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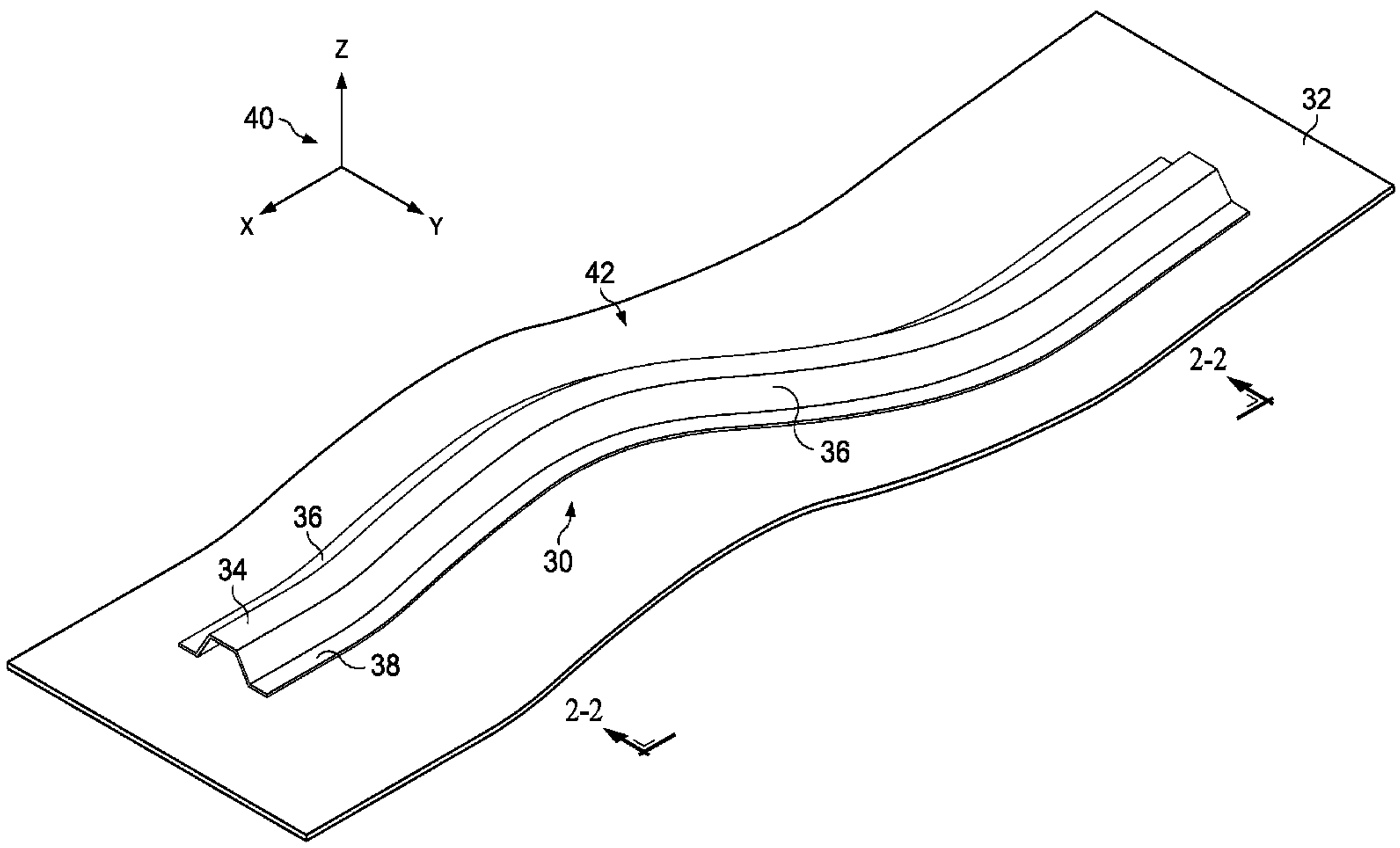
(54) **Titre :** COMPACTAGE D'ELEMENTS COMPOSITES NON DURCIS SUR DES SURFACES DE MANDRIN PROFILEES
(54) **Title:** COMPACTING UNCURED COMPOSITE MEMBERS ON CONTOURED MANDREL SURFACES



(57) **Abrégé/Abstract:**
An uncured composite member (30) is formed over a mandrel (66) having a contour using a flexible compactor (44). Forming is performed outwardly from the apex of the contour.

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(54) **Title**: COMPACTING UNCURED COMPOSITE MEMBERS ON CONTOURED MANDREL SURFACES

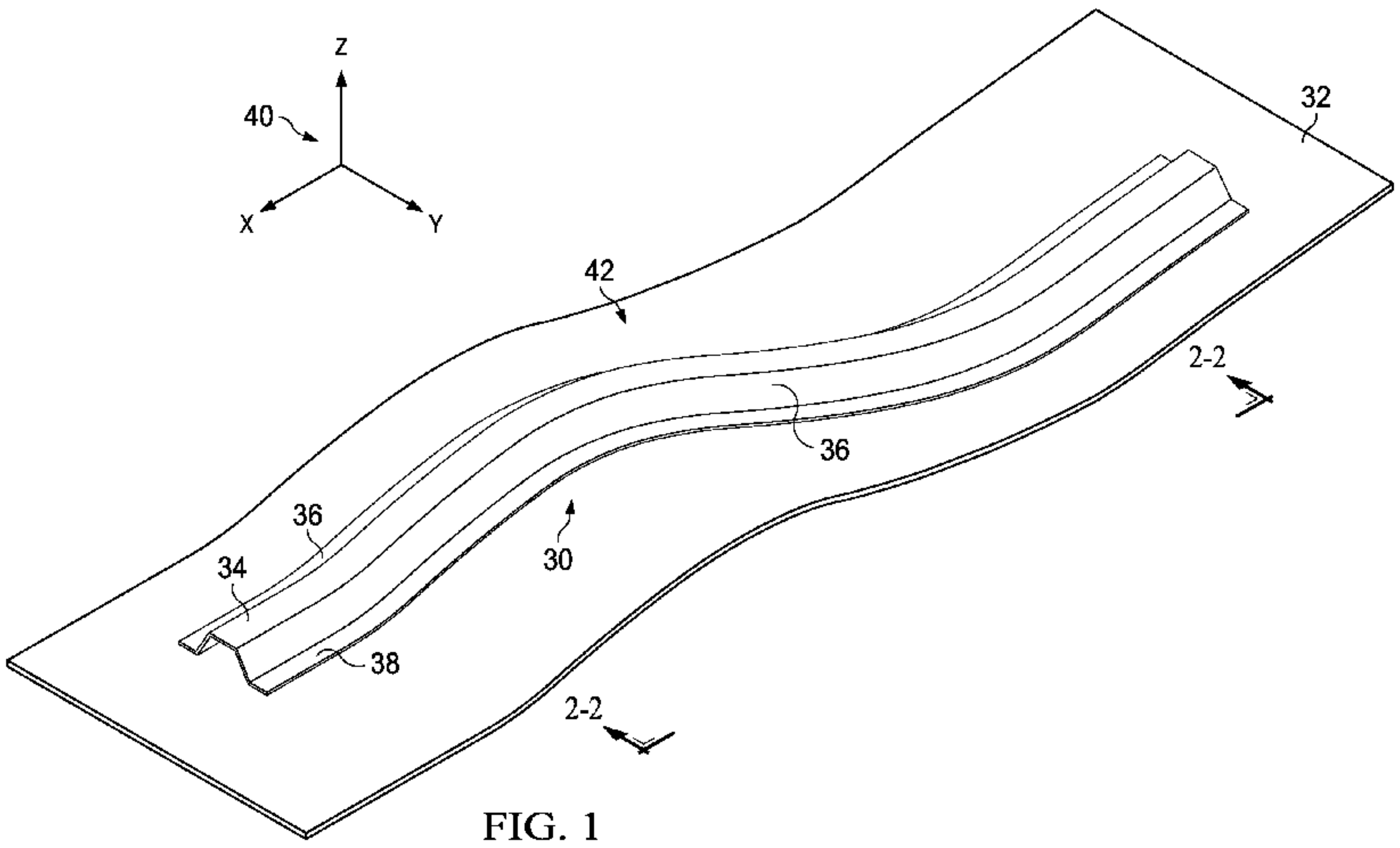

FIG. 1

(57) **Abstract**: An uncured composite member (30) is formed over a mandrel (66) having a contour using a flexible compactor (44). Forming is performed outwardly from the apex of the contour.

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COMPACTING UNCURED COMPOSITE MEMBERS ON CONTOURED MANDREL SURFACES

BACKGROUND INFORMATION

1. Field:

The present disclosure generally relates to processes for manufacturing composite structures, and deals more particularly with compaction of composite laminate stringers on contoured mandrel surfaces.

2. Background:

Elongate composite members such as stringers used in the aircraft industry may be contoured in one or more planes along their length to conform to the curvature of a structure such as a fuselage skin. Contouring of a stringer may be accomplished using a compactor to compact an uncured stringer layup against contoured surfaces of a mandrel, such as a cure tool. Flexible compactors have been developed which flex or bend, allowing them to conform to contoured tool surfaces during the compaction process.

Depending on the degree of tool contour, the uncured stinger layup may develop wrinkles as it is being compacted against the tool, particularly near the center of curvature or greatest contour of the tool. This wrinkling occurs as a result of bending of the layers of composite material nearest the contoured tool surface, placing them in compression. Compression of the material in this manner causes excess material to accumulate and bunch into wrinkles. Wrinkling may have an undesired effect on the performance of the cured stringer.

Accordingly, there is a need for a method of compacting uncured composite members, such as stringers, on contoured tools, which controls material wrinkling. There is also a need for a method of compacting a stringer on a cure tool using a flexible compactor that reduces the size of the wrinkles while distributing the wrinkles generally uniformly along the length of the stringer.

SUMMARY

Uncured composite members such as stringers may be bent to conform to a shaping mandrel such as a contoured cure tool, while avoiding the formation of relatively large wrinkles in the composite material. Any wrinkling of the composite material is limited to relatively small wrinkles which are distributed generally uniformly along the contoured areas of the stringer. The avoidance of large wrinkles results in stringers having improved structural performance and uniformity. Uniform distribution of material wrinkling is achieved using an apex forming method and a flexible compactor. During the apex forming, the flexible compactor is used to place and bend the uncured stringer against a contoured tool surface, beginning at the apex of the contour, and moving outwardly from the apex. The flexible compactor includes a series of transverse kerfs therein into which excess composite material may be received during the compaction process to allow controlled formation of relatively small material wrinkles which do not materially affect stringer performance.

In one embodiment there is provided a method of compacting an uncured composite member against a mandrel surface having a longitudinal contour and curing. The method involves adhering the uncured composite member to a flexible elongate compactor using a suction force, using the compactor to align the uncured composite member with the longitudinal contour of the mandrel surface, and using the compactor to bring the uncured composite member initially into contact with the mandrel surface at an apex of the longitudinal contour. The method further involves forming the uncured composite member over the contour of the mandrel surface outwardly from the apex, using the compactor to compact the uncured composite member against the mandrel surface, and curing the uncured composite member between the mandrel surface and the compactor.

The method may further include distributing any wrinkles that form in the uncured composite member during the forming by allowing material in the uncured composite member to become compressed into kerfs in the compactor.

The uncured composite member may have a neutral axis and the method may further include using the compactor to reduce wrinkling of the uncured composite member during forming by shifting the location of the neutral axis of the uncured composite member.

Forming the uncured composite member may include using the compactor to form a twist into the uncured composite member.

Forming the uncured composite member may be performed by drape forming the uncured composite member onto the mandrel surface.

The drape forming may include maintaining a substantially constant relationship between ends of the uncured composite member and the mandrel surface as the uncured composite member is being formed onto the mandrel surface.

Forming the uncured composite member may be performed by lash forming.

Lash forming may include reducing localized compressive forces in the uncured composite member adjacent the mandrel surface by inducing an S-shaped bend into the uncured composite member.

Forming the uncured composite member over the contour may be performed after the uncured composite member has been brought into initial contact with the mandrel surface at the apex.

Forming may be performed by forming the uncured composite member onto the mandrel surface progressively outwardly along the uncured composite member from the apex.

The uncured composite member may have a preselected positional attitude when it is brought into initial contact with the mandrel surface at the apex, and the positional attitude of outer sections of the uncured composite member are maintained substantially parallel to the preselected positional attitude as the uncured composite member is being formed over the contour of the mandrel surface.

Forming the uncured composite member may include bending the uncured composite member to a progressively smaller radius of curvature.

In another embodiment there is provided a composite member compacted by the method.

In another embodiment there is provided a method of controlling wrinkling of an uncured composite member during forming of a composite stringer over a longitudinal contour of a mandrel surface and curing. The method involves installing a flexible elongate compactor within the uncured composite member, adhering the uncured composite member to the compactor using a suction force, and aligning the uncured composite member with an apex of the longitudinal contour of the mandrel surface. The method further involves bringing the uncured composite member initially into contact with the mandrel surface at the apex using the compactor, forming the uncured composite member from the apex down onto the mandrel surface using the compactor to form an uncured composite stringer, and curing the uncured composite stringer between the compactor and mandrel surface.

The method wherein forming the composite stringer from the apex may include bending the composite stringer down against the mandrel surface and progressively outwardly from the apex.

Forming the composite stringer from the apex may include maintaining a substantially constant relationship between ends of the composite stringer and the mandrel surface.

Forming the composite stringer may be performed by one of drape forming and lash forming.

The method may further include installing a flexible compactor within the composite stringer; adhering the composite stringer to the compactor; and using the compactor to bring the composite stringer into contact with the mandrel surface at the apex, and to form the composite stringer from the apex down onto the mandrel surface.

Adhering the composite stringer to the compactor may be performed using a suction force.

Wrinkling of the uncured composite member may be controlled by allowing material of the uncured composite member to be compressed into the compactor.

Forming the composite stringer from the apex down onto the mandrel surface may be performed using a compactor, and the compactor may be used to encourage at substantially uniformly distribute wrinkles in the composite stringer.

In another embodiment there is provided a composite stringer having controlled wrinkles produced by the method.

In another embodiment there is provided a method of forming an uncured composite member into a contoured groove in a cure tool and curing. The method involves adhering the uncured composite member to a flexible elongate compactor using a suction force, using the compactor to bring the uncured composite member into initial contact with the cure tool at an apex of a longitudinal contour along the contoured groove, and using the compactor to form the uncured composite member down into and along the contoured groove and progressively outwardly from the apex. The method further involves using the compactor to distribute wrinkles formed in the uncured composite member during forming of the uncured composite member down into and along the contoured groove and curing the uncured composite member between the cure tool and the compactor.

Using the compactor to form the uncured composite member is performed by one of drape forming and lash forming.

In one embodiment there is provided a method of compacting an uncured composite member against a mandrel surface having a contour. The method comprises:

adhering the uncured composite member to a compactor;

using the compactor to align the uncured composite member with the contour of the mandrel surface;

using the compactor to bring the uncured composite member initially into contact with the mandrel surface at an apex of the contour;

forming the uncured composite member over the contour of the mandrel surface outwardly from the apex; and

using the compactor to compact the uncured composite member against the mandrel surface.

Any wrinkles that form in the uncured composite member during the forming may be distributed by allowing material in the uncured composite member to become compressed into kerfs in the compactor.

The uncured composite member may have a neutral axis and the method may further comprise:

using the compactor to reduce wrinkling of the uncured composite member during forming by shifting the location of the neutral axis of the uncured composite member.

Forming the uncured composite member may include using the compactor to form a twist into the uncured composite member.

Forming the uncured composite member may be performed by drape forming the uncured composite member onto the mandrel surface.

Drape forming may include maintaining a substantially constant relationship between ends of the uncured composite member and the mandrel surface as the uncured composite member is being formed onto the mandrel surface.

Forming the uncured composite member may be performed by lash forming.

Lash forming may include reducing localized compressive forces in the uncured composite member adjacent the mandrel surface by inducing an S-shaped bend into the uncured composite member.

Forming the uncured composite member over the contour may be performed after the uncured composite member has been brought into initial contact with the mandrel surface at the apex.

Forming may be performed by forming the uncured composite member onto the mandrel surface progressively outwardly along the uncured composite member from the apex.

The uncured composite member may have a preselected positional attitude when it is brought into initial contact with the mandrel surface at the apex, and the positional attitude of outer sections of the uncured composite member may be maintained substantially parallel to the preselected positional attitude as the uncured composite member is being formed over the contour of the mandrel surface.

Forming the uncured composite member may include bending the uncured composite member to a progressively smaller radius of curvature.

In another embodiment there is provided a composite member compacted by the method above.

In another embodiment there is provided a method of controlling wrinkling of an uncured composite stringer during forming of the composite stringer over a contour of a mandrel surface. The method comprises:

aligning the composite stringer with an apex of the contour of the mandrel surface; and,

bringing the composite stringer into contact with the mandrel surface at the apex; and

forming the composite stringer from the apex down onto the mandrel surface.

Forming the composite stringer from the apex may include bending the composite stringer down against the mandrel surface and progressively outwardly from the apex.

Forming the composite stringer from the apex may include maintaining a substantially constant relationship between ends of the composite stringer and the mandrel surface.

Forming the composite stringer may be performed by one of drape forming and lash forming.

The method may further include:

installing a flexible compactor within the composite stringer;

adhering the composite stringer to the compactor; and

using the compactor to bring the composite stringer into contact with the mandrel surface at the apex, and to form the composite stringer from the apex down onto the mandrel surface.

Adhering the composite stringer to the compactor may be performed using a suction force.

Forming the composite stringer from the apex down onto the mandrel surface may be performed using a compactor, and wrinkling of the composite stringer may be controlled by allowing material of the composite stringer to be compressed into the compactor.

Forming the composite stringer from the apex down onto the mandrel surface may be performed using a compactor, and the compactor may be used to encourage at substantially uniformly distribute wrinkles in the composite stringer.

In another embodiment, there is provided a composite stringer having controlled wrinkles produced by the method above.

In another embodiment there is provided a method of forming an uncured composite member into a contoured groove in a cure tool. The method comprises

adhering uncured composite number to a compactor;

using the compactor to bring the uncured composite member into initial contact with the cure tool at an apex of a contour along the contoured groove;

using the compactor to form the uncured composite member down into and along the contoured groove and progressively outwardly from the apex; and

using the compactor to distribute wrinkles formed in the uncured composite member during forming of the uncured composite member down into and along the contoured groove.

Using the compactor to form the uncured composite member is performed by one of drape forming and lash forming.

The features, functions, and advantages can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and advantages thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

Figure **1** is an illustration of a perspective view of a stringer contoured along its length in an XZ plane.

Figure **2** is an illustration of a cross-sectional view taken along the line **2-2** in Figure **1**.

Figure **3** is an illustration of a plan view of a stringer contoured along its length in XY plane.

Figure **4** is an illustration of a perspective view of a flexible compactor used to compact the stringers shown in Figures **1-3** against a cure tool.

Figure **5** is an illustration of a longitudinal sectional view of the compactor shown in Figure **4**, along with a stringer layup during compaction on a cure tool.

Figure **6** is an illustration of the area designated as FIG. **6** in Figure **5**.

Figure **7** is an illustration of a cross-sectional view showing the compactor removing a stringer from a forming die.

Figure **8** is an illustration of a cross-sectional view showing the compactor indexed and aligned in readiness for forming the stringer into a contoured cure tool cavity.

Figure **9** is an illustration of a cross-sectional view showing the stringer having been formed into the contoured tool cavity, and a vacuum bag having been installed in preparation for curing the stringer.

Figure **10** is an illustration of a cross-sectional view showing the compactor being lifted away from the stringer following curing.

Figure **11** is an illustration of a perspective view of a portion of a stringer, useful in explaining stresses on the stringer as it is being formed into the cure tool.

Figure **12** is an illustration of an end view of the stringer shown in Figure **11**, showing the centroid and neutral axis of the stringer.

Figure **13** is an illustration of a longitudinal side view of a stringer, in which the stringer has been brought into initial contact with the apex of a contoured mandrel surface in preparation for apex forming of the stringer.

Figure **14** is an illustration of a diagram useful in explaining the apex forming method using a lash technique.

Figure **15** is an illustration of the area designated as FIG. **15** in Figure **14**.

Figure **16** is an illustration of a diagram useful in explaining the apex forming method using a draping technique.

Figure **17** is an illustration showing the progressive shaping of the stringer during apex forming using the draping technique.

Figure **18** is an illustration of a flow diagram of a method of fabricating a stringer that includes use of the apex forming method.

Figure **19** is an illustration of a flow diagram of aircraft production and service methodology.

Figure **20** is illustration of a block diagram of an aircraft.

DETAILED DESCRIPTION

The disclosed embodiments may be employed in the fabrication of an elongate, composite member that is contoured or curved in one or more planes. For example, referring to Figures **1** and **2**, a composite fuselage stringer **30** is attached by any suitable means to a skin **32**. The stringer **30** possesses a hat shaped cross-sectional shape, comprising a cap **34**, inclined sidewalls or webs **36**, and outwardly turned, substantially flat flanges **38**. Other cross sectional shapes are possible. In this example, the stringer **30** possesses a contour **42** lying in the XZ plane of an orthogonal coordinate system **40**. The stringer **30** may comprise a multi-ply composite laminate, such as, without limitation, CFRP (carbon fiber reinforced plastic). It should be noted here that while a stringer **30** has been illustrated, the disclosed embodiments may be employed to fabricate any of a variety of elongate, composite members that have one or more curvatures in one or more planes.

As shown in Figure **3**, the stringer **30** may be contoured **42** in other planes, such as in the XY plane. In still other examples, the stringer **30** may be contoured in multiple planes. As will be discussed below in more detail, the stringer **30** is fabricated by laying up and forming prepreg to the desired cross-sectional shape. A compactor **44** (Figure **4**) is used to form the uncured stringer **30** into a contoured cure tool **68** (Figure **8**), and then compact it during a cure cycle.

Referring now to Figure **4**, a compactor **44** may be used to assist in transporting, placing, forming and compacting the uncured stringer **30**. The stringer **30** is releasably held or adhered to the compactor **44** using a vacuum or suction force which will be discussed below. The compactor **44** is generally semi-rigid, with a degree of flexibility that allows it to flex and conform to contoured tool surfaces **66** (see Figure 5) during placement and compaction of the stringer **30**. The compactor **44** may be constructed of materials that are suitable for the application such as, without limitation, a combination of CFRP and elastomer rubber. The compactor **44** functions both as a device for installing and forming the stringer **30**, and for controlling the cross-sectional shape of the formed stringer **30** as it is being cured. The vacuum adherence of the stringer **30** to the compactor **44** may reduce the risk of damage to the stringer **30** during handling, and controls the stringer **30** during installation onto a contoured mandrel surface such as a cure tool **68** (see Figure **5**).

The compactor **44** broadly comprises a hat section **46**, a flange section **52** and end walls **48** defining a generally open interior space **58**. The hat section **46** includes a plurality of longitudinally spaced, transversely extending slits or kerfs **54** which provide the compactor **44** with flexibility, and allow air to be drawn into the open interior space **58**. The vacuum fittings **50** in either, or both end walls **48**, are adapted to be coupled with a vacuum source (not shown) for evacuating the open interior space **58**. Although not shown in Figure **4**, the flange section **52** may include one or more sections or joints along its length which are flexible, allowing the compactor **44** to flex in either or both of the XY and XZ planes.

The vacuum created within the open interior space **58** causes air to be drawn in through the kerfs **54**, producing a vacuum suction force **55**. This vacuum suction force grips the uncured stringer **30**, causing it to adhere and cling to the compactor **44** during the transport, placement and compaction processes. More particularly, the cap **34** and the webs **36** of the stringer **30** are adhered to the hat section **46** of the compactor **44** due to the vacuum suction force **55**, while the flanges **38** of the stringer **30** are in face-to-face contact with, but are not adhered to the flange section **52** of the compactor **44**. The vacuum adhesion of the stringer **30** to the compactor **44** may also permit a more symmetrical distribution of ply wrinkling and gathering during stringer compaction, as will be discussed below in greater detail. Moreover, the compactor **44** induces acceptable wrinkles **60**a at the locations of the kerfs **54**. "Acceptable wrinkles or wrinkling", as used herein, refers to wrinkles which are sufficiently small in size and generally distributed along a sufficient length such that they do not have a material impact of the performance of the cured stinger **30** in-service, when placed under load.

Referring now to Figures **5** and **6**, the compactor **44** may be used to form and compact the uncured stringer **30** onto a contoured surface **66** of a cure tool **68** or similar contoured mandrel surface. In Figure **5**, the compactor **44** is shown having flexed in the XZ plane, to form the stringer **30** down onto the contoured surface **66** of the cure tool **68**. The vacuum adhesion of the stringer **30** to the compactor **44** may aid in encouraging desired planar ply slippage between the outer plies (closest to the compactor **44**) and the inner plies (closest to the cure tool surface **66**) during this forming process. The method used to align, initially engage and then form the stringer **30** onto the contoured surface **66** will be hereinafter referred to as an "apex" forming method.

The apex forming method results in the distribution of excess stringer material **60** along the length of the stringer **30** facing the contoured tool surface **66**. This distributed, excess stringer material **60** is allowed and encouraged to move partially into the kerfs **54** under the compaction force applied to the stringer **30** by the compactor **44**. The excess stringer material **60** which is under compression **78** (see Figure **6**), forms into a series of distributed, relatively small acceptable wrinkles **60**a respectively within the kerfs **54**. Because of the relatively small size of the wrinkles **60**a, and the fact that they are distributed generally uniformly along a sufficient the length of the stringer **30**, stress concentrations within the cured stringer **30** under load, caused by material wrinkling, are substantially reduced or eliminated. The location and distribution of the wrinkles **60**a is dependent in part, upon the distance

"D" between the kerfs **54**. The distance "D" between the kerfs **54** may be generally constant along the length of the compactor **44** to produce a substantially even distribution of the wrinkles **60**a. However, in some embodiments, it may be desirable to tailor the distribution of the wrinkles **60**a such that they are not evenly distributed. As the number of kerfs **54** provided in the compactor **44** increases, the number of induced wrinkles likewise increases while the size of each of the induced wrinkles decreases. Also, as the number of kerfs **54** increase, the ability of the compactor **44** to bend around tool surfaces with tighter radii increases. Generally, it may be desirable to increase the number of wrinkles **60**a while decreasing their size to the point that the wrinkles **60**a have a substantially negligible effect on the performance of the stringer **30** when placed in service.

Figures **7-10** illustrate the sequential steps of forming, transporting, placing, forming and compacting the stringer **30** on the contoured surface **66** of a cure tool **68** using the compactor **44**. A prepreg layup may be formed into a desired hat shaped cross-section using any of various techniques, such as by stamp forming a flat layup (not shown) between male and female dies (only the female die **64** is shown in Figure **7**), or by the vacuum bag forming a flat layup onto a male die (not shown).

With the stringer **30** having been formed to the desired cross-sectional shape, for example in a female die **64**, the compactor **44** is placed in the stringer **30** such that the hat section **46** of the compactor **44** engages webs **36** and the cap **34** of the stringer **30**, and the flange section **38** of the compactor **44** overlies and engage the flanges **38** of the stringer **30**. Depending upon the material and surface finish from which the compactor **44** is formed, it may be necessary to install a release agent, such as a peel ply, between the compactor **44** and the stringer **30**. For example, and without limitation a layer (not shown) of FEP (fluorinated ethylene propylene) film may be taped to the compactor **44**, covering the hat section **46** of the compactor **44**. Vertical slits (not shown) may be formed in the FEP film along the length of the compactor **44** to allow air to flow through the film and into the kerfs **54** of the compactor **44**.

The stringer **30** and the compactor **44** may remain in the female die **64** which may be used as a holding fixture to maintain the shape of the stringer **30** until the stringer **30** is ready to be removed and transported for placement. Optionally, the stringer **30** may be transferred to a holding fixture (not shown) until ready for transfer to a cure tool **68**. In order to remove stringer **44** from the female die **64** (or an optional holding fixture), a vacuum is drawn within the compactor **44** which draws air in through the kerfs **54** (Figures **4-6**) to create a suction force that causes the stringer **30** to adhere to and be gripped by the compactor **44**.

With the stringer **30** adhered to the compactor **44** along its length, the stringer **30** and compactor **44** behave as a single unit during subsequent processing, including forming onto the cure tool **68**. In order to control wrinkling of the stringer **30** during subsequent processing, the vacuum causing the stringer **30** to adhere to the compactor **44** is maintained until the stringer **30** has been formed onto the cure tool **68**. In order to assure that the stringer **30** is not dis-bond from the compactor **44** during the forming process, it may be necessary to adjust the forming rate relative to the amount of vacuum force applied to the stringer **30** to allow the stringer **30** to bend slowly along with bending of the compactor **44**. The vacuum-generated adhesion force adhering the stringer **30** to the compactor **44** must be stronger than the localized bending forces induced in the stringer **30** in order to disperse the wrinkles **60**a along the stringer **30**.

As shown in Figure **7**, with the stringer **30** adhered to the compactor **44**, the compactor **44** is lifted along with the stringer **30** away from female die **64**, and is used to transport the stringer **30** to a forming mandrel such as the cure tool **68** shown in Figure **8**. The cure tool **68** has contoured tool surfaces **66** forming a contoured tool cavity or groove **70**. The contoured tool surfaces **66** are curved or contoured in at least one plane and substantially match the outer mold line (OML) surface (not shown) of the stringer **30**.

The compactor **44** is used to place and form the stringer **30** onto the contoured tool surfaces **66**, along the length of the tool cavity **70**, as shown in Figure **8**. As will be later discussed, the compactor **44** flexes to conform to the contoured surfaces **66** of the tool cavity **70**, causing the stringer **30** to also be formed to the contoured shape of the tool cavity **70**. According to the disclosed apex method of forming, any wrinkling of the stringer **30** as it is being formed down into the contoured tool cavity **70** will be limited to relatively small scale "acceptable" wrinkles that are generally evenly distributed along the length of the stringer **30**.

With the compactor **44** and the stringer **30** having been formed into the tool cavity **70**, a vacuum bag **62** (Figure **9**) is installed over the compactor **44** and the stringer **30**, and a vacuum is drawn in the bag **62** which, along with the compactor **44**, compacts the layup **30** against the contoured tool surfaces **66**. Following compaction of the stringer **30**, as shown in Figure **10**, the compactor **44** is drawn away from the stringer **30**. In some applications, it may be desirable to apply a tackifier to the contoured tool surfaces **66** prior to installation of the stringer **30** and the cure tool **68** in order to aid separation of the compactor **44** from the cured stringer **30** following curing. The stringer **30** may then be further processed. For example, fillers (not shown) may be installed in the stringer **30**, one or more bladders (not shown) may be installed against the stringer **30**, the stringer **30** may be attached to the skin **32** (Figure **1**) or other structure, and cured in an autoclave (not shown).

Attention is now directed to Figures **11** and **12** which illustrate stresses acting upon the stringer **30** when it is being formed onto contoured tool surfaces **66** of a mandrel, such as the cure tool **68** previously described. The stringer **30** may be formed along a curvature (not shown in figure **11**) in either the XY or the XZ planes. The geometry of the stringer **30** will determine which of these two planes has the most influence on the installation. Regardless of the particular cross-sectional geometry of the stringer **30**, the stringer **30** possesses a neutral axis **80**, and a centroid or geometric center **82**. In Figure **11**, the location of the neutral axis **80** is shown when forming the stringer **30** in the XY plane, while figure **12** shows the location of the neutral axis **80** when forming the stringer **30** in the XZ plane.

Referring to Figure **11**, when the stringer **30** is formed along a curvature in the XY plane, a bending moment **M** about the Z axis (axis of moment induction) is produced which causes one side of the stringer **30** be placed in tension **76**, and the other side of the stringer **30** to be placed in compression **78**. The neutral axis **80** shown in Figure **12** is substantially perpendicular to the neutral axis **80** shown in Figure **11** because the XZ and XY planes are perpendicular to each other, and likewise, the axes of momentum (the Y axis and the Z axis) are perpendicular to each other. The neutral axis **80** of the stringer **30** is a line or plane within the cross section of the stringer **30** at which no extension or compression of the stringer **30** occurs when it is bent, as occurs when the stringer **30** is being formed into a tool cavity **70** (Figure **8**) that is curved in either or both of the XY and XZ planes. Referring to Figure **12**, when the stringer **30** is formed along a curvature in the XZ plane, a bending moment **M** is produced about the neutral axis **80** (the Y axis) which causes the area **81** above the neutral axis **80** to be placed in tension, and the area **83** below the neutral axis **80** to be placed in compression.

The area **83** of the stringer **30** below the neutral axis **80** is the area most likely to wrinkle because it is loaded into compression **78** as the stringer **30** is being formed in either the XY or XZ planes. In contrast, the area **81** that is in tension **76** during forming experiences a relatively small amount of strain, and thus normally does not wrinkle. The compression **78** below the neutral axis **80** causes a wrinkle **60**a (see Figure **6**) to be formed in the stringer **30** as the stringer **30** is being bent to a progressively smaller radius of curvature during a forming process, because the same amount of stringer material is being conformed to a smaller radius within the area **83** below the neutral axis **80**. In effect, the flexible compactor **44** functions to shift **85** (Figure **12**) the neutral axis **80** downwardly, toward the cap **34** of the stringer **30**. As a result of the neutral axis **80** being shifted **85** downwardly, the amount of compression in the area **83** below the neutral axis **80** within the stringer **30** is reduced, and less wrinkling occurs in this area due to the reduced compressive forces.

As previously discussed, apex forming is used to form the stringer **30** into and along the contoured tool cavity **70** (Figure **8**) in order to control wrinkling of the stringer **30** during the forming process. Figure **13** diagrammatically illustrates the apex forming method, generically. A cure tool **68** has a contoured tool surface **66** over which a substantially straight stringer **30** is to be formed by bending it to a progressively smaller radius of curvature until it conforms to the curvature of the contoured tool surface **66**. The straight stringer **30** comprises a stack of substantially planar plies of uncured composite material such as pre-preg. The curvature of the contoured tool surface **66** has an apex **84** which corresponds to the point of maximum curvature on tool surface **66**. With the stringer **30** adhered to the compactor **44** (as shown in Figure **8**), the compactor **44** is used to align and index the stringer **30** relative to the cure tool **68**. The compactor **44** then initially brings the stringer **30** into contact with the tool surface **66** at the apex **84**. After this initial contact at the apex **84**, the stringer **30** is formed down **72** onto the contoured tool surface **66** and into the tool cavity **70** (Figure **8**). The particular technique used to form the stringer **30** down onto the contoured tool surface **66** after compaction at the apex **84** will depend upon whether the stringer **30** is being formed in the XY or the XZ plane, as will be discussed below. In applications where the tool surface **66** has compound contours and it is necessary to form the stringer **30** in both the XY and XZ planes, the compactor **44** may flex simultaneously in both the XY and XZ planes. The compactor **44** may also form a torsional twist into the stringer **30** during the forming process, either independently of, or in addition to flexing in either of the XY and XZ planes.

Figures **14** and **15** illustrate apex forming of a stringer **30** onto a contoured mandrel surface **66**, such as that of a contoured cure tool **68**, contoured in the XZ plane, using a lash forming technique. The sequential positions and bend shapes of the stringer **30** are respectively designated by the letters “A-D” in Figure **14**, and the individual laminate plies **90** of the stringer **30** are shown in Figure **15**. During this lash forming, the outer sections **74** not already in contact with the tool surface **66** are held substantially parallel to the initial positional attitude (designated by the letter “A”) of the stringer **30** when it initially comes into contact with apex **84**. Lash forming of the stringer **30** in this manner induces an "S" bend **87** (see Figure **15**) into the stringer **30**. The formation of the "S" bend **87** shifts the location within the stringer **30** where tensile and compressive forces **76**, **80** respectively are acting. Inducing an "S" bend **87** into the plies **90** of the stringer **30** helps spread the wrinkling of the plies by reducing the localized compressive forces in the area adjacent the contoured tool surface **66** where wrinkling may be expected to occur.

Figures **16** and **17** illustrate apex forming of a stringer **30** contoured in the XY plane, using the compactor **44** to carry out a drape forming technique. The compactor is aligned and indexed such that it initially brings the stringer **30** into a first point of contact “A” corresponding to the apex **84** of the contoured tool surface **66**. The stringer **30** is then evenly draped onto the cure tool **68**, into the contoured tool cavity **70** (Figure **8**), by bending the stringer **30** about the apex **84**. The letters “B”, “C”, “D” and “E” in Figure **16** respectively represent simultaneous points of contact between the stringer **30** and the tool surface **66** as the bending process progresses. The corresponding bent positions of the stringer **30** are likewise designated in Figure **17** by the letters “B’”, “C’”, “D’” and “E’”. During the bending process, the relationship of the distances **92**, **94** (Figure **16**) between the ends of the stringer **30** and the tool surface **66** is maintained substantially constant in order to maintain an attitude of the stringer **30** that results in substantially even bending about the apex **84**. As previously noted, during this forming process, the vacuum adhesion of the stringer **30** to the compactor **44** may aid in encouraging desired slippage between the planar plies of the stringer **30**.

Attention is now directed to Figure **18** which broadly illustrates the steps of a method of fabricating a contoured composite stringer **30** using the apex forming method and the compactor **44** described above. Beginning at **96**, a stringer charge is laid up and trimmed as necessary. The stringer layup is then formed to the desired stringer cross-sectional shape at step **98**. Optionally, at step **100**, a suitable perforated release film such as FEP, may be placed over and adhered to the compacting surface of a flexible compactor **44**. The perforations allow vacuum airflow through the film and may be formed, for example and without limitation, by creating a series of slits in the film. At step **102**, the compactor **44** is installed into the cavity of the formed the stringer **30**.

At **104**, a vacuum is generated within the compactor **44** which adheres the stringer **30** to the compactor **44**, effectively causing the compactor **44** to grip the stringer **30**. At **106**, the compactor **44** may be used to remove and transport the stringer **30** to a contoured forming mandrel, which may comprise a cure tool **68**. As the stringer **30** is being removed and transported, vacuum is held within the compactor **44** to maintain adherence between the compactor **44** and the stringer **30**. At **108**, the apex **84** of the contoured mandrel or cure tool **68** is located, and may be marked as a reference starting point to aid in the subsequent forming process. At step **110**, the compactor **44** is used to align and bring the stringer **30** initially into contact with the contoured mandrel surface or cure tool **68**, at the apex **84** of the contoured tool surface **66**.

At **112**, the compactor **44** is used to bend the stringer **30** down onto the mandrel or cure tool surface **66**, substantially evenly, outward from the apex, using either the drape forming or lash forming technique previously described. During the bending process, the compactor **44** along with the stringer **30** flexes to conform to the contour of the mandrel or tool **68**, causing the stringer material to wrinkle in a substantially even distribution along the length of the stringer contour. At **114**, the formed stringer **30** may be vacuum bagged and then compacted at room temperature using the compactor **44**, during which the vacuum within compactor **44** is maintained. At step **116**, the stringer **30** is debagged, and the vacuum within the compactor **44** is released, allowing removal of the compactor **44** and the stringer **30** from the cure tool **68**.

Embodiments of the disclosure may find use in a variety of potential applications, particularly in the transportation industry, including for example, aerospace, marine, automotive applications and other applications where contoured elongate composite members, such as stringers, may be used. Thus, referring now to Figures **19** and **20**, embodiments of the disclosure may be used in the context of an aircraft manufacturing and service method **118** as shown in Figure **19** and an aircraft **120** as shown in Figure **20**. Aircraft applications of the disclosed embodiments may include, for example, without limitation, elongate stiffener members such as stringers used in the airframe **136** of the aircraft **120**. During pre-production, exemplary method **118** may include specification and design **122** of the aircraft **120** and material procurement **124**. During production, component and subassembly manufacturing **126** and system integration **128** of the aircraft **120** takes place. Thereafter, the aircraft **120** may go through certification and delivery **130** in order to be placed in service **132**. While in service by a customer, the aircraft **120** is scheduled for routine maintenance and service **134**, which may also include modification, reconfiguration, refurbishment, and so on.

Each of the processes of method **118** may be performed or carried out by a system integrator, a third party, and/or an operator (e.g., a customer). For the purposes of this description, a system integrator may include without limitation any number of aircraft manufacturers and major-system subcontractors; a third party may include without limitation any number of vendors, subcontractors, and suppliers; and an operator may be an airline, leasing company, military entity, service organization, and so on.

As shown in Figure **20**, the aircraft **120** produced by exemplary method **118** may include an airframe **136** with a plurality of systems **138** and an interior **140**. Examples of high-level systems **138** include one or more of a propulsion system **142**, an electrical system **144**, a hydraulic system **146** and an environmental system **148**. Any number of other systems may be included. Although an aerospace example is shown, the principles of the disclosure may be applied to other industries, such as the marine and automotive industries.

Systems and methods embodied herein may be employed during any one or more of the stages of the production and service method **118**. For example, components or subassemblies corresponding to production process **126** may be fabricated or manufactured in a manner similar to components or subassemblies produced while the aircraft **120** is in service. Also, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during the production stages **126** and **128**, for example, by substantially expediting assembly of or reducing the cost of an aircraft **120**. Similarly, one or more of apparatus embodiments, method embodiments, or a combination thereof may be utilized while the aircraft **120** is in service, for example and without limitation, to maintenance and service **134**.

As used herein, the phrase "at least one of", when used with a list of items, means different combinations of one or more of the listed items may be used and only one of each item in the list may be needed. For example, "at least one of item A, item B, and item C" may include, without limitation, item A, item A and item B, or item B. This example also may include item A, item B, and item C or item B and item C. The item may be a particular object, thing, or a category. In other words, "at least one of" means any combination items and number of items may be used from the list but not all of the items in the list are required.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different advantages as compared to other illustrative embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

EMBODIMENTS IN WHICH AN EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS FOLLOWS:

1. A method of compacting an uncured composite member against a mandrel surface having a longitudinal contour and curing, comprising:

adhering the uncured composite member to a flexible elongate compactor using a suction force;

using the compactor to align the uncured composite member with the longitudinal contour of the mandrel surface;

using the compactor to bring the uncured composite member initially into contact with the mandrel surface at an apex of the longitudinal contour;

forming the uncured composite member over the contour of the mandrel surface outwardly from the apex;

using the compactor to compact the uncured composite member against the mandrel surface; and

curing the uncured composite member between the mandrel surface and the compactor.

2. The method of claim **1**, further comprising:

distributing any wrinkles that form in the uncured composite member during the forming by allowing material in the uncured composite member to become compressed into kerfs in the compactor.

3. The method of claim **1**, wherein the uncured composite member has a neutral axis and the method further comprises:

using the compactor to reduce wrinkling of the uncured composite member during forming by shifting the location of the neutral axis of the uncured composite member.

4. The method of claim **1**, wherein forming the uncured composite member further comprises using the compactor to form a twist into the uncured composite member.

5. The method of claim **1**, wherein forming the uncured composite member is performed by drape forming the uncured composite member onto the mandrel surface.

6. The method of claim **5**, wherein the drape forming further comprises maintaining a substantially constant relationship between ends of the uncured composite member and the mandrel surface as the uncured composite member is being formed onto the mandrel surface.

7. The method of claim **1**, wherein forming the uncured composite member is performed by lash forming.

8. The method of claim **7**, wherein the lash forming further comprises reducing localized compressive forces in the uncured composite member adjacent the mandrel surface by inducing an S-shaped bend into the uncured composite member.

9. The method of claim **1**, wherein:

the uncured composite member has a preselected positional attitude when it is brought into initial contact with the mandrel surface at the apex, and

the positional attitude of outer sections of the uncured composite member are maintained substantially parallel to the preselected positional attitude as the uncured composite member is being formed over the contour of the mandrel surface.

10. The method of claim **1**, wherein forming the uncured composite member further comprises bending the uncured composite member to a progressively smaller radius of curvature.

11. A composite member compacted by the method of claim **1**.

12. A method of controlling wrinkling of an uncured composite member during forming of a composite stringer over a longitudinal contour of a mandrel surface and curing, comprising:

installing a flexible elongate compactor within the uncured composite member;

adhering the uncured composite member to the compactor using a suction force;

aligning the uncured composite member with an apex of the longitudinal contour of the mandrel surface; and,

bringing the uncured composite member initially into contact with the mandrel surface at the apex using the compactor;

forming the uncured composite member from the apex down onto the mandrel surface using the compactor to form an uncured composite stringer; and

curing the uncured composite stringer between the compactor and mandrel surface.

13. The method of claim **12**, wherein forming the uncured composite member from the apex comprises bending the uncured composite member down against the mandrel surface and progressively outwardly from the apex.

14. The method of claim **12**, wherein forming the uncured composite member from the apex comprises maintaining a substantially constant relationship between ends of the uncured composite member and the mandrel surface.

15. The method of claim **12**, wherein forming the uncured composite member is performed by one of drape forming and lash forming.

16. The method of claim **12**, wherein:

wrinkling of the uncured composite member is controlled by allowing material of the uncured composite member to be compressed into the compactor.

17. The method of claim **12**, wherein:

forming the uncured composite member from the apex down onto the mandrel surface is performed using a compactor, and

the compactor is used to encourage substantially uniform distribution of wrinkles in the uncured composite-member.

18. A composite stringer having controlled wrinkles produced by the method of claim **12**.

19. A method of forming an uncured composite member into a contoured groove in a cure tool and curing, comprising:

adhering the uncured composite member to a flexible elongate compactor using a suction force;

using the compactor to bring the uncured composite member into initial contact with the cure tool at an apex of a longitudinal contour along the contoured groove;

using the compactor to form the uncured composite member down into and along the contoured groove and progressively outwardly from the apex;

using the compactor to distribute wrinkles formed in the uncured composite member during forming of the uncured composite member down into and along the contoured groove; and

curing the uncured composite member between the cure tool and the compactor.

20. The method of claim **19**, wherein using the compactor to form the uncured composite member is performed by one of drape forming and lash forming.

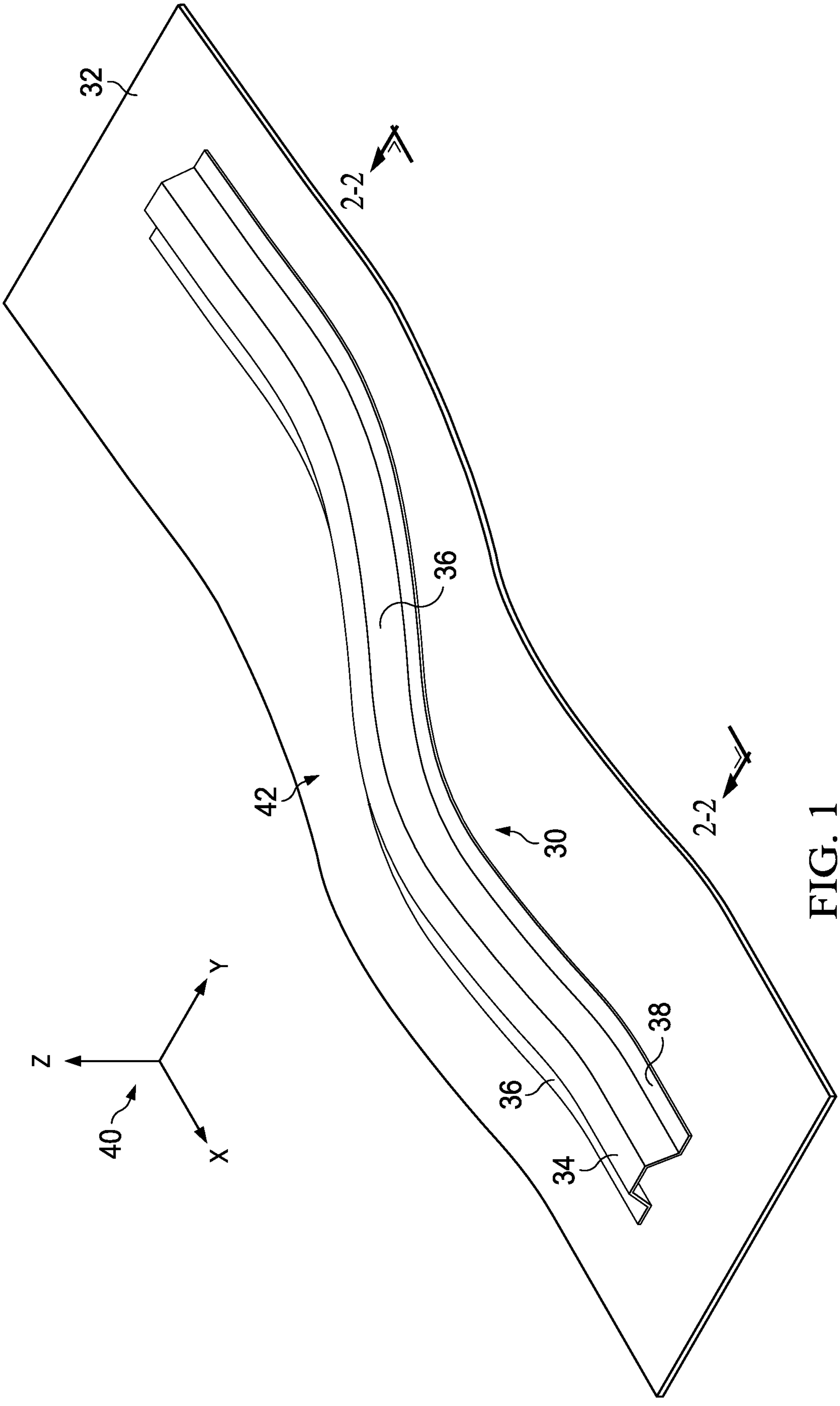


FIG. 1

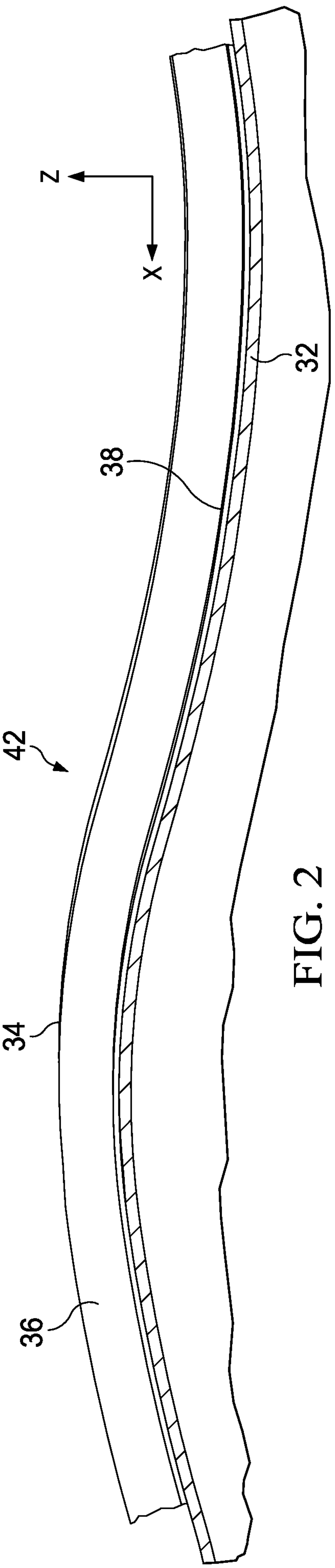


FIG. 2

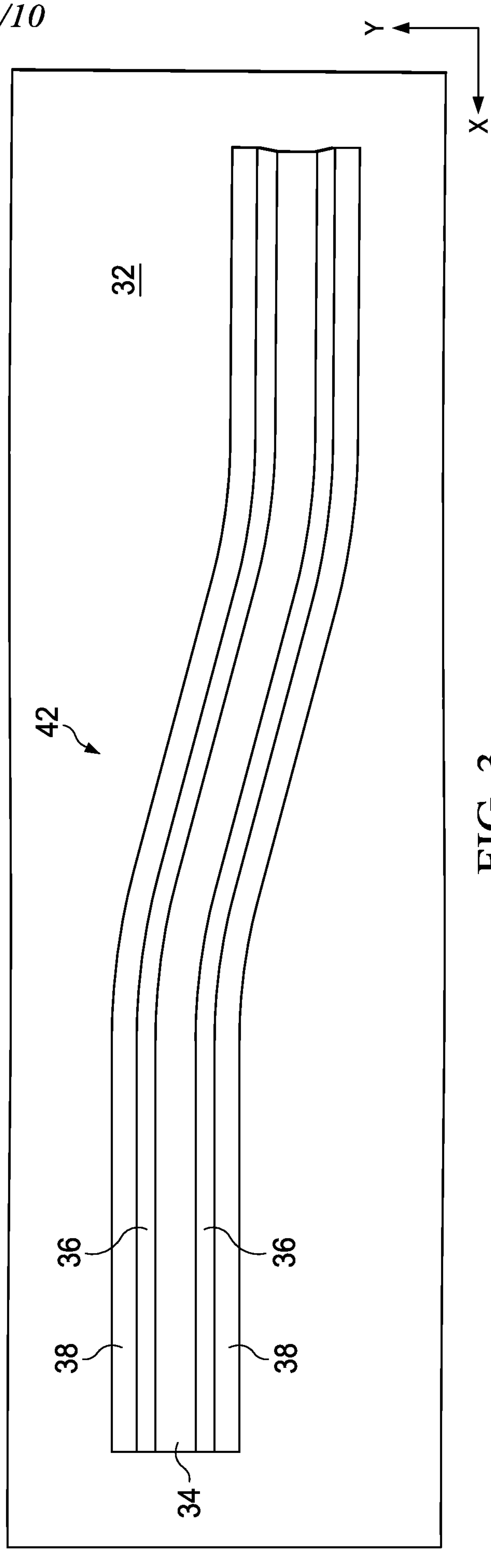


FIG. 3

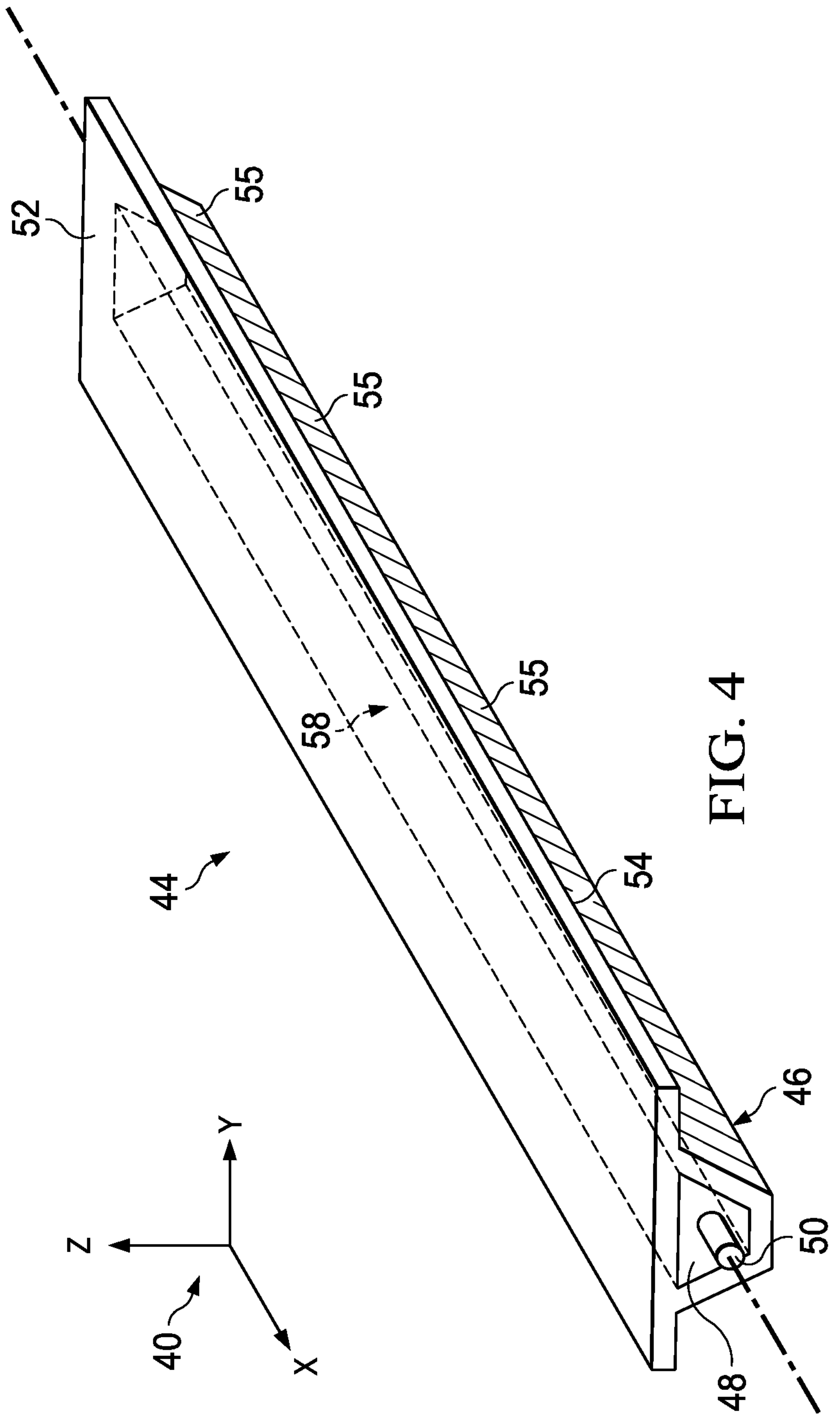


FIG. 4

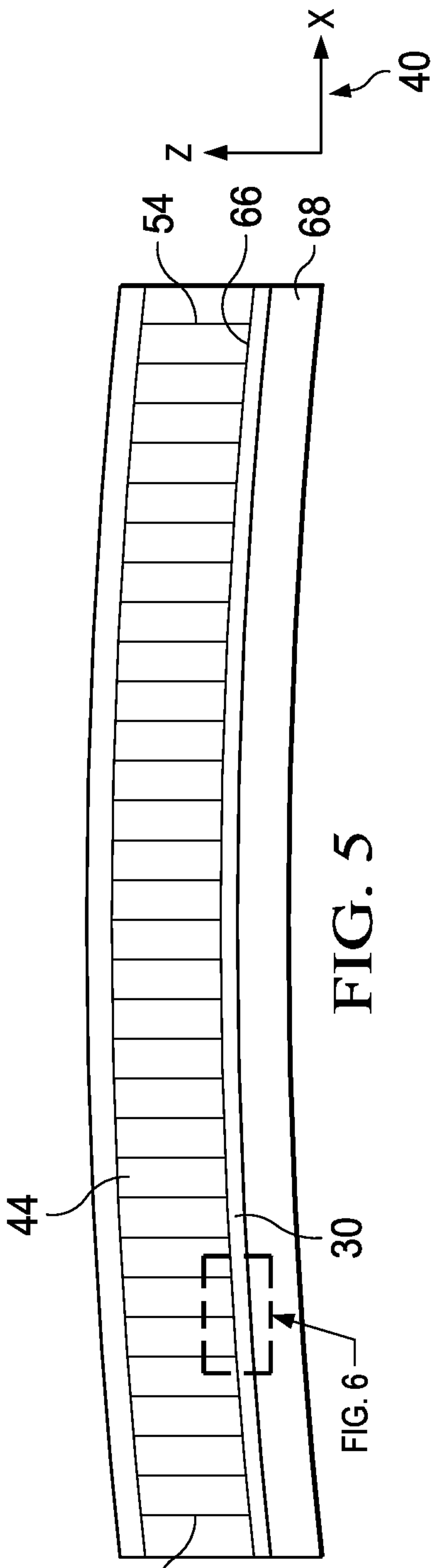

X
40
Z
54
66
68
44
30
FIG. 6
54

FIG. 5

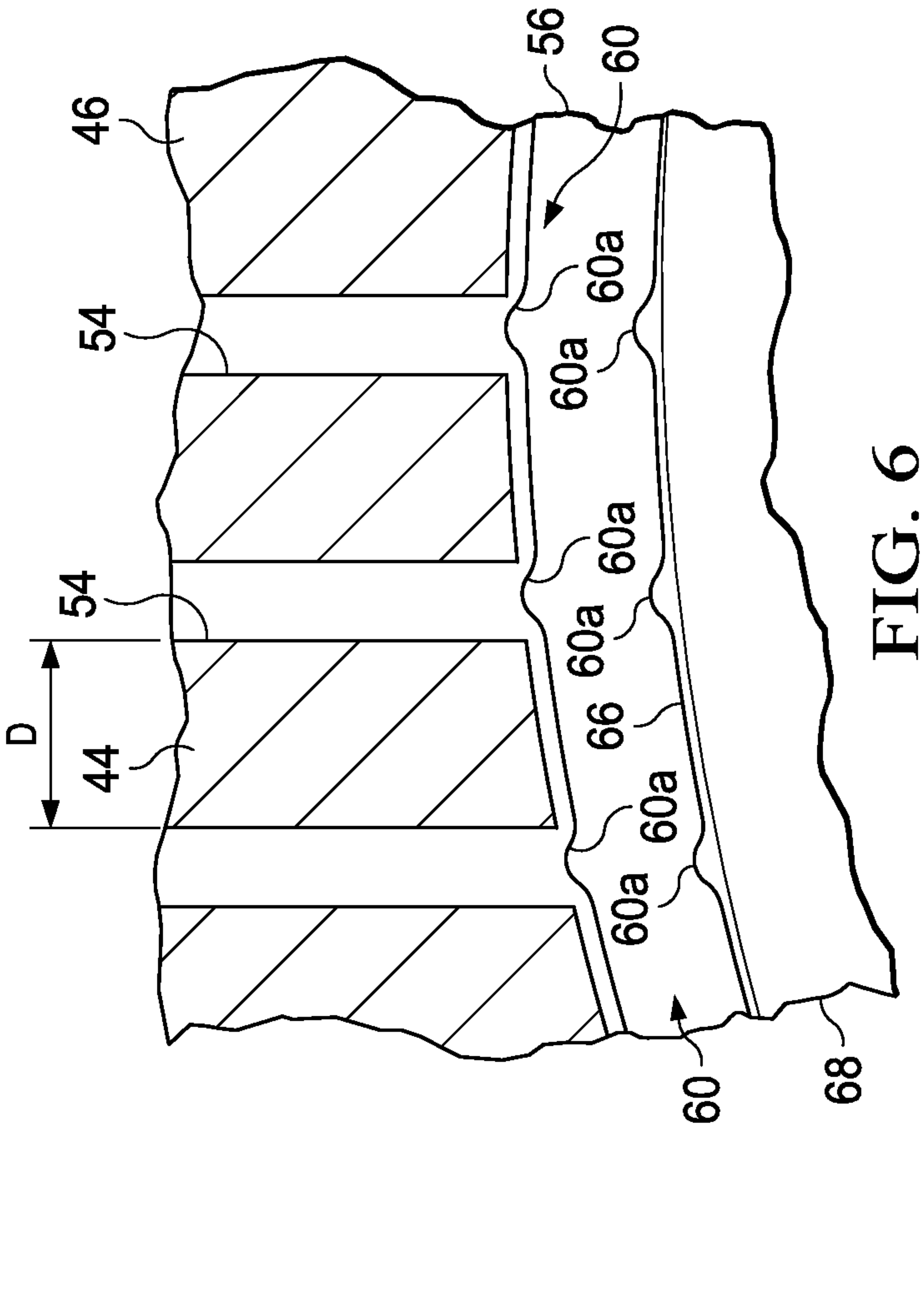

46
56
60
54
60a
60a
60a
60a
60a
60a
60a
60a
54
D
44
66
60
68

FIG. 6

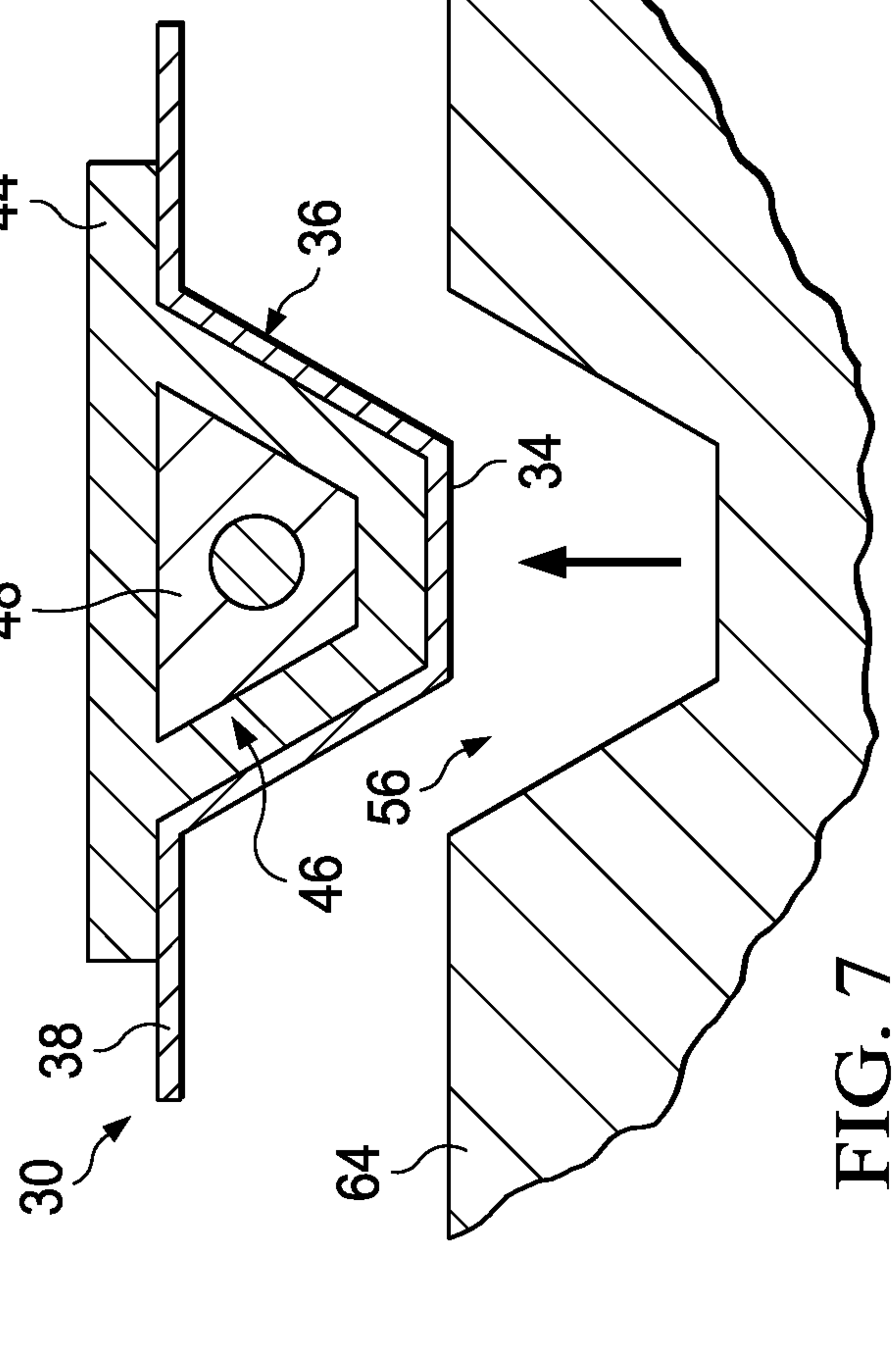


FIG. 7

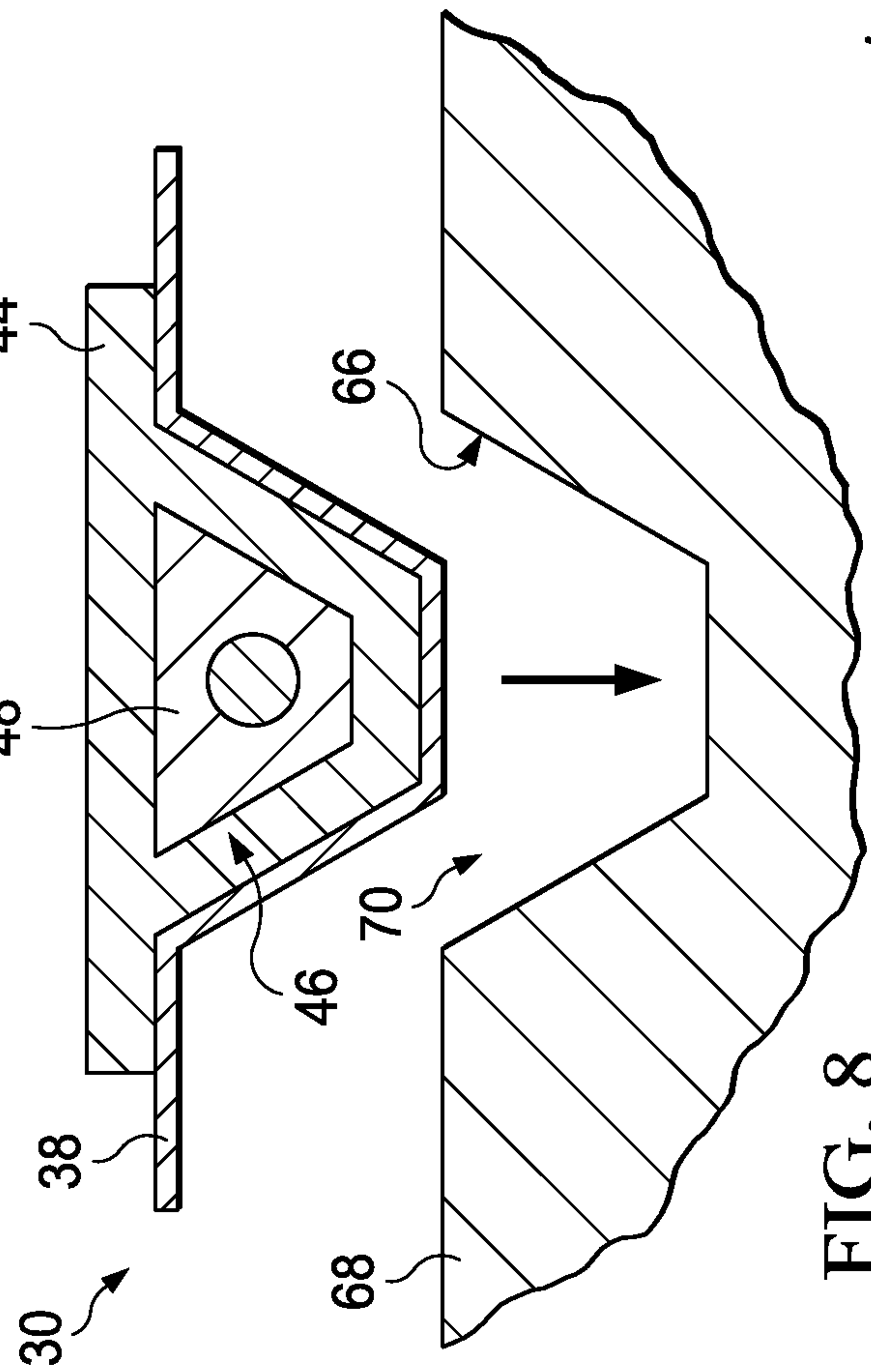


FIG. 8

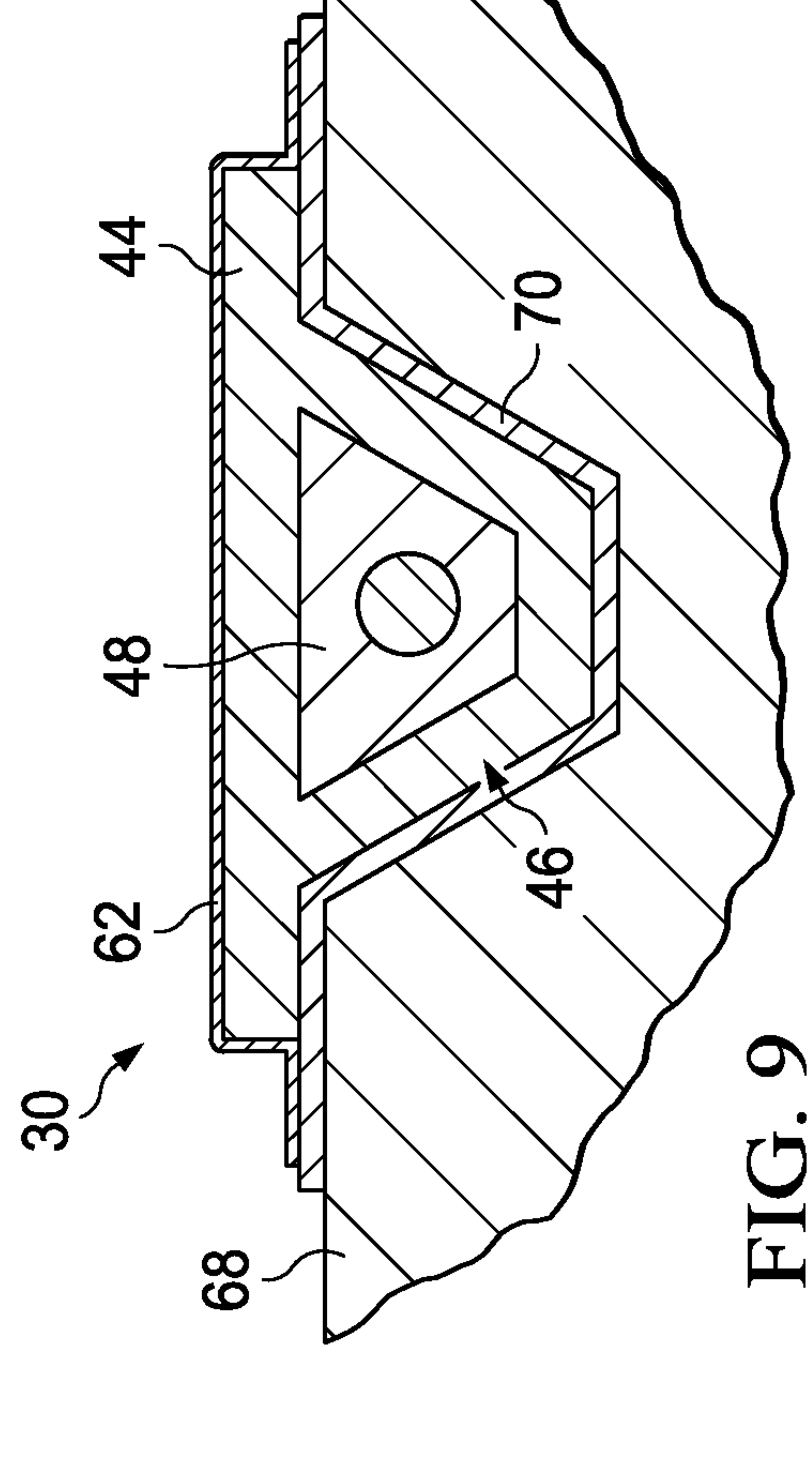


FIG. 9

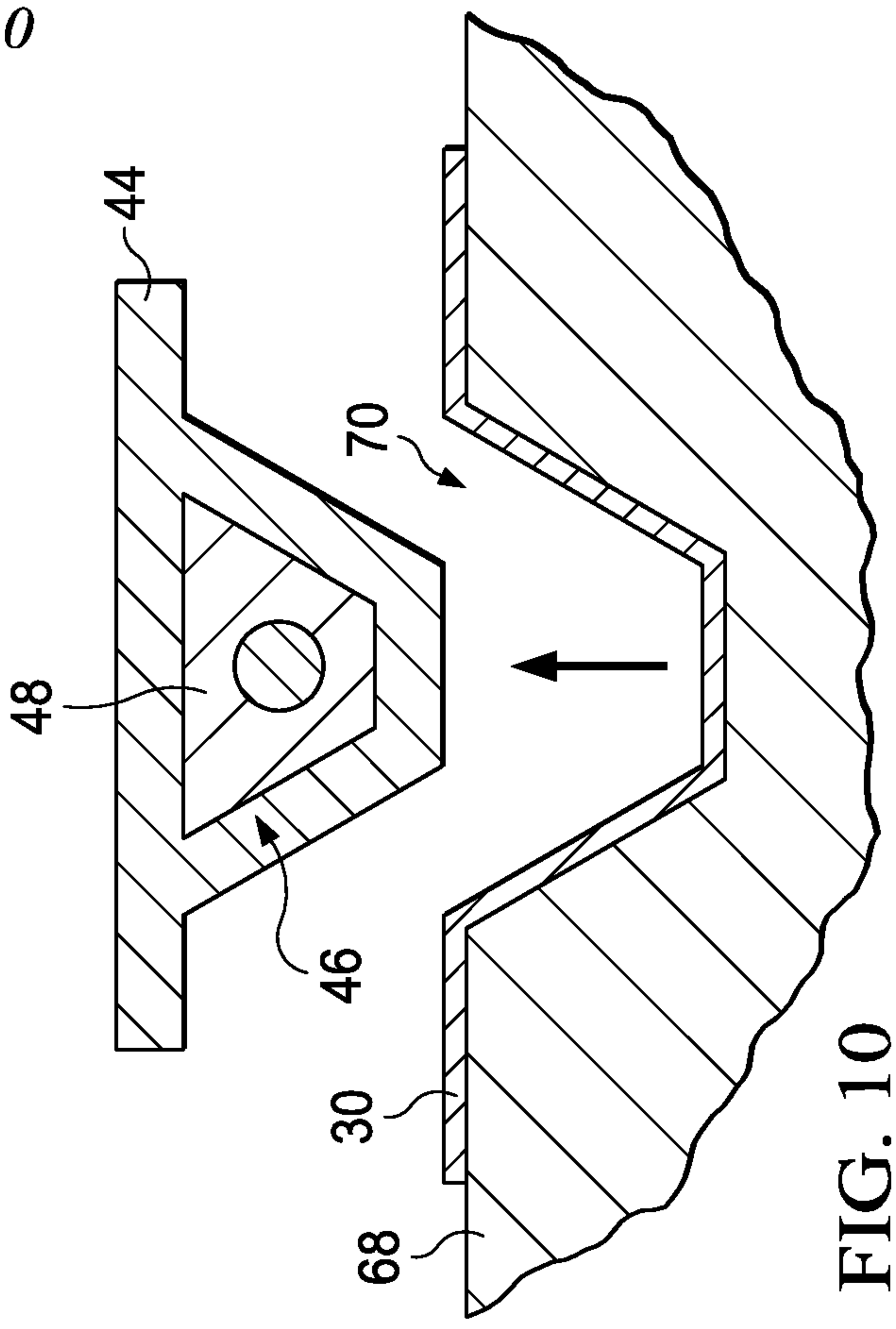


FIG. 10

6/10

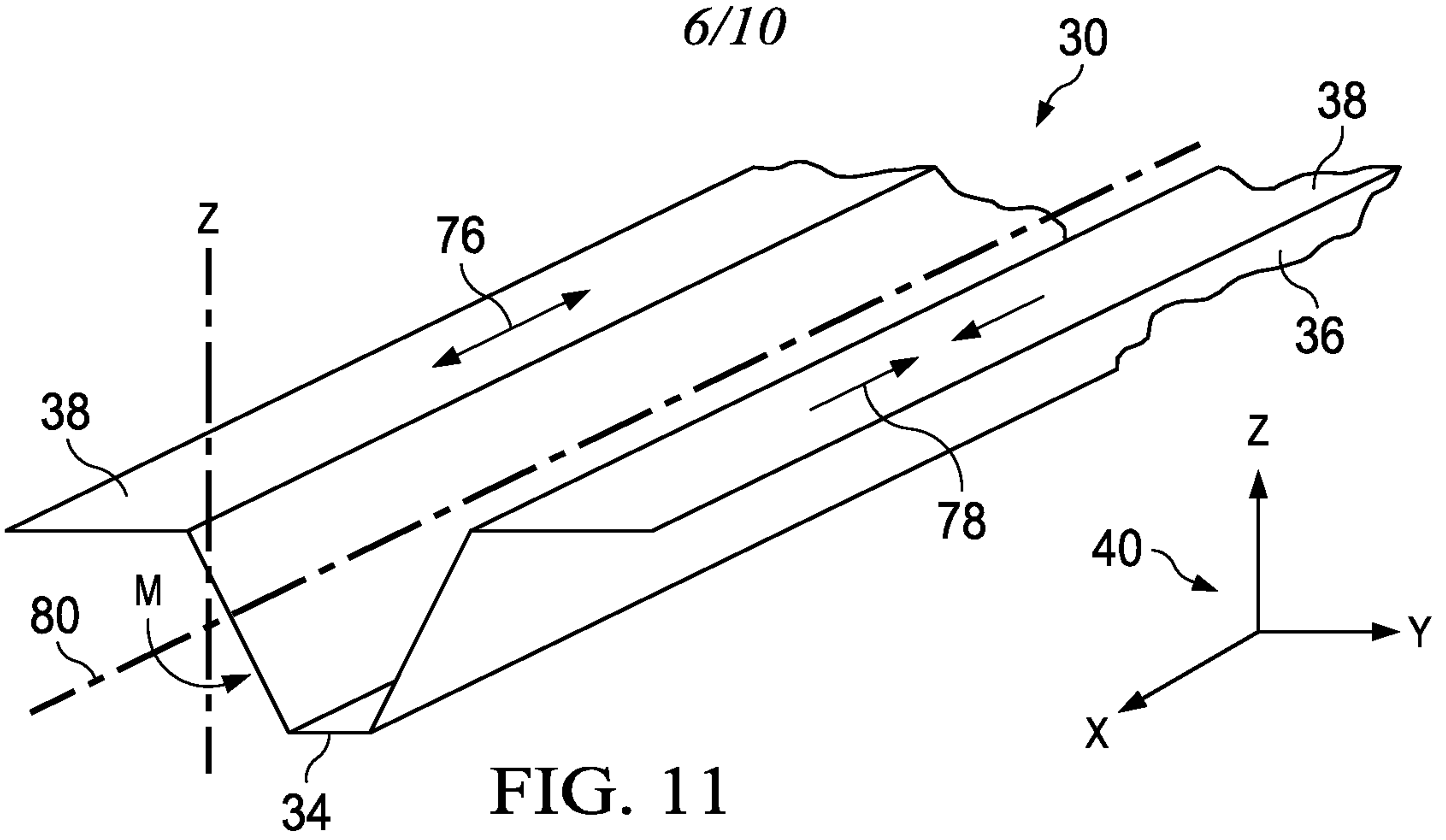


FIG. 11

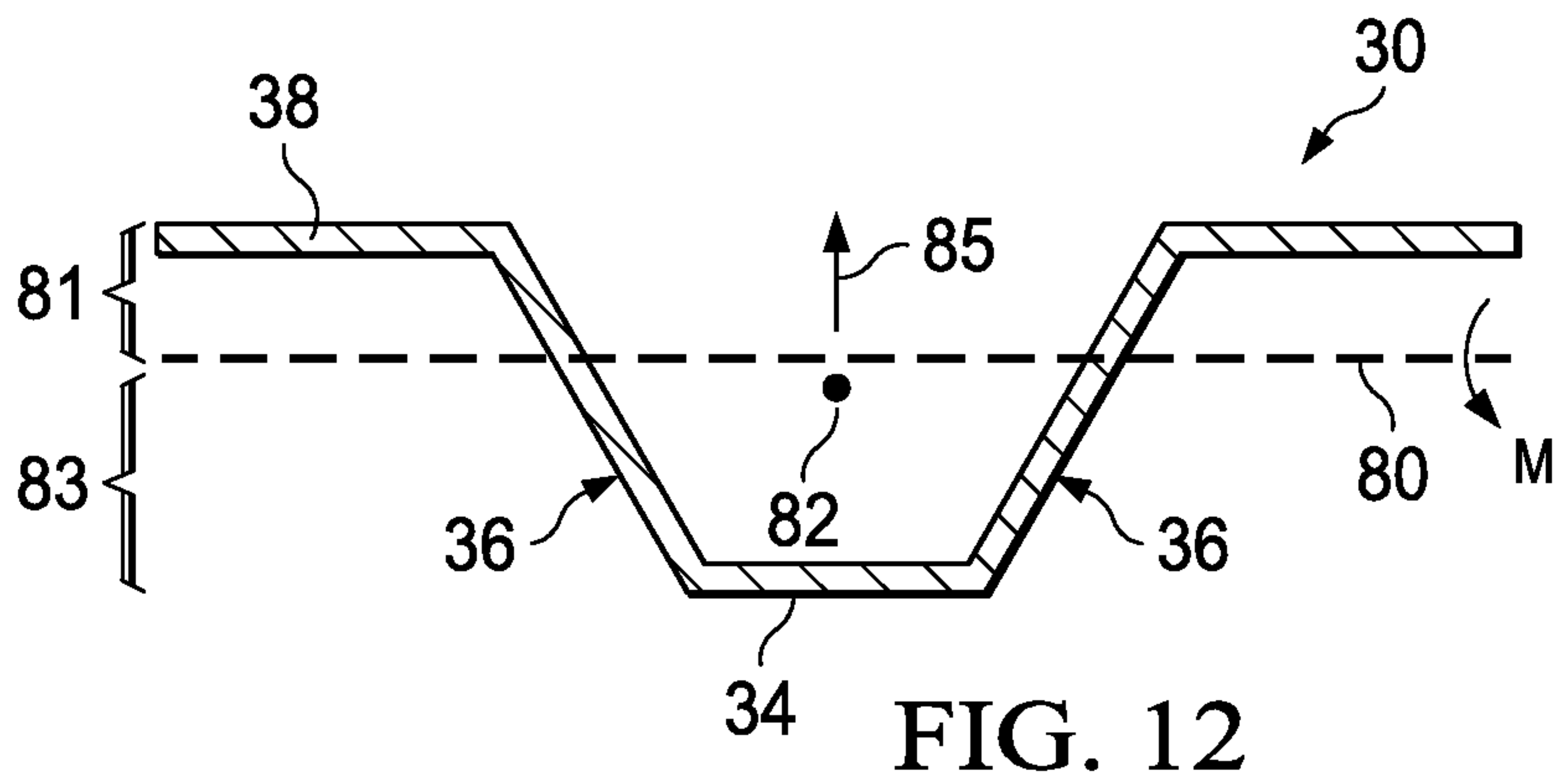


FIG. 12

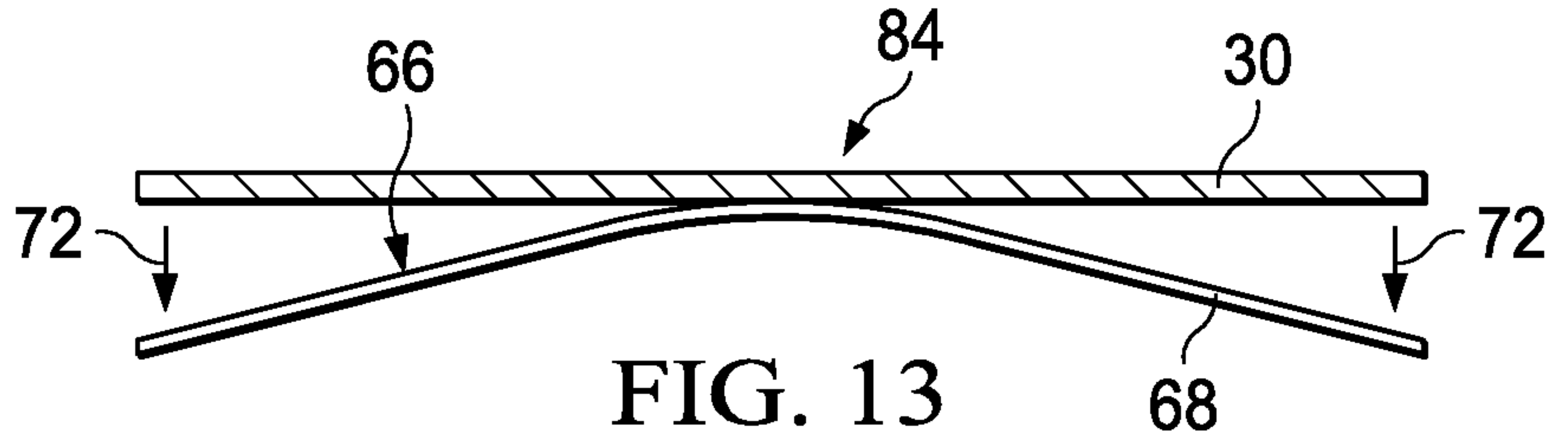


FIG. 13

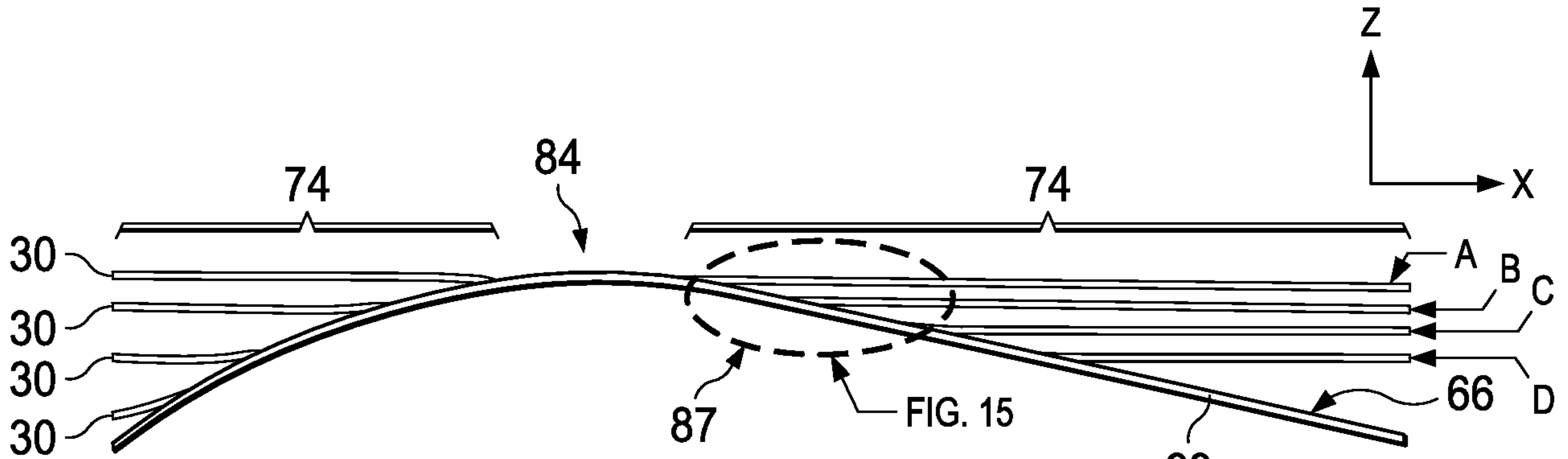


FIG. 14

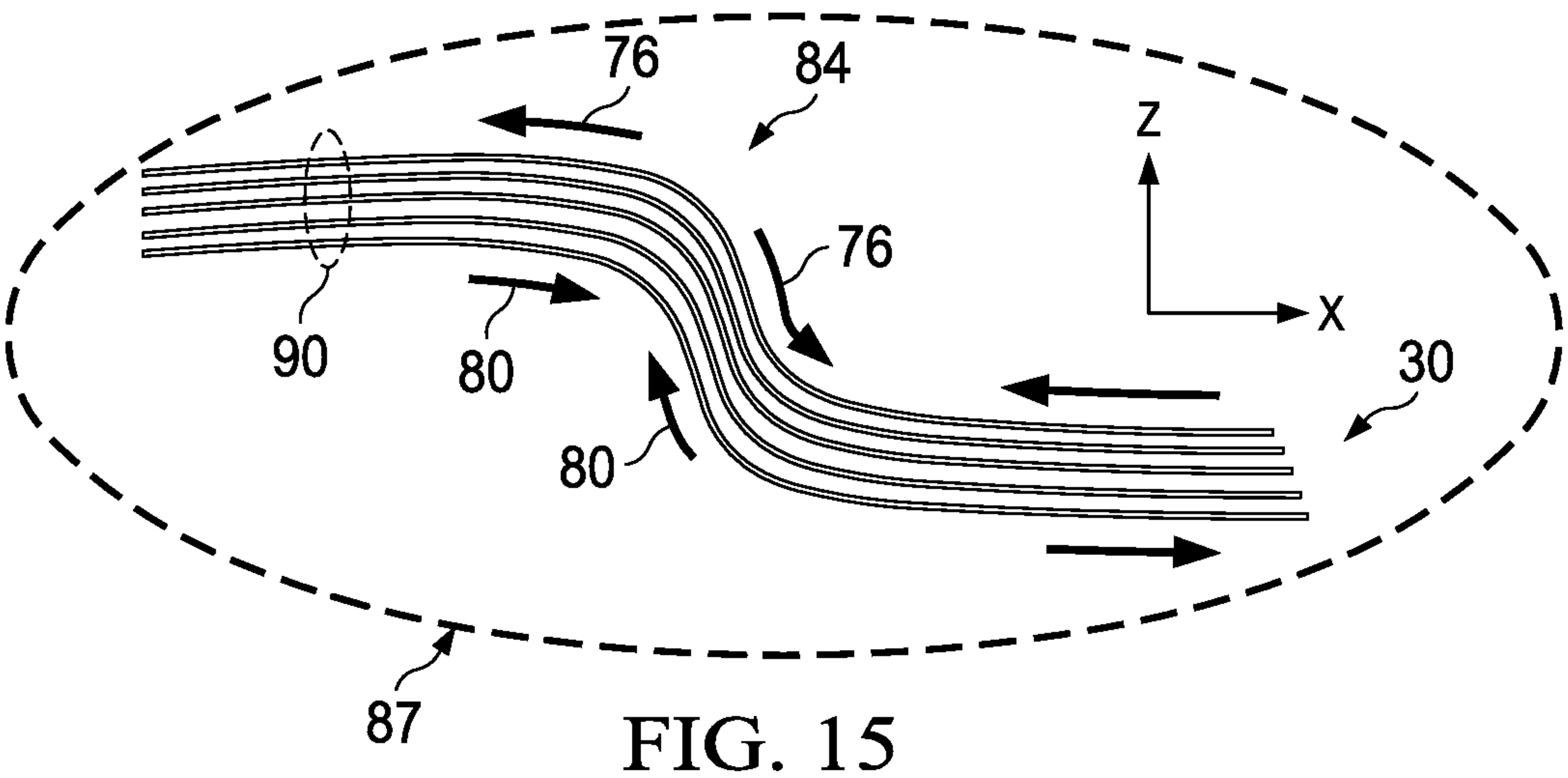


FIG. 15

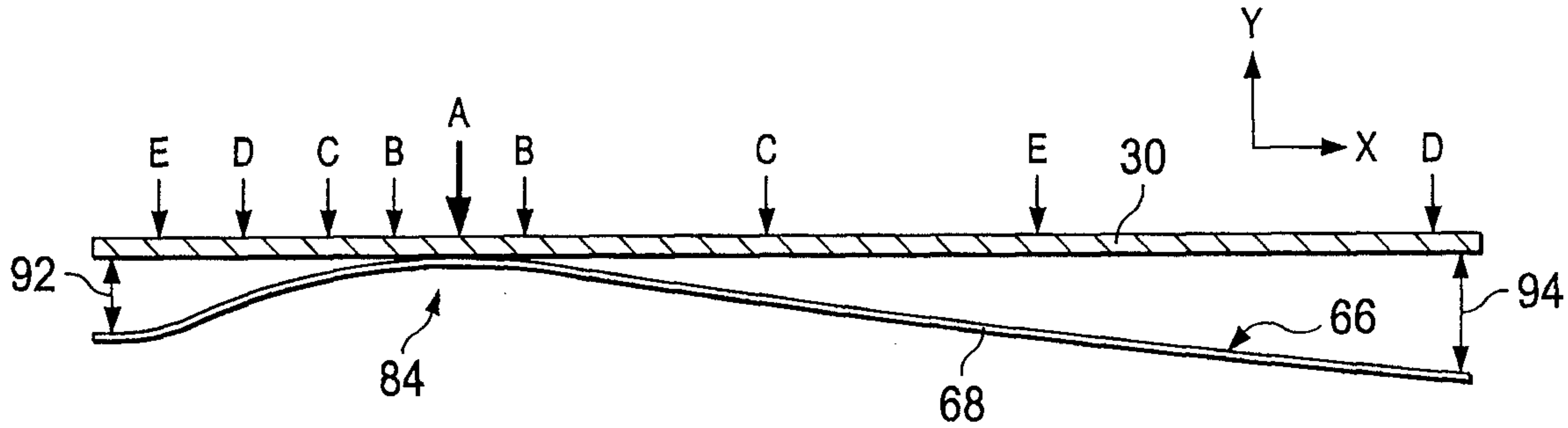


FIG. 16

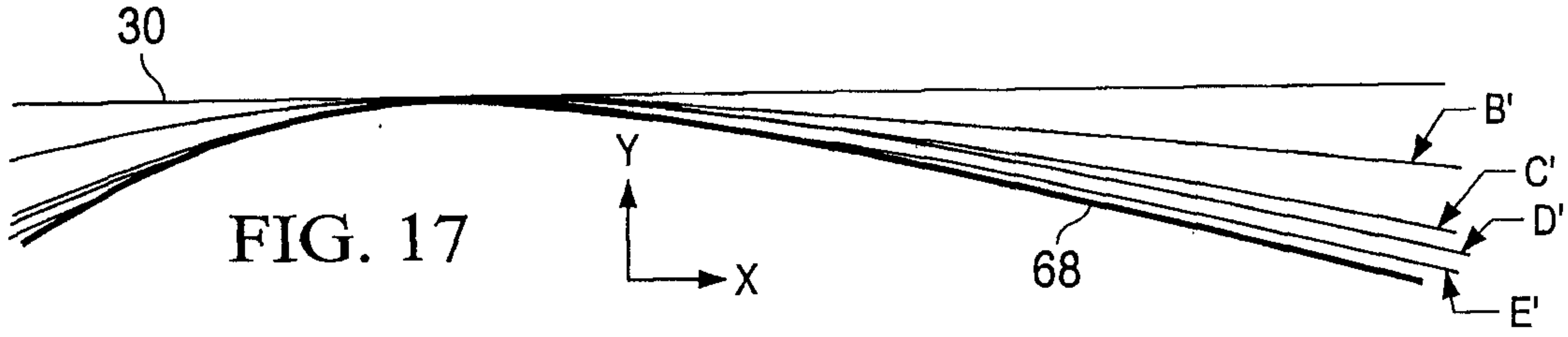


FIG. 17

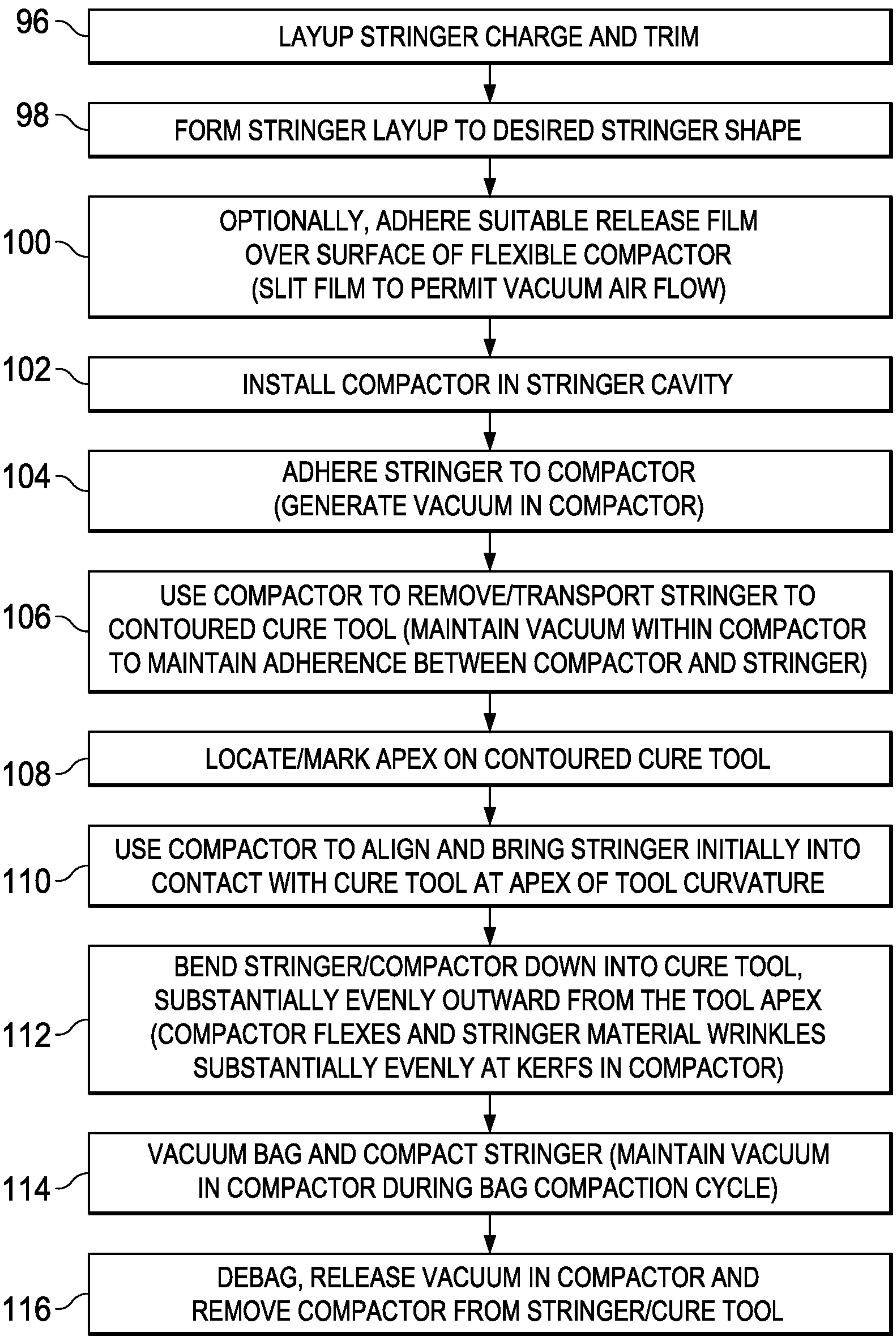

96
LAYUP STRINGER CHARGE AND TRIM
98
FORM STRINGER LAYUP TO DESIRED STRINGER SHAPE
100
OPTIONALLY, ADHERE SUITABLE RELEASE FILM OVER SURFACE OF FLEXIBLE COMPACTOR (SLIT FILM TO PERMIT VACUUM AIR FLOW)
102
INSTALL COMPACTOR IN STRINGER CAVITY
104
ADHERE STRINGER TO COMPACTOR (GENERATE VACUUM IN COMPACTOR)
106
USE COMPACTOR TO REMOVE/TRANSPORT STRINGER TO CONTOURED CURE TOOL (MAINTAIN VACUUM WITHIN COMPACTOR TO MAINTAIN ADHERENCE BETWEEN COMPACTOR AND STRINGER)
108
LOCATE/MARK APEX ON CONTOURED CURE TOOL
110
USE COMPACTOR TO ALIGN AND BRING STRINGER INITIALLY INTO CONTACT WITH CURE TOOL AT APEX OF TOOL CURVATURE
112
BEND STRINGER/COMPACTOR DOWN INTO CURE TOOL, SUBSTANTIALLY EVENLY OUTWARD FROM THE TOOL APEX (COMPACTOR FLEXES AND STRINGER MATERIAL WRINKLES SUBSTANTIALLY EVENLY AT KERFS IN COMPACTOR)
114
VACUUM BAG AND COMPACT STRINGER (MAINTAIN VACUUM IN COMPACTOR DURING BAG COMPACTION CYCLE)
116
DEBAG, RELEASE VACUUM IN COMPACTOR AND REMOVE COMPACTOR FROM STRINGER/CURE TOOL

FIG. 18

FIG. 19

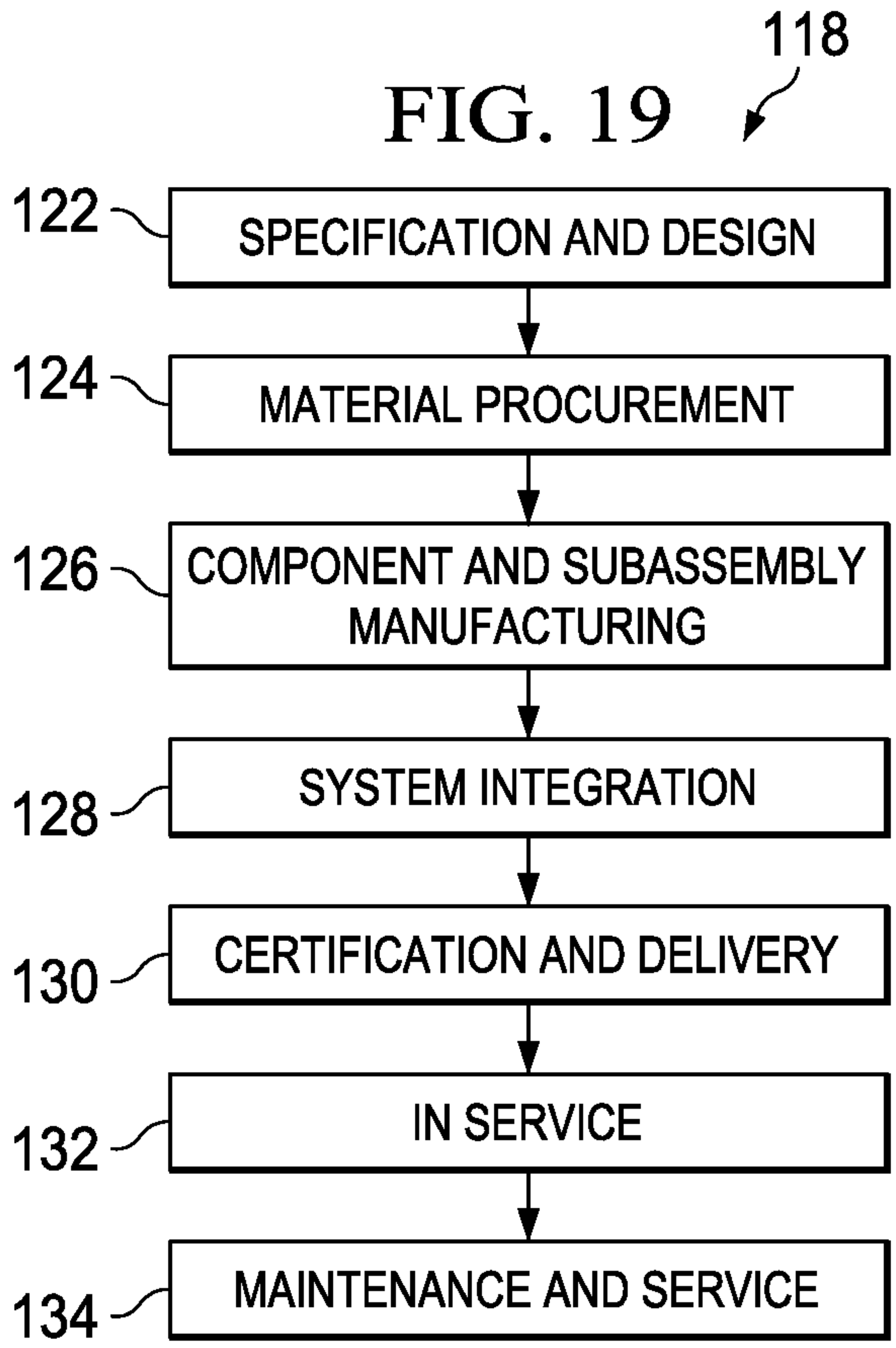
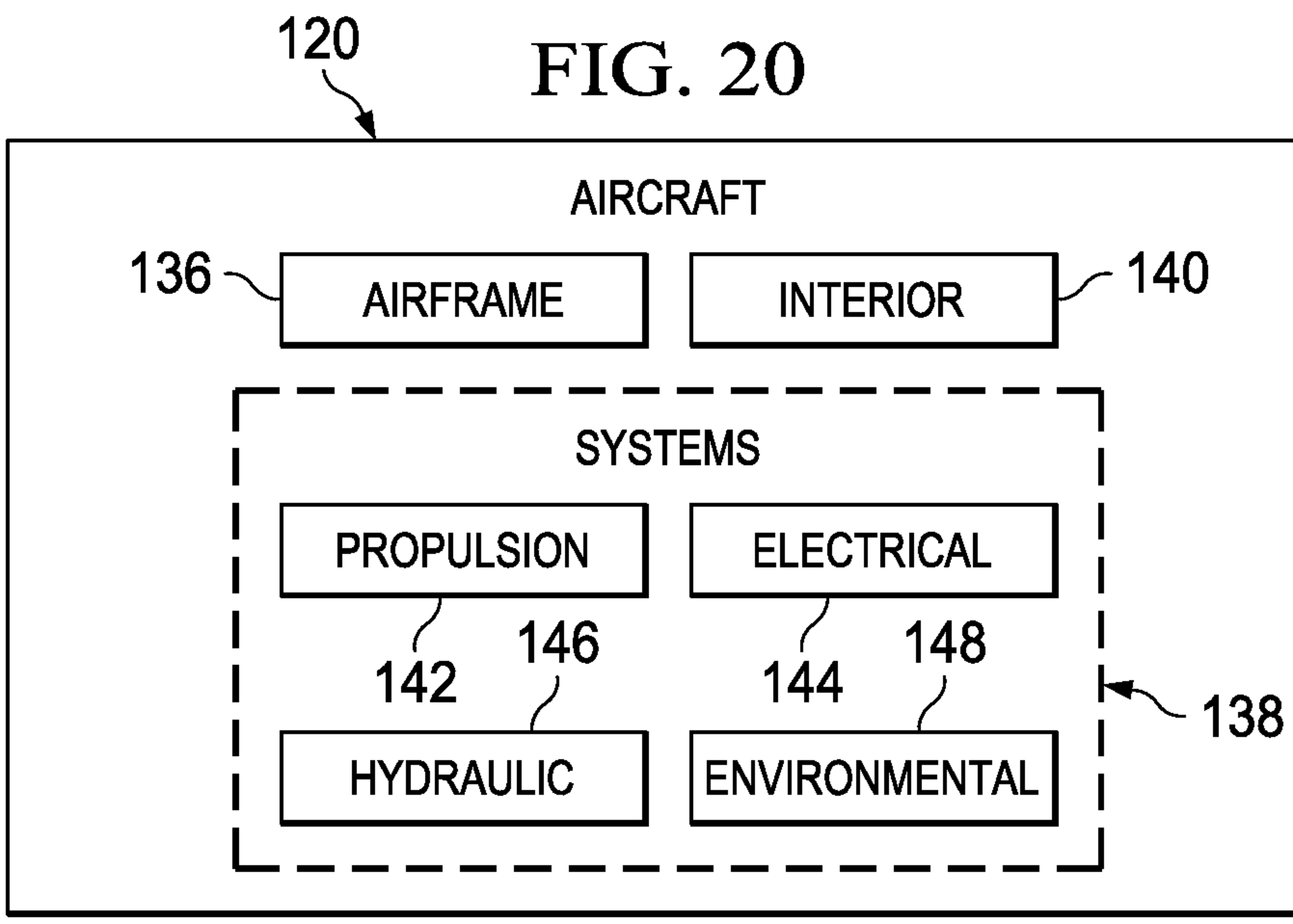
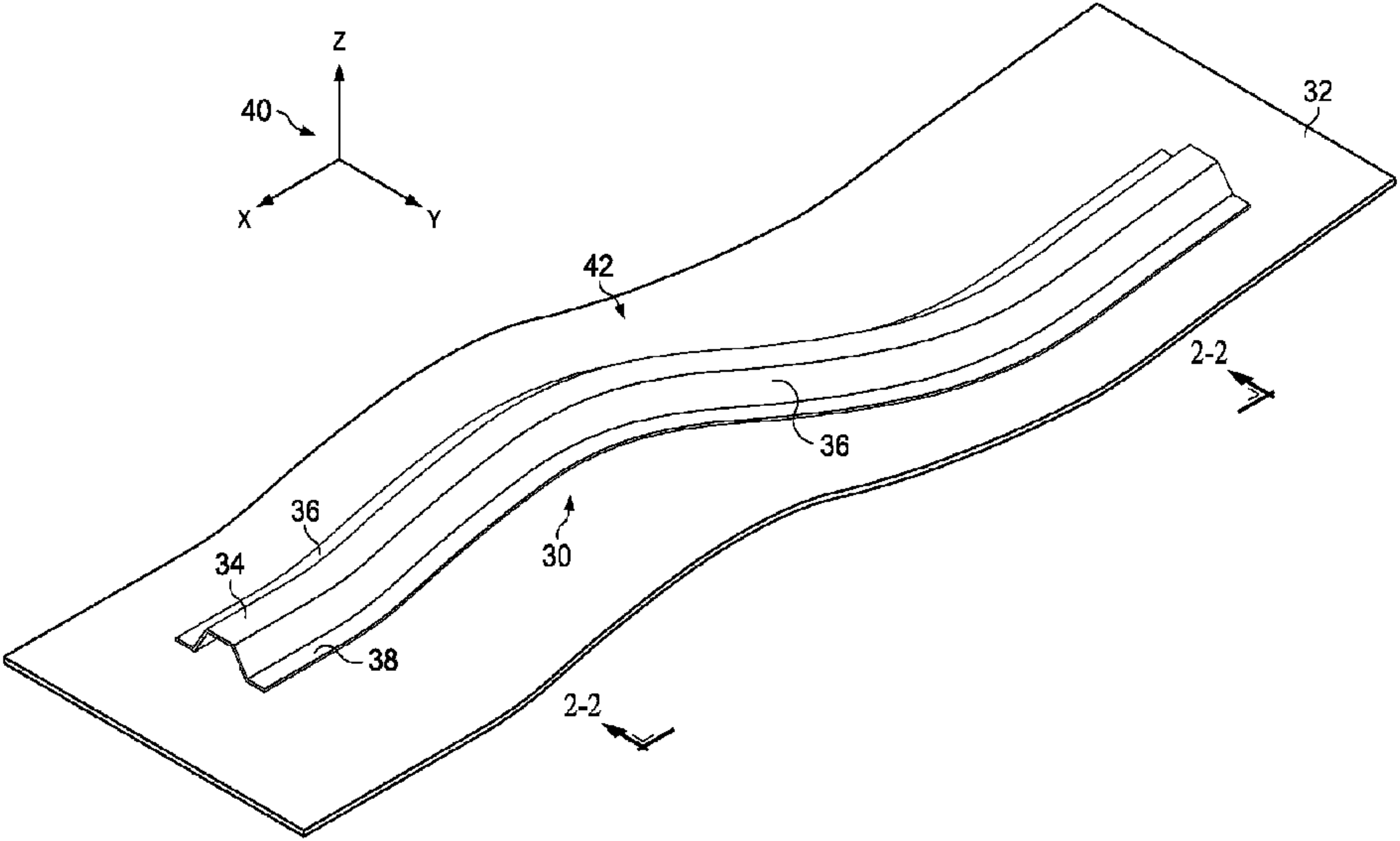

118
122
SPECIFICATION AND DESIGN
124
MATERIAL PROCUREMENT
126
COMPONENT AND SUBASSEMBLY MANUFACTURING
128
SYSTEM INTEGRATION
130
CERTIFICATION AND DELIVERY
132
IN SERVICE
134
MAINTENANCE AND SERVICE

FIG. 20


120
AIRCRAFT
136
AIRFRAME
INTERIOR
140
SYSTEMS
PROPULSION
ELECTRICAL
142
146
144
148
138
HYDRAULIC
ENVIRONMENTAL



Z
40
X
Y
32
42
2-2
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