and bulkheads **46** of the substructure **40**. The weld joints **60, 62** can be formed by friction stir welding. Friction stir welding is a known welding technique in which a rotating friction stir welding pin or probe is inserted into the members to be joined. The pin and a shoulder from which the pin extends generate sufficient friction with the members to plasticize a portion of the members, and the plasticized material is mixed by the pin. As the plasticized material cools, a friction stir weld joint is formed, characterized by a mixed portion, or nugget, that has a refined grain structure. Friction stir welding is further described in U.S. Patent No. 5,460,317 to Thomas, et al., the entirety of which is incorporated herein by reference. Friction stir welding can be used to form butt joints (with the pin inserted generally parallel to an interface between abutting members being joined) as well as lap joints (with the pin inserted generally perpendicular to an interface between overlapping members being joined). In fact, it is appreciated that friction stir welding can be performed with a variety of types and configurations of pins, which can be inserted into the members in various configurations.

The skins **20, 30** can be held in place against the substructure **40** during the welding operation with clamps, straps, tooling, or the like. In some cases, however, the skins **20, 30** can differ slightly in shape from the outer contour defined by the substructure **40**. Thus, with the skins **20, 30** disposed against the sides of the substructure **40**, spaces may be defined therebetween. The skins **20, 30** are also typically relatively rigid. That is, to the extent that the

skins **20, 30** define a contour that is different than the substructure **40**, the skins **20, 30** cannot be easily flexed during assembly to correspond precisely with the substructure **40**. The stiffness of the skins **20, 30** can be due to the thickness, size, material, and/or geometric configuration of the skins **20, 30**. In some cases, if a space is defined between one of the skins **20, 30** and the
5 substructure **40**, the skin **20, 30** can be deformed by the force exerted by the friction stir welding tool during the friction stir welding operation and/or excessive amounts of flash can be generated during the welding operation.

According to one aspect of the present invention, a space between one of the skins **20, 30** and the substructure **40** is substantially filled and thereby accommodated using a shim **70**, i.e., an
10 additional piece of structural material that is disposed as a solid member. Figure 3 illustrates the shim **70** disposed in a space **72** between the first skin **20** and the substructure **40** of the assembly **10**. The shim **70** extends longitudinally along a portion of one of the center frames **44** and the corresponding outer frame **48**. As illustrated, the shim **70** can define a nonuniform shape along its length. That is, the shim **70** can be thicker or thinner along the length of the shim **70** to
15 correspond with the shape of the space **72** between the skin **20** and the substructure **40** so that the shim **70** substantially fills the space **72**. As shown in Figure 4, the width of the shim **70** can correspond generally to the width of the frame **44**.

As illustrated in Figures 4 and 5, a friction stir welding tool **80** is used to form the friction weld joints **60, 62** between the skin **20** and the substructure **40**. In addition, the friction stir weld
20 joints **60, 62** can be formed through the shim **70**. The friction stir welding tool **80** includes a rotatable pin **82** extending from a shoulder **84**. The pin **82** is inserted through an interface **86** of the skin **20** and the shim **70** and/or through an interface **88** of the shim **70** and the substructure **40**, e.g., perpendicular to the interfaces **86, 88** or at an angle of about 3-5° from a line normal to the interfaces **86, 88**. For example, the friction stir weld tool **80** can be configured outside the
25 assembly **10**, with the shoulder **84** of the tool **80** disposed and urged against the skin **20**, and with the pin **82** configured to extend through the skin **20**, through the shim **70**, and into the substructure **40**. The friction stir welding tool **80** is then urged in a direction **90** against the skin **20** and advanced in a direction **92** along the skin **20** as the pin **82** rotates in a direction indicated by reference numeral **94**. One or more actuators (not shown) can be provided for rotating the
30 tool **80** and adjusting the tool **80** along a predetermined path to form the welds **60, 62**. The motion of the pin **82** and shoulder **84** generates frictional heat, which plasticizes material from the skin **20**, shim **70**, and/or substructure **40**, and the plasticized material is mixed by the pin **82**. As the plasticized material cools and hardens, the friction stir weld joint **60, 62** is formed

connecting the skin **20** to the substructure **40** via the shim **70**. Each friction weld joint **60**, **62** includes a nugget region proximate to the path of the pin **82**, the nugget region being characterized by a refined granular structure. Figure 5A illustrates a section view of one of the weld joints **60** formed in the structural assembly **10**.

5 As shown in Figures 4 and 5, the weld joint **62** can be formed along a center line of the center frame **44** such that the weld joint **62** extends into or proximate to a web portion of the center frame **44**. Alternatively, the weld joint **62** can be formed at other locations, e.g., such that the joint **62** extends into or through a flange portion of the center frame **44**. In either case, multiple friction stir weld joints **60**, **62** can be formed through each shim **70**. For example, the skin **20** can be connected to the substructure **40** by two friction stir weld joints **62** that join the skin **20** to one of the center frames **44** and the corresponding outer frames **48**. Friction stir weld joints **60** extending in the longitudinal direction of the assembly **10** can also extend through the shim **70**. In some cases, an anvil (not shown) or other support can be disposed generally opposite the skin **20**, shim **70**, and/or part of the support structure **40** to oppose the force of the friction stir weld tool **80** against the skin **20**.

15 The shim **70** can substantially fill the space **72** so that the force exerted by the friction stir welding device **80** in direction **90** is resisted by the skin **20** and the substructure **40** without substantial flexing of the skin **20** toward the substructure **40**. That is, the shim **70** can prevent the skin **20** from deforming during the welding operation from the desired shape of the outer surface **12**.

20 In other embodiments of the present invention, shims **70** can be used to fill other spaces defined between the skins **20**, **30** and the substructure **40**. For example, as shown in Figures 6 and 7A, adjacent skin portions or members **22a**, **22b**, **22c** can define spaces **26a**, **26b** therebetween, and the shims **70** can be disposed in those spaces **26a**, **26b**. The shims **70** can have a variety of shapes and sizes, e.g., according to the respective space **26a**, **26b** between the skin members **22a**, **22b**, **22c** in which the shim **70** is to be disposed. In some cases, the shim **70** can define a nonuniform width so that the shim **70** corresponds to the space **26a**, **26b**, even if the adjacent edges of the skin members **22a**, **22b**, **22c** are not parallel or define curves, angles, or other nonuniformities. Further, the shim **70** can define a curved shape to correspond to the desired outer contour of the assembly **10**. Thus, if the edges of the adjacent skin members **22a**, **22b**, **22c** do not make contact when disposed on the substructure **40**, each shim **70** can be used to bridge the respective space **26a**, **26b** between the skin members **22a**, **22b**, **22c** and thereby achieve a continuous or otherwise desired contour of the outer surface **12**.

The shim 70 can be friction stir welded to one or both of the adjacent skin members 22a, 22b, 22c and/or to the substructure 40. In some cases, the friction stir welding operation can plasticize the shim 70 across the width of the shim 70. That is, as shown in Figure 7B, the shim 70 disposed in the space 26a is substantially completely consumed during the friction stir welding operation so that the resulting friction weld joint 62 extends through the width of the shim 70 between the edges of the skin members 22a, 22b. Alternatively, the formation of the friction stir weld joint 62 can plasticize only a portion of the width of the shim 70. For example, each of the edges of the shim 70 disposed in the space 26b are joined to the adjacent skin member 22b, 22c, with a portion 78 of the shim 70 between the edges remaining unplasticized during the friction stir welding operation so that two distinct friction stir weld joints 62 can be formed to connect the shim 70 to the respective skin members 22b, 22c. Thus, in some cases, the entire shim 70 can be plasticized during the friction stir welding operation while in other cases at least a portion of the shim 70 remains unplasticized throughout the welding operation.

The use, placement, and configurations of the shims 70 can be determined, at least in part, according to the spaces defined in the structural assembly 10. Typically, the shims 70 are not used for very small spaces or gaps in the assembly 10. For example, if the width of each space 26a, 26b between adjacent skin members 22a, 22b, 22c is small, such as about 10% or less than the thickness of the skin members 22a, 22b, 22c, then the space 26a, 26b can be closed without the use of the shim 70 by friction stir welding through the space to thereby fill the space with plasticized material from the adjacent members. Alternatively, if the space 26a, 26b is larger, e.g., about 10% or more than the thickness of the skin members 22a, 22b, 22c, then one or more of the shims 70 can be disposed in each space 26a, 26b before friction stir welding. As described above in connection with Figures 7A and 7B, in some cases only part of the shim 70 is plasticized during friction stir welding, while in other cases the entire shim 70 is plasticized, i.e., the shim is consumed during friction stir welding. Typically, if the shim 70 is relatively narrow, then the shim 70 is consumed during friction stir welding. Otherwise, if the shim 70 is relatively wide, only the edges of the shim 70 are plasticized and friction stir welded to the adjacent members such that the unplasticized portion 78 of the shim 70 acts as a splice between the two adjacent members 22b, 22c.

The members of the assembly 10 can be formed of a variety of materials. In one embodiment of the present invention, all or part of each of the skins 20, 30, substructure 40, and shims 70 are formed of aluminum or aluminum alloys. Each of the members of the skins 20, 30, the substructure 40, and the shims 70 can be formed of materials that are the same as or different

than the materials of the other members of the assembly **10**. That is, the shims **70** can be formed of a material that is the same or different than the materials of the skins **20**, **30** and the substructure **40**, which can also be formed of similar or different materials. The materials can be selected according to the desired materials properties for each member of the assembly **10**. For example, in one embodiment, the skins **20**, **30** are formed of 2000 series aluminum, which provides a high fatigue resistance, while the substructure **40** is formed of 7000 series aluminum, which provides high strength. The shims **70** can be formed of a material that can be easily machined so that a particular shape can be easily imparted to each shim **70** according to the space in the assembly **10** that is to receive the shim **70**. The shims **70** can also be formed of a material that can be easily friction stir welded to the skins **20**, **30** and/or the substructure **40**. For example, the shims **70** can be formed of relatively pure aluminum or various alloys of aluminum.

Further, the material of at least a portion of the skins **20**, **30**, the substructure **40**, and/or the shims **70** can have a granular structure that is refined during the friction stir welding operation. The materials with refined grain structure can also be characterized by improved material properties such as strength, durability, and/or corrosion resistance.

The skins **20**, **30**, substructure **40**, and/or the shims **70** can be trimmed, treated, or otherwise processed after joining. For example, one or both of the skins **20**, **30** can include tabs **14** for use in gripping the skins **20**, **30** during manufacture, and the tabs **14** can be trimmed from the assembly **10** after the weld joints **60**, **62** are formed. In addition, the assembly **10** and/or members thereof can be subjected to heat treatments or other material processes before or after the joints **60**, **62** are formed, e.g., to improve and/or stabilize the material properties thereof.

The shims of the present invention can be similarly disposed between portions of various other structural assemblies. For example, the structural assembly **100** illustrated in Figures 8 and 8A can be used as a fuselage of an aircraft. The assembly **100** includes skin members **122** that are joined by longitudinally extending weld joints **160** so that the skin members **122** in combination define a generally cylindrical structure. Stringers **144**, which can be elongate, beam-shaped members, are joined to an inner surface **116** of the skin members **122** by weld joints **162**. The weld joints **160**, **162** can be formed by friction stir welding, as described above. In addition, shims **170** can be positioned between the various members **122**, **144** in spaces that are defined by the assembly **100** when the members **122**, **144** are assembled. For example, if a space exists between a portion of one of the stringers **144** and the inner surface **116** of the corresponding skin member **122**, one or more of the shims **170** can be disposed in the space. Similarly, one or more of the shims **171** can be disposed in a space between the skin members

122. During subsequent friction stir welding of the members **122, 144**, the shims **170, 171** can be partially or entirely consumed, as described above in connection with Figures 7A and 7B.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertains having the benefit of the teachings
5 presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

THAT WHICH IS CLAIMED:

1. A method of friction stir welding a rigid skin member to a rigid substructure to form a structural assembly, the method comprising:
 - disposing the skin member on the substructure such that the skin member and the
 - 5 substructure define a space therebetween;
 - disposing a shim in the space between the substructure and the skin member to substantially fill the space; and
 - friction stir welding the skin member to the substructure via the shim.
2. A method according to Claim 1, further comprising providing the substructure having a
- 10 plurality of joined members with an outer contour defining an airfoil.
3. A method according to Claim 1 wherein said friction stir welding step comprises welding a first skin member to a first side of the substructure, and further comprising friction stir welding a second skin member to a second side of the substructure opposite the first side, such that the substructure extends between the first and second skins on the opposite sides.
- 15 4. A method according to Claim 1 wherein said friction stir welding step comprises disposing a rotating friction stir welding tool through the skin member, through the shim, and into the substructure to thereby plasticize material of the skin member, the shim, and the substructure.
5. A method according to Claim 1 wherein said friction stir welding step comprises forming
- 20 an elongate weld joint along the skin member to connect the skin member to the substructure.
6. A method according to Claim 1, further comprising forming the shim to have a thickness that is nonuniform along at least a portion of the length of the shim such that the shim corresponds to a shape of the space between the skin member and the substructure.
7. A method of friction stir welding a plurality of skin members to a substructure to form a
- 25 structural assembly, the method comprising:
 - disposing first and second skin members on the substructure such that the skin members define a space between the first and second skin members;
 - disposing a shim in the space between the skin members; and
 - friction stir welding the first skin member to the second skin member via the shim.

8. A method according to Claim 7, further comprising providing the substructure having a plurality of joined members with an outer contour defining an airfoil.

9. A method according to Claim 7 wherein said friction stir welding step comprises welding the first and second skin members to a first side of the substructure, and further comprising
5 friction stir welding a third skin member to a second side of the substructure opposite the first side, such that the substructure extends between the third skin and the first and second skins on the opposite sides.

10. A method according to Claim 7 wherein said friction stir welding step comprises disposing a rotating friction stir welding tool through the shim and thereby plasticizing material
10 of the shim and the first and second skin members adjacent the shim.

11. A method according to Claim 10 wherein said friction stir welding step comprises disposing the friction stir welding tool through the shim and into the substructure to thereby plasticize material of the skin members, the shim, and the substructure.

12. A method according to Claim 7 wherein said friction stir welding step comprises forming
15 an elongate weld joint along the shim to thereby join the skin members along the shim.

13. A method according to Claim 7, further comprising forming the shim to have a width that is nonuniform along at least a portion of the length of the shim such that the shim corresponds to a shape of the space between the skin members.

14. A friction stir welded structural assembly comprising:
20 a rigid substructure defining an outer contour;
a rigid skin member disposed on the substructure at the outer contour of the substructure;
at least one shim disposed between the skin member and the substructure; and
at least one friction stir weld joint extending through the shim between the skin member and the substructure to connect the skin member to the substructure via the shim.

15. A structural assembly according to Claim 14 wherein the shim is formed of a material
25 that is dissimilar to a material of at least one of the skin member and the substructure.

16. A structural assembly according to Claim 14 wherein the substructure has a plurality of joined members with an outer contour defining an airfoil.

17. A structural assembly according to Claim 14 wherein the skin member is welded to a first side of the substructure, and further comprising a second skin member welded to a second side of the substructure opposite the first side.

18. A structural assembly according to Claim 14 wherein the friction stir weld joint extends
5 in an elongate direction along the length of the shim.

19. A structural assembly according to Claim 14 wherein the shim defines a thickness that is nonuniform along at least a portion of the length of the shim such that the shim corresponds to a shape of a space between the skin member and the substructure.

20. A friction stir welded structural assembly comprising:
10 first and second skin members disposed on a substructure;
a shim disposed between the first and second skin members; and
a friction stir weld joint extending through the shim between the first and second skin members to connect the skin members via the shim.

21. A structural assembly according to Claim 20 wherein the shim is formed of a material
15 that is dissimilar to a material of at least one of the skin members.

22. A structural assembly according to Claim 20 wherein the substructure has a plurality of joined members with an outer contour defining an airfoil.

23. A structural assembly according to Claim 20 wherein the skin members are welded to a first side of the substructure, and further comprising a third skin member welded to a second side
20 of the substructure opposite the first side.

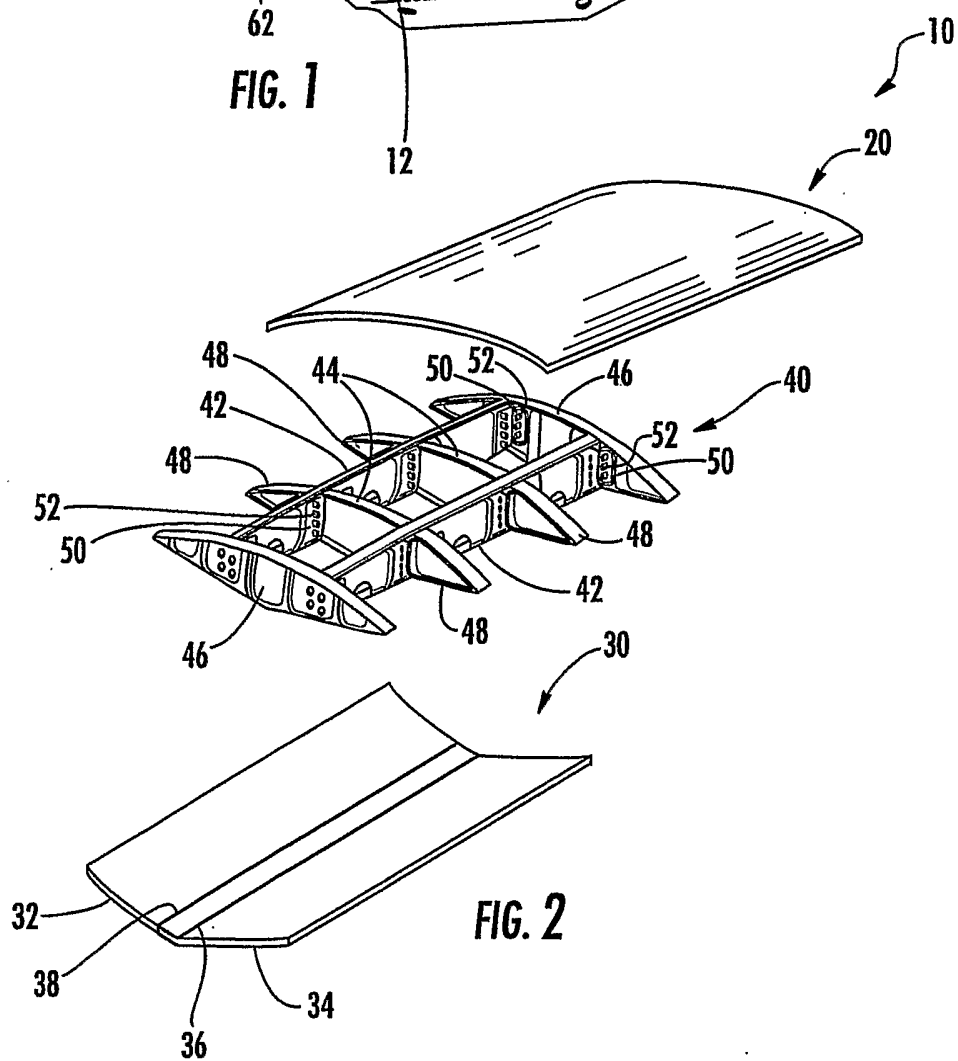
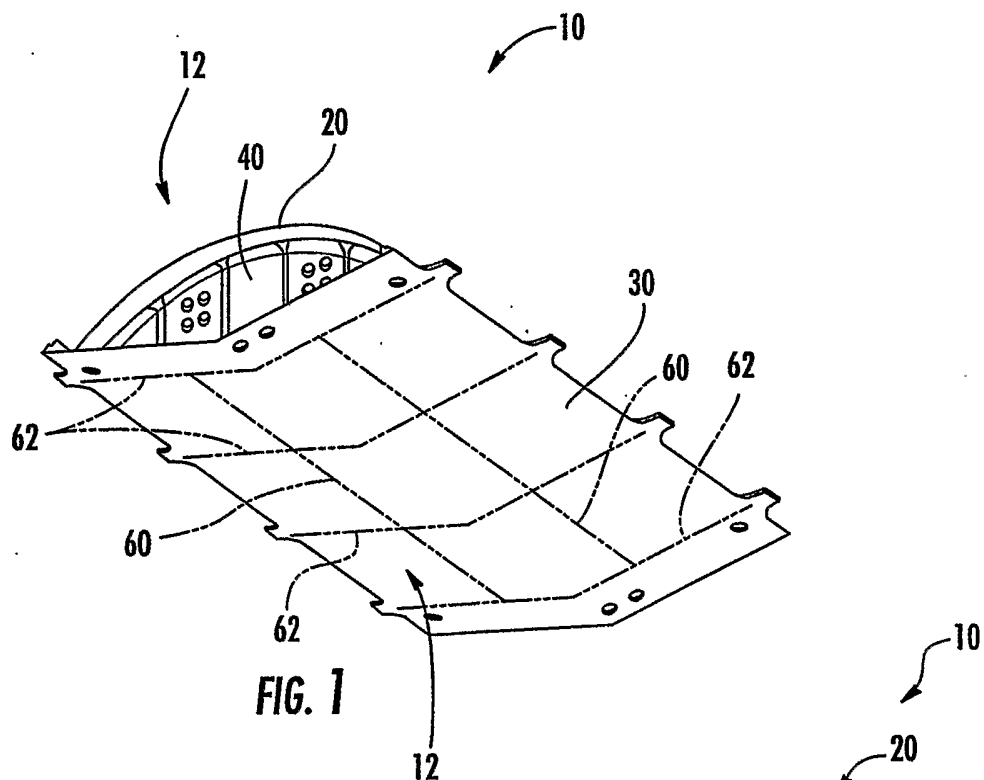
24. A structural assembly according to Claim 20 wherein the weld joint defines a width that extends in a transverse direction between the first and second skin members adjacent the shim.

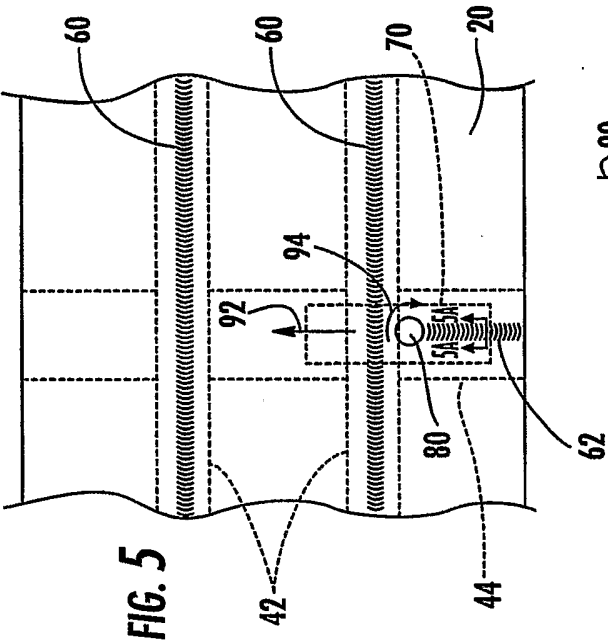
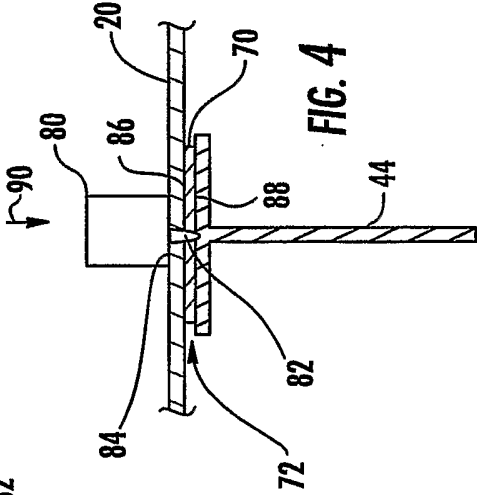
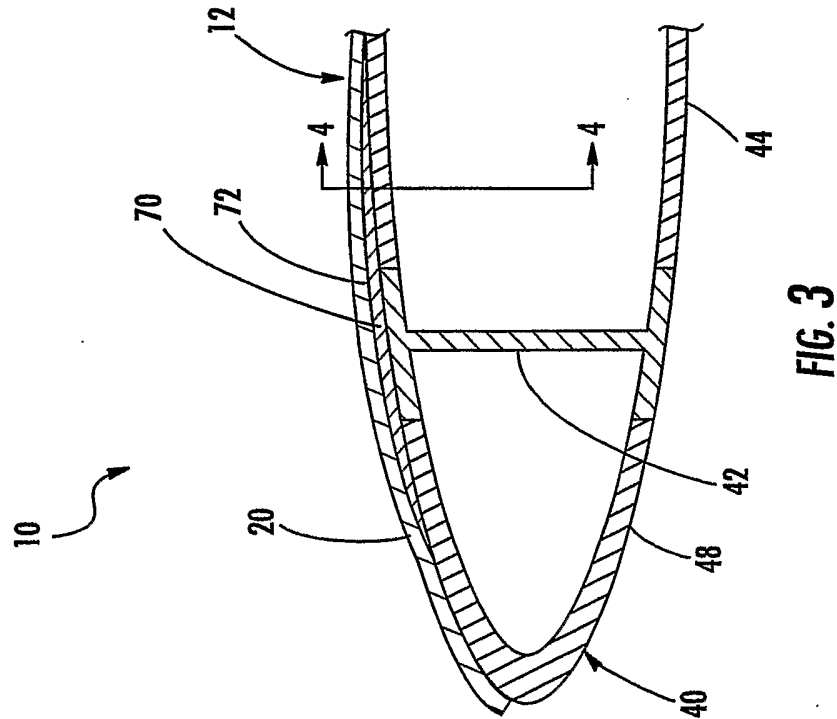
25. A structural assembly according to Claim 20 wherein the weld joint extends through the shim and into the substructure to thereby join the shim and skin members to the substructure.

25 26. A structural assembly according to Claim 20 wherein the weld joint extends in an elongate direction along the shim to thereby join the skin members along the shim.

27. A structural assembly according to Claim 20 wherein the shim defines a width that is nonuniform along at least a portion of the length of the shim such that the shim corresponds to a shape of the space between the skin members.

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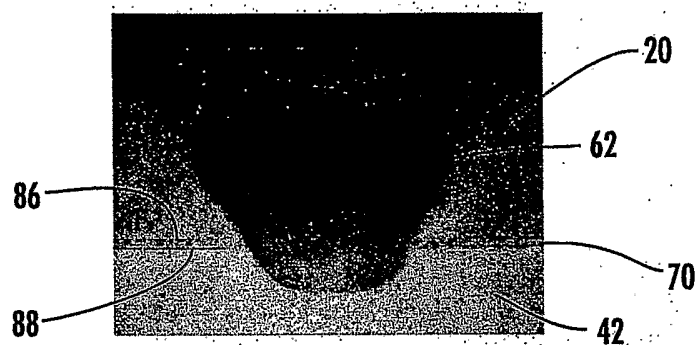


FIG. 5a

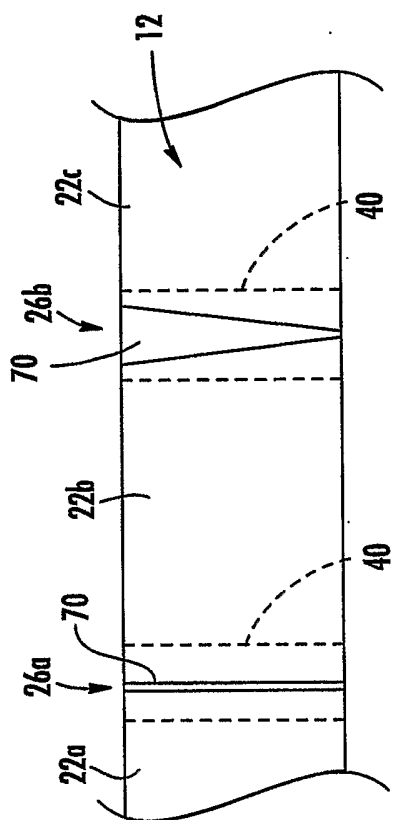


FIG. 7A

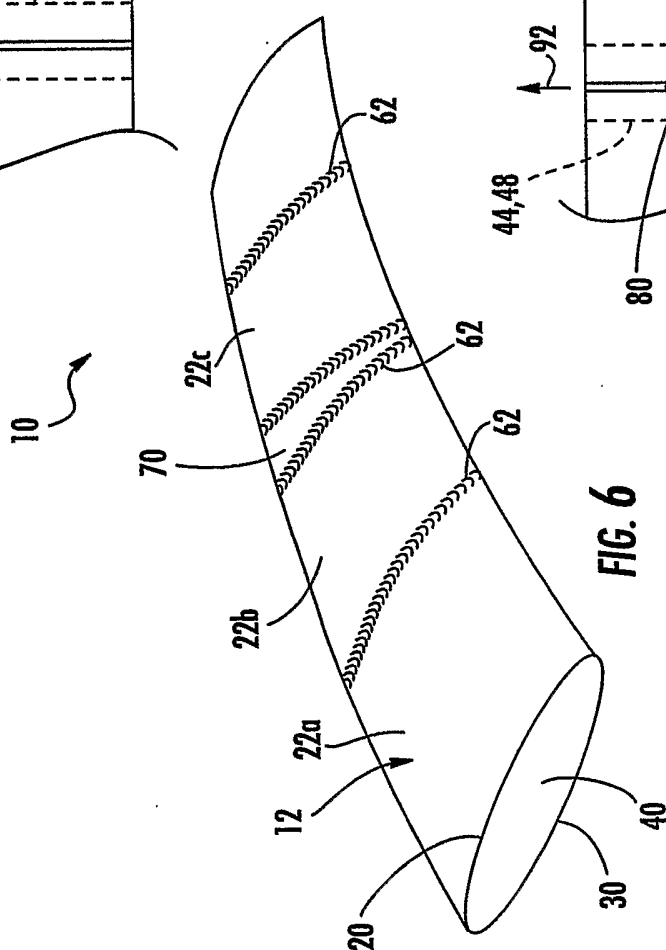


FIG. 6

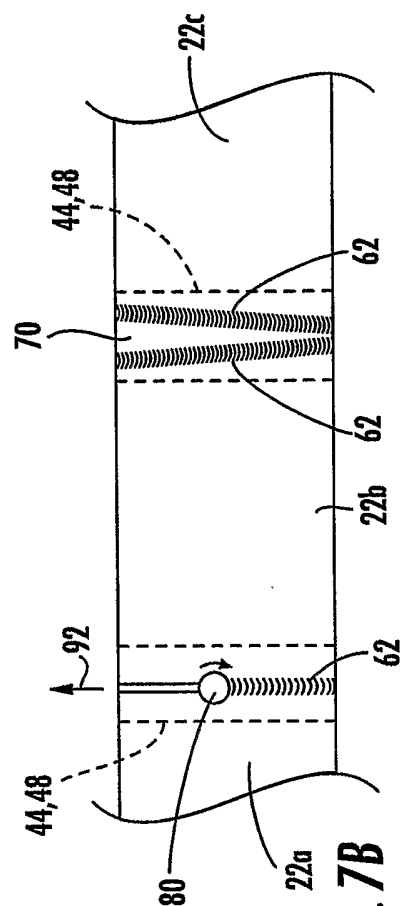


FIG. 7B

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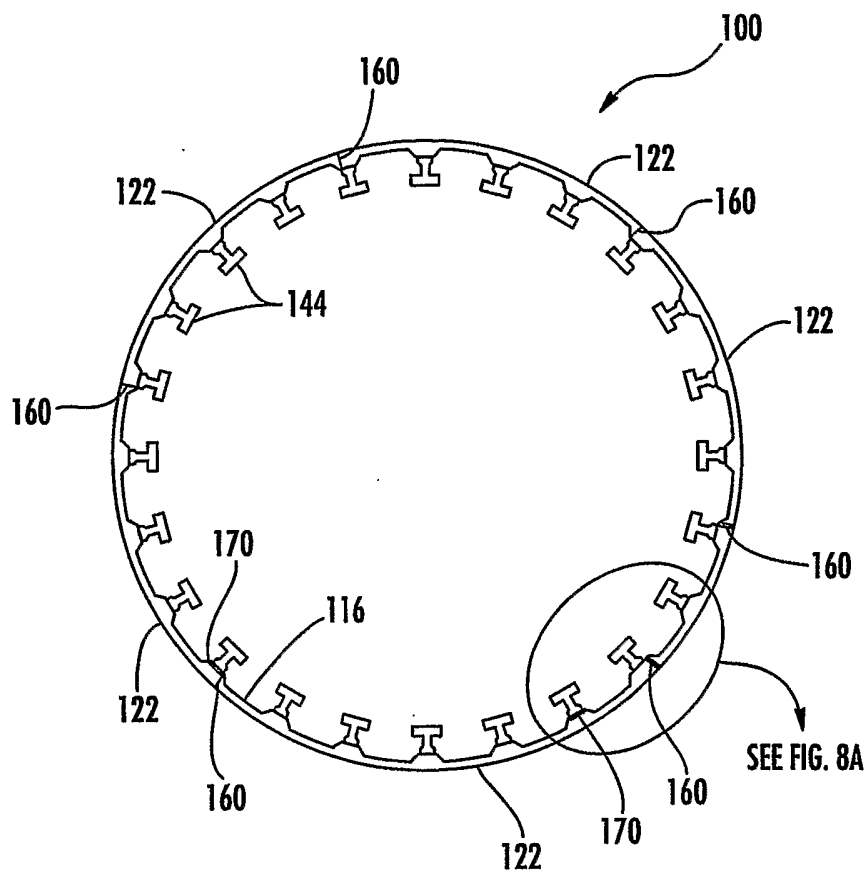


FIG. 8

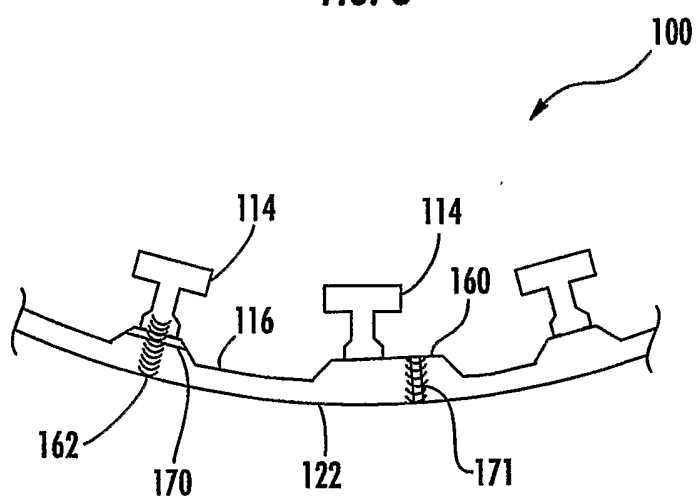


FIG. 8A