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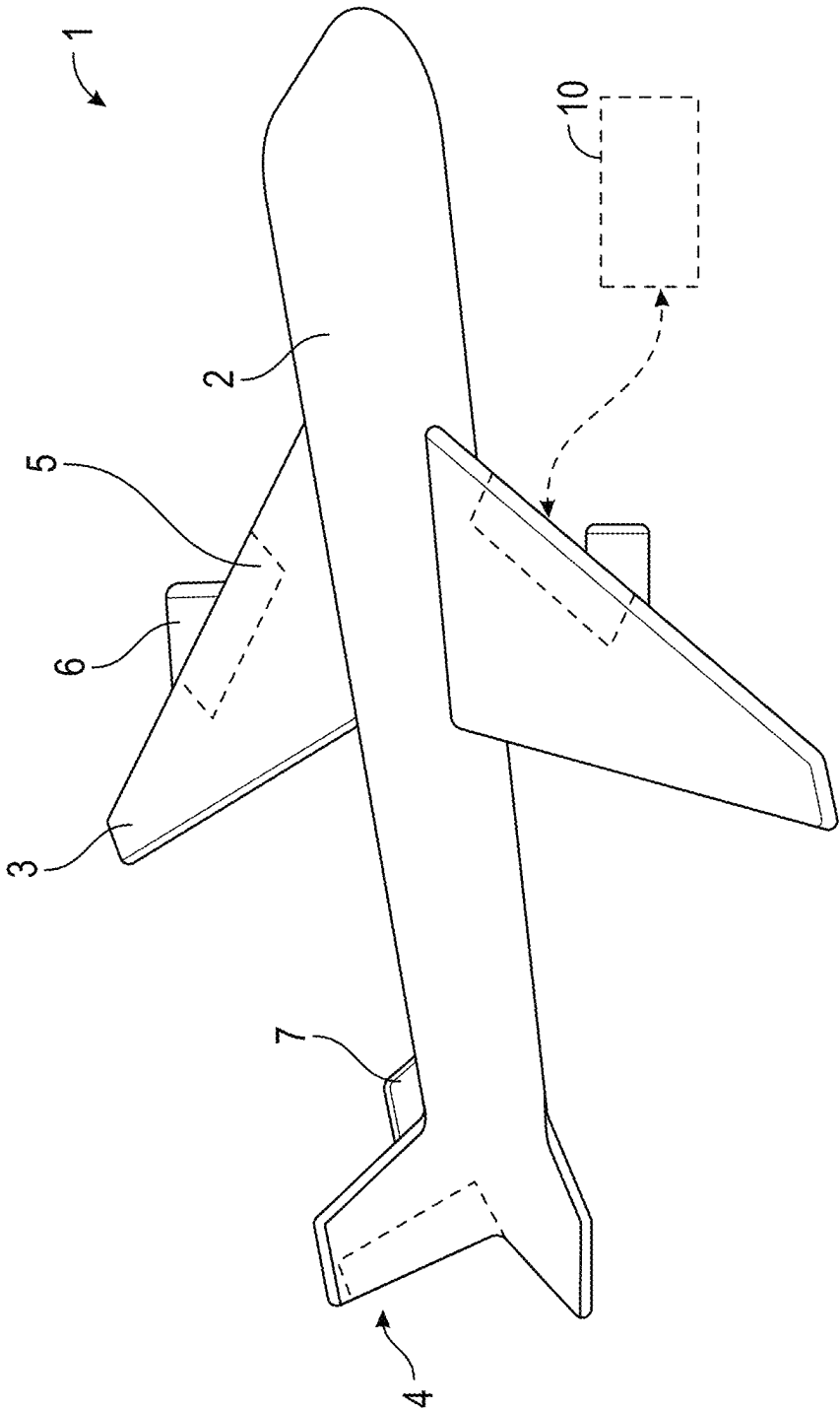
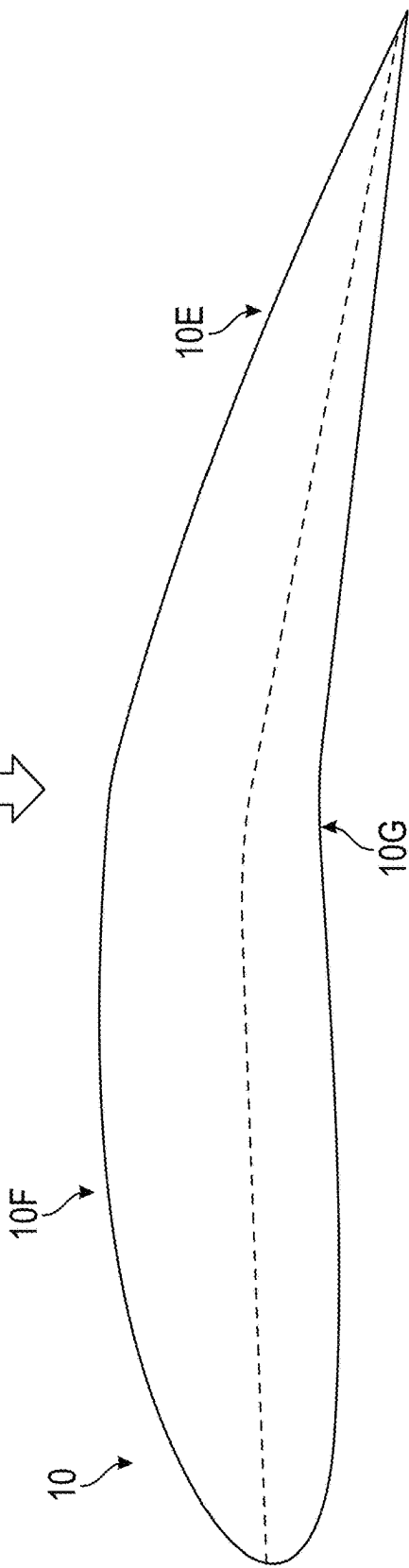
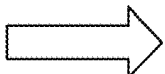
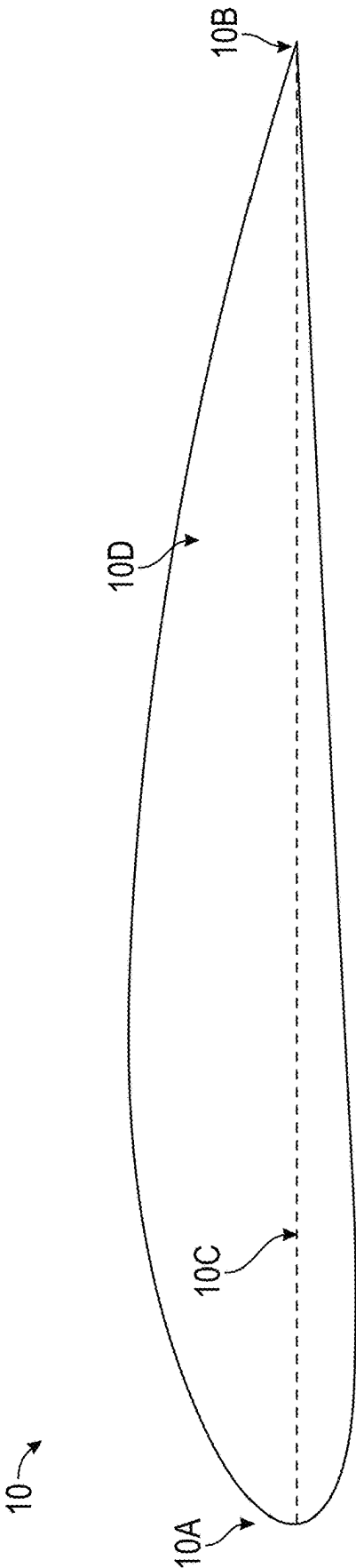


FIG. 1A



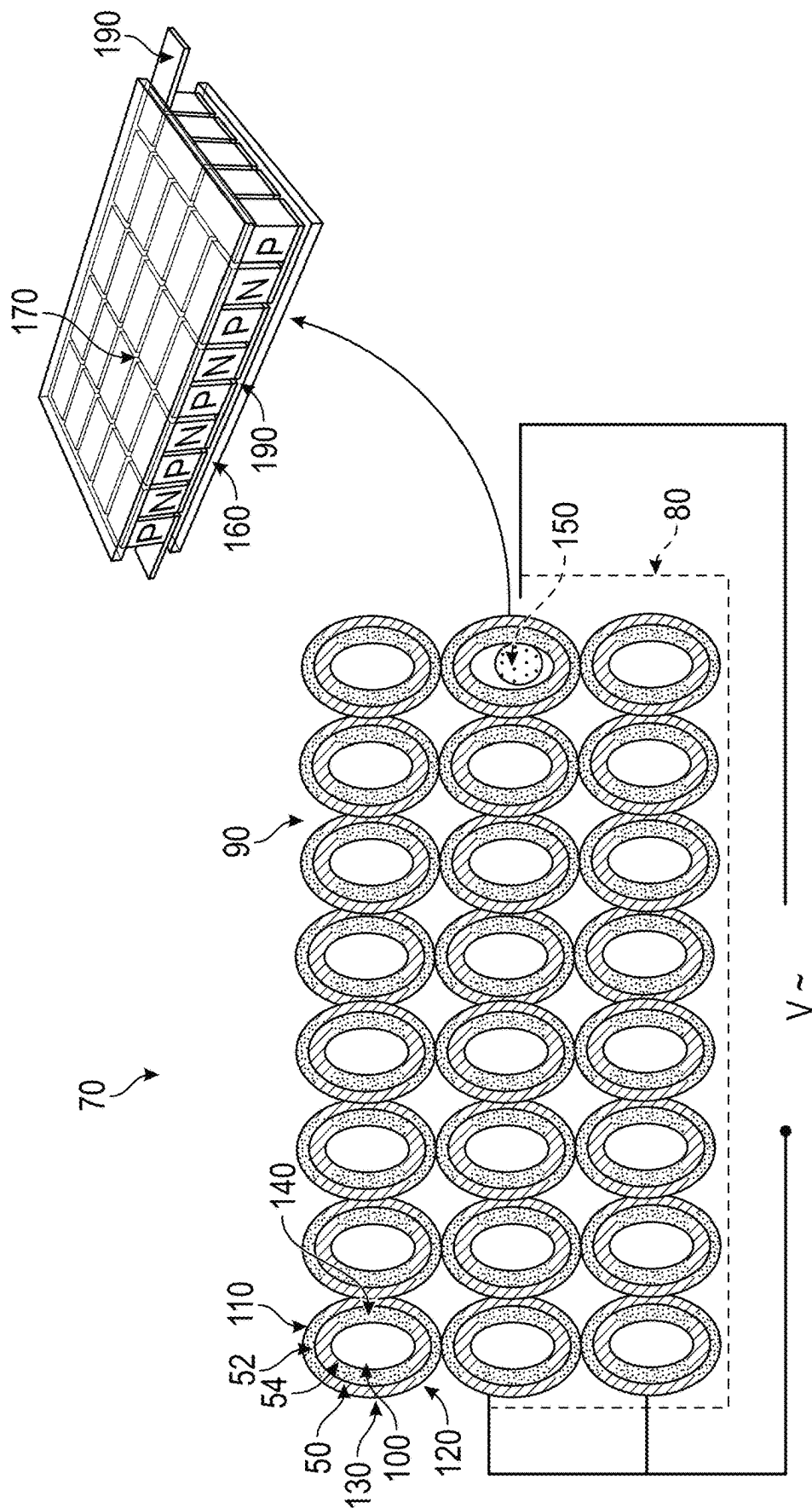


FIG. 2

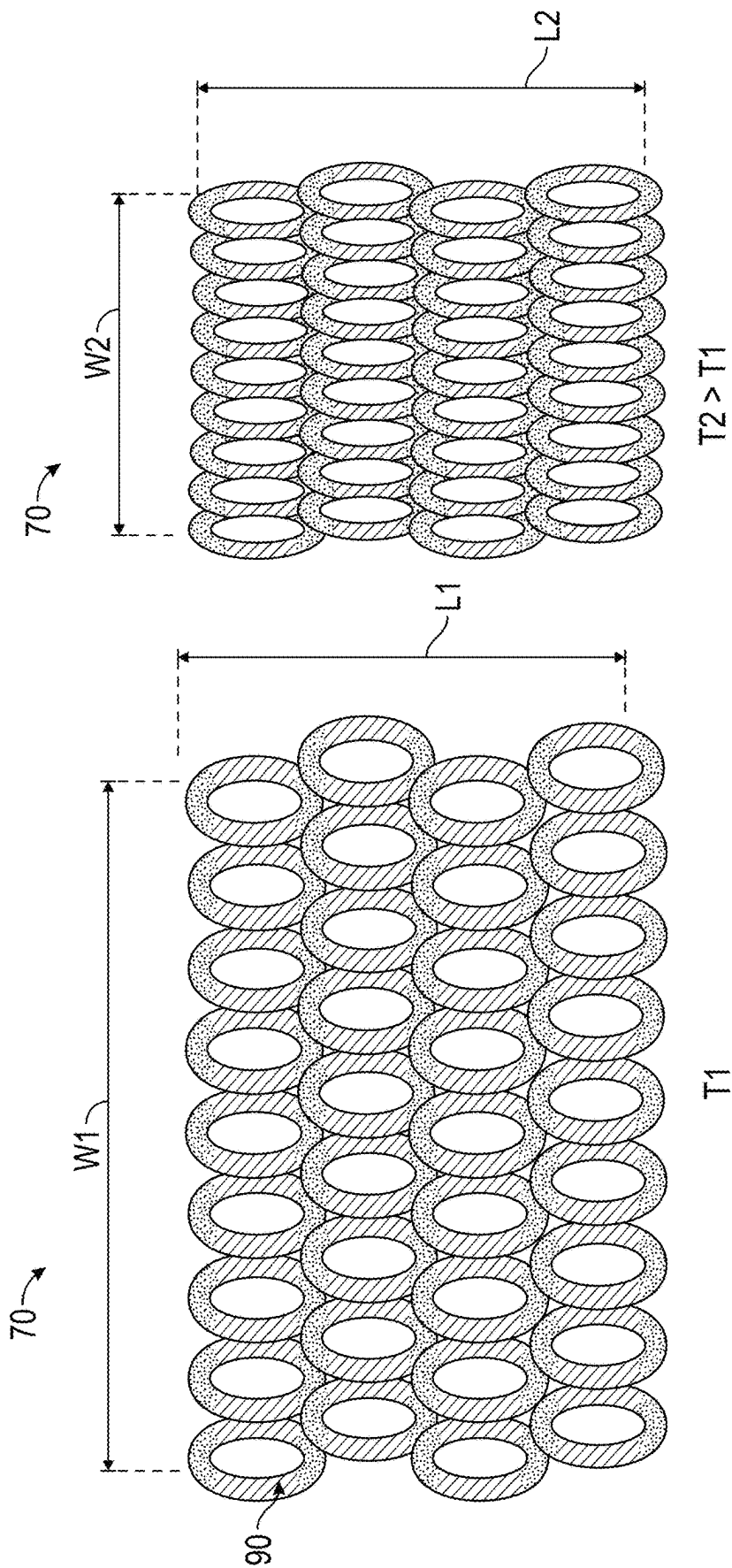
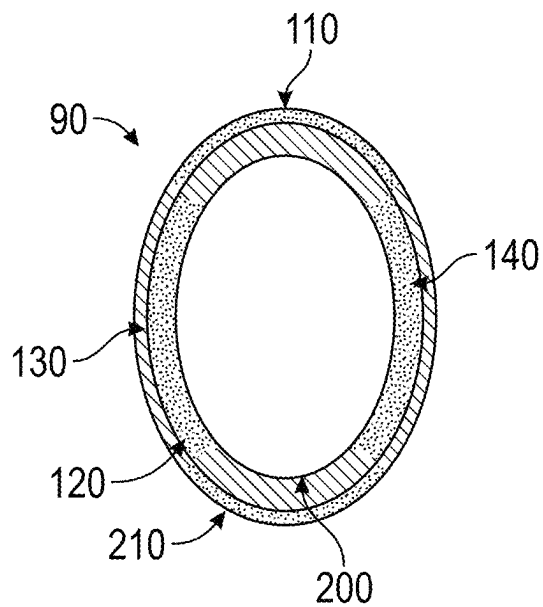


FIG. 4

FIG. 3



T1

FIG. 5

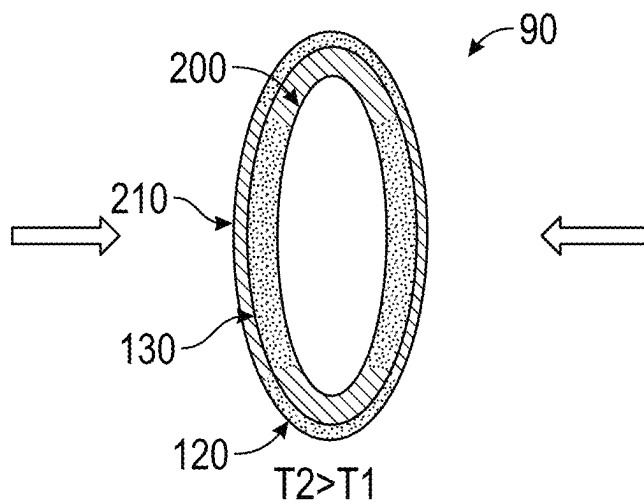


FIG. 6

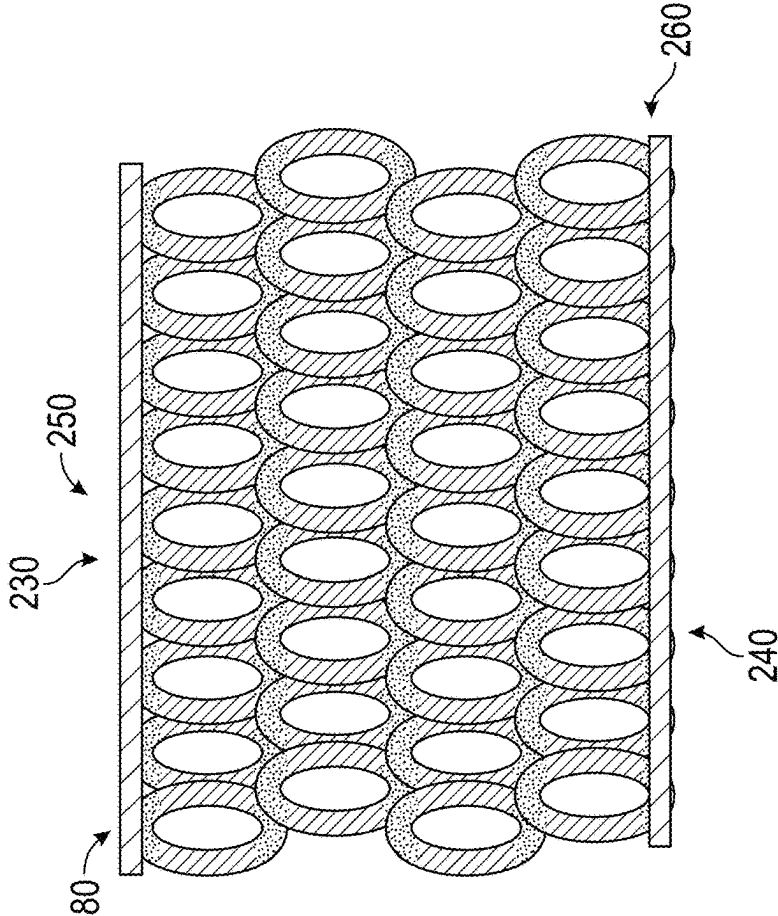


FIG. 7

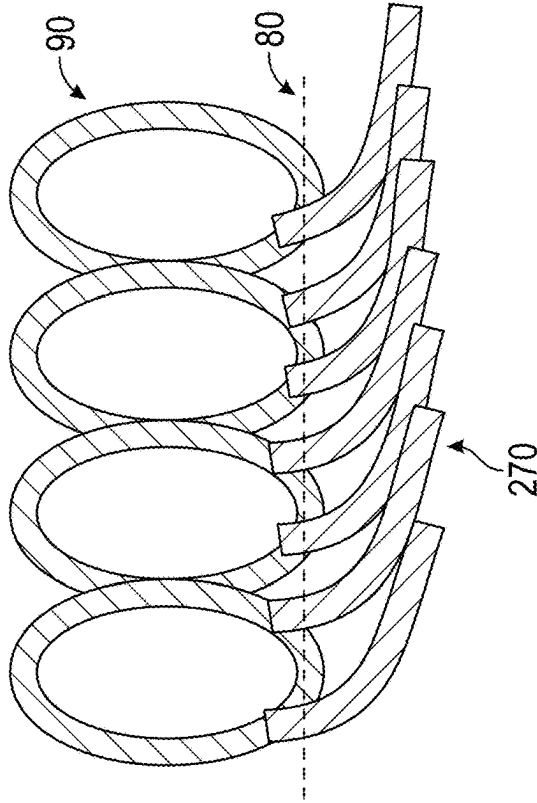


FIG. 8

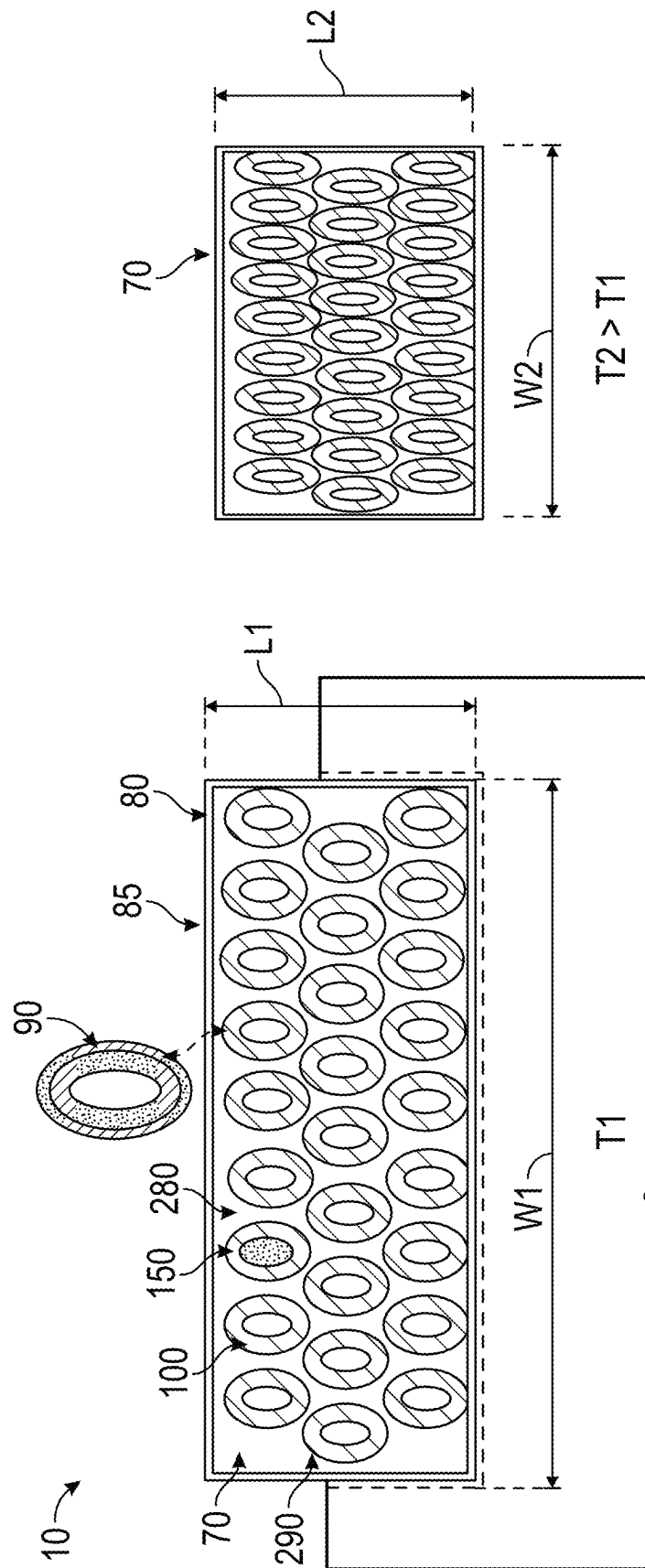


FIG. 10

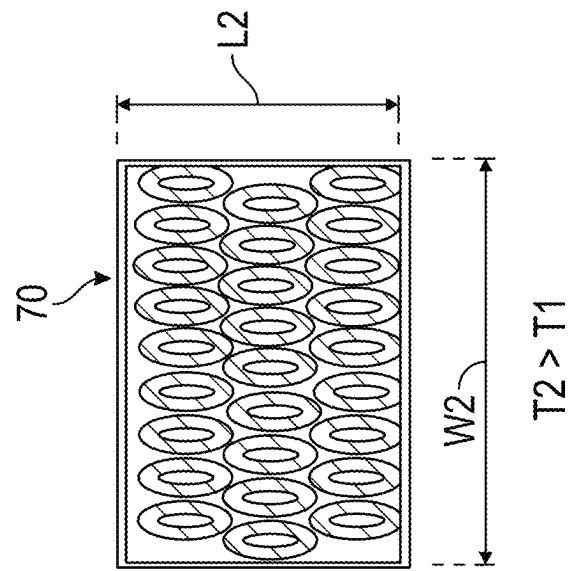


FIG. 9

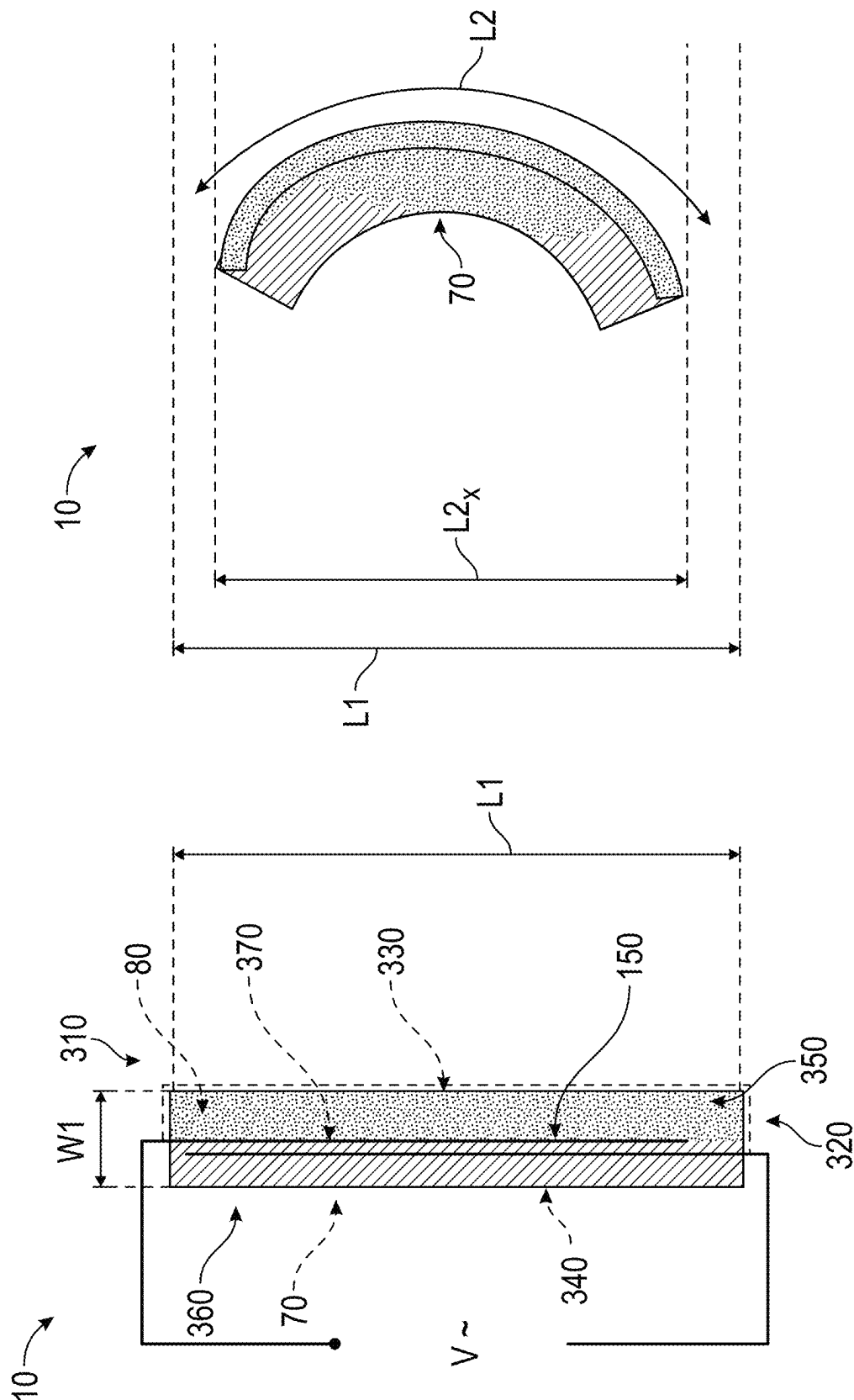


FIG. 12

Fig. 11

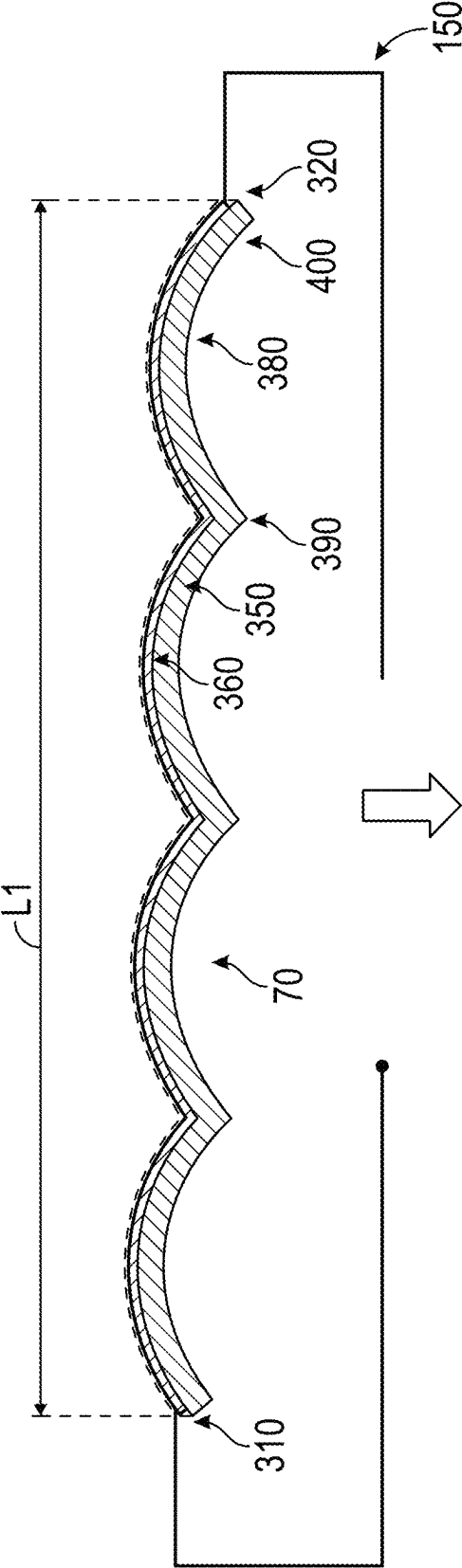


FIG. 13

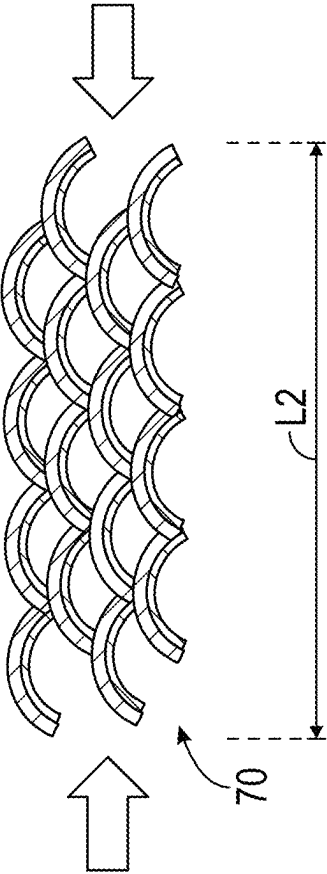
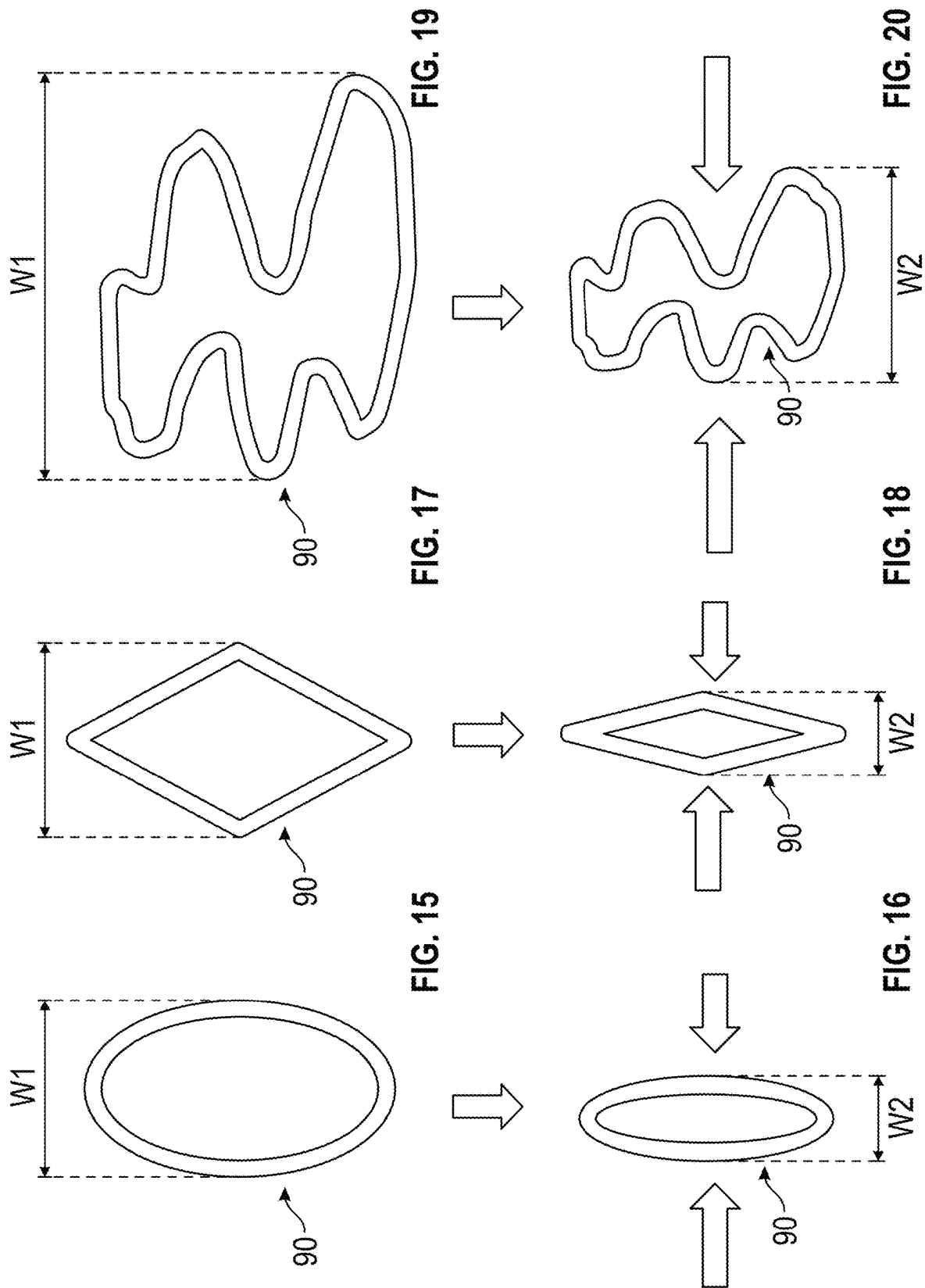


FIG. 14



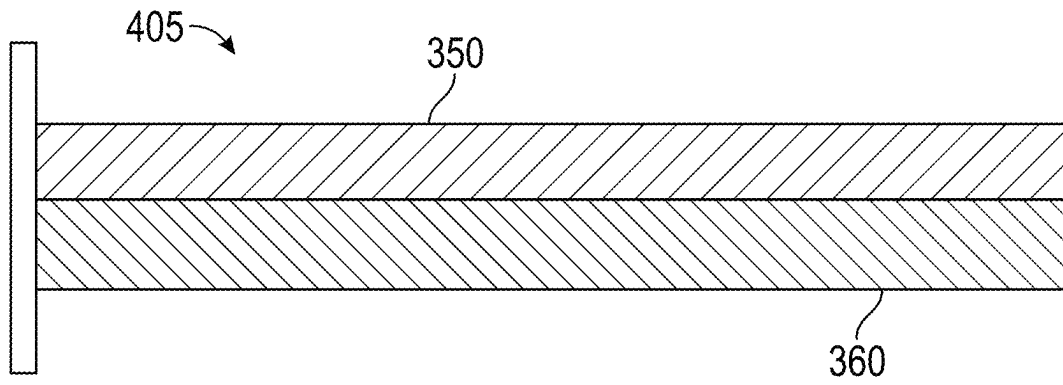


FIG. 21

($T_2 > T_1$)

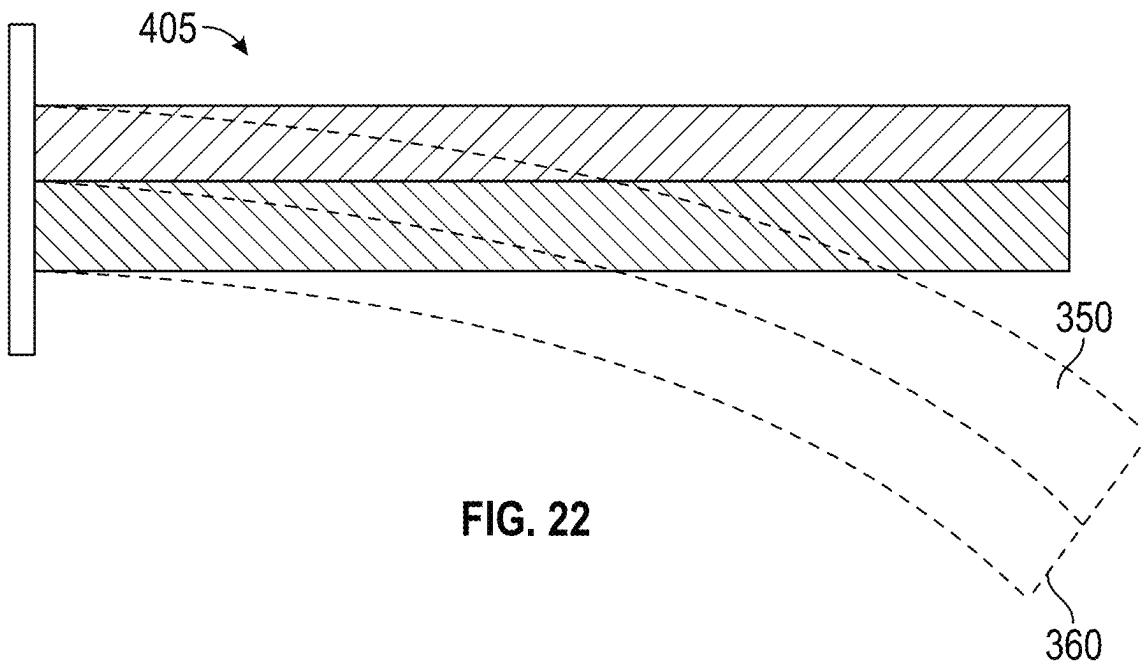


FIG. 22

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AIRFOIL FORMED OF THERMALLY ADAPTIVE MATERIALS AND A THERMOELECTRIC JUNCTION

BACKGROUND

The embodiments are directed to an airfoil and more specifically to an airfoil formed of thermally adaptive materials and a thermoelectric junction.

Memory shape alloy or bimetallic parts may be utilized for various applications to avoid the requirement of utilizing complex machinery. However, working fluid temperatures may undesirably control the shape of the alloy.

BRIEF DESCRIPTION

Disclosed is an airfoil including: a composition gradient defining a first coefficient of thermal expansion and a second coefficient of thermal expansion that differs from the first coefficient of thermal expansion; and a thermoelectric junction operationally coupled to the composition gradient, wherein the composition gradient is formed of either of a plurality of dissimilar metals or of plastic with fillings or fibers.

In addition to one more aspects of the airfoil, or as an alternate, the airfoil includes a base formed by the composition gradient defining the first coefficient of thermal expansion and the second coefficient of thermal expansion that differs from the first coefficient of thermal expansion, so that: the base defines an outer boundary and beads within the outer boundary, each of the beads has a bead void, and each of the beads includes: first and second perimeter segments that are opposite each other and formed to define the first CTE; and third and fourth perimeter segments that are opposite each other, adjacent to the first and second perimeter segments, and formed to define the second CTE; and the thermoelectric junction is provided around the outer boundary or in one or more of the bead voids.

In addition to one more aspects of the airfoil, or as an alternate, each perimeter segment has a radial inner portion and a radial outer portion; the radial inner portion of the first and second perimeter segments is formed of to define the first CTE and the radial outer portion of the first and second perimeter segments is formed to define the second CTE; and the radial inner portion of the third and fourth perimeter segments is formed to define the second CTE and the radial outer portion of the third and fourth perimeter segments is formed to define the first CTE.

In addition to one more aspects of the airfoil, or as an alternate, adjacent ones of the beads are interconnected to form a lattice.

In addition to one more aspects of the airfoil, or as an alternate, the outer boundary defines a first outer end and a second outer end, wherein the first and second outer ends are opposite each other, and the base includes a top elastomer layer that is disposed against the first outer end of the outer boundary and a bottom elastomer layer that is disposed against the second outer end of the outer boundary.

In addition to one more aspects of the airfoil, or as an alternate, the base includes an elastomer segment that extends from each of the beads that are located along the outer boundary of the base, so that adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.

In addition to one more aspects of the airfoil, or as an alternate, the base includes a support material that forms a support structure that defines the outer boundary of the base

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and a plurality of base voids, wherein each of the plurality of base voids is lined with one of the beads.

In addition to one more aspects of the airfoil, or as an alternate, the support material differs from the bead.

In addition to one more aspects of the airfoil, or as an alternate, the beads define an oval or diamond shape.

In addition to one more aspects of the airfoil, or as an alternate, the thermoelectric junction is a Peltier airfoil.

In addition to one more aspects of the airfoil, or as an alternate, the composition gradient is formed of a first material having the first CTE and a second materials having the second CTE, and one or both of the first and second materials is a bistable metal, alloy or composite.

In addition to one more aspects of the airfoil, or as an alternate, the airfoil includes a base defining a first CTE, and a second CTE that differs from the first CTE, wherein the base defines an outer boundary and extends in a first direction from first end to a second end and in a second direction from a first side to a second side, so that: a first layer extends in the first direction between the first and second ends to define the first CTE; a second layer extends in the first direction between the first and second ends to define the second CTE, wherein a layer junction is defined between the first and second layers; and a thermoelectric junction extends along the layer junction or the outer boundary.

In addition to one more aspects of the airfoil, or as an alternate, the base includes a chain of connected elements.

In addition to one more aspects of the airfoil, or as an alternate, the elements define an arcuate shape.

In addition to one more aspects of the airfoil, or as an alternate, one or both of the first and second layers are formed of first and second materials, one or both of which is a bistable metal, alloy or composite.

In addition to one more aspects of the airfoil, or as an alternate, the thermoelectric junction is a Peltier airfoil.

BRIEF DESCRIPTION OF THE DRAWINGS

The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1A shows an aircraft according to embodiment;

FIG. 1B shows an airfoil according to an embodiment, where the airfoil has a first camber profile;

FIG. 1C shows the same airfoil of FIG. 1B with a second camber profile;

FIG. 2 shows a section of the airfoil, having a base formed of a lattice of beads utilizing composition gradients across the hoop-shaped walls, having inner and outer surfaces, to define perimeter segments along the walls of the beads, where the segments have different coefficients of thermal expansion (CTE) selected to provide a predetermined deformation, and where the lattice is formed with a thermoelectric junction;

FIG. 3 shows the lattice of beads in a normal state;

FIG. 4 shows the lattice of beads in a deformed state;

FIG. 5 shows an embodiment of a bead utilized in the configuration shown in FIGS. 2-4, where the bead is in a normal state;

FIG. 6 shows the bead of FIG. 5 in a deformed state;

FIG. 7 shows the lattice of beads of FIG. 2 with top and bottom elastomer layers;

FIG. 8 shows a plurality of the beads, from the lattice of beads of FIG. 2, with an elastomer segment extending from each bead, over an adjacent bead, to form a continuous elastomer boundary;

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FIG. 9 shows an alternate configuration of the section of the airfoil, having a base that defines voids, where ones of the voids are lined with the beads shown in FIGS. 2-4, and a thermoelectric junction is formed either within at least one of the beads or around the base, and where the base is in a normal state;

FIG. 10 shows the section of FIG. 9 in a deformed state;

FIG. 11 shows another configuration of the section of the airfoil, having a base formed of a composition gradient defined by two material layers that extend alongside each other, where the two material layers have different CTEs selected to provide a predetermined deformation when subjected to heating, where a thermoelectric junction is formed between the two material layers, and where the section is in a normal state;

FIG. 12 shows the section of FIG. 11 in a deformed state;

FIG. 13 shows an alternate configuration relative to the configuration of FIG. 11, where the composition gradient, formed of the two material layers, are formed of semicircular elements connected to one another, and where the section is in a normal state;

FIG. 14 shows the section of FIG. 13 in a deformed state;

FIG. 15 shows an oval shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. 2-10, in a normal state;

FIG. 16 shows the bead of FIG. 15 in a deformed state;

FIG. 17 shows a diamond shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. 2-10, in a normal state;

FIG. 18 shows the bead of FIG. 17 in a deformed state;

FIG. 19 shows a random shaped bead, which may be utilized in the disclosed embodiments shown in FIGS. 2-10, in a normal state;

FIG. 20 shows the bead of FIG. 17 in a deformed state;

FIG. 21 shows an equivalent structure with a composition gradient formed of a plurality of materials having different coefficients of thermal expansion (CTE), at a temperature T_1 ; and

FIG. 22 shows the structure of FIG. 21 at a temperature $T_2 > T_1$.

DETAILED DESCRIPTION

A detailed description of one or more embodiments of the disclosed apparatus and method are presented herein by way of exemplification and not limitation with reference to the Figures.

FIG. 1A shows an aircraft 1 having a fuselage 2 with a wing 3 and tail assembly 4, which may have control surfaces 5. The wing 3 may include an engine 6, such as a gas turbine engine, and an auxiliary power unit 7 may be disposed at the tail assembly 4. FIG. 1B shows an airfoil 10 of the aircraft 1 according to an embodiment. The airfoil 10 can be applied to fan blades, helicopter blades, rocket control surfaces, turbine blades, etc. The airfoil may have a leading edge 10A, a trailing edge 10B, a chord extending 10C between the leading and trailing edges 10A, 10B, and the airfoil skin 10D may define a first camber profile. FIG. 1C shows the same airfoil with a second camber profile, which is increased relative to the first camber profile, by pitching an aft portion 10E of the airfoil relative to a forward portion 10F. That is, a pitch region 10G is located at an intersection between the forward and aft portions 10F, 10E.

In one embodiment, as shown in FIG. 2, the airfoil 10 may be additively manufactured with a base 70, utilized at least for the pitch region 10G of the airfoil of FIGS. 1A-1B, formed to have a composition gradients across the hoop-

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shaped walls 50, having an outer surface 52, an inner surface 54, to define first through fourth perimeter segments 110, 120, 130, 140 along the walls of the beads. The segments 110, 120, 130, 140 have different coefficients of thermal expansion (CTE) selected to provide a predetermined deformation. The lattice is formed with a thermoelectric junction. The composition gradient may be formed of a first material having a first coefficient of thermal expansion (CTE) and a second material having a second CTE that differs from the first CTE. The composition gradient may be formed by the utilization of different metals or may be formed by plastic, fillings or fibers. The base 70 may define an outer boundary 80 and a lattice of beads 90 within the boundary 80. The beads 90 may have an oval cross section, though such shape is not intended on limiting the scope of the embodiments.

Each of the beads 90 may have a bead void 100 or cavity and may include the first and second perimeter segments 110, 120 that are opposite each other. The beads 90 may include the third and fourth perimeter segments 130, 140 that are opposite each other, adjacent to the first and second perimeter segments 110, 120. With this configuration, each of the beads 90 forms a circumferential (or perimeter) CTE gradient.

Adjacent ones of the beads 90 may be interconnected with each other, e.g., along the perimeter segments 110-140. With this interconnected configuration, the beads 90 form the lattice.

A thermoelectric junction 150 may be disposed in one more of the bead voids 100, or may be disposed around the boundary 80 of the base 70. The thermoelectric junction 150 may form a Peltier or a Thomson device. For example, alternating P and N-type pillars made with materials with different Seebeck coefficients, or legs, are placed thermally in parallel to each other and electrically in series and joined with a thermally conducting plate on each side, e.g., ceramic, including a cooling plate 160 and a heating plate 170. When a voltage is applied to the free ends of the two semiconductors, via connections 190 there is a flow of DC current across the junction of the semiconductors, causing a temperature difference. The side with the cooling plate 160 absorbs heat which is then transported by the semiconductor to the other side of the device. One of the cooling plate 160 or heating plate 170 may be exposed to the atmosphere if desired to bleed energy from it rather than directing energy from it back to the airfoil 10.

The beads 90 may be formed of a bistable metal, alloy or composite. The beads 90 may be configured to change shape by a predetermined amount when subject to thermal input, e.g., heat, due to the second CTE obtained with the composition gradient. For example, when the beads 90 are subject to thermal input from the thermoelectric junction 150 (FIG. 2), shape of the base 70 may change from a first state (FIG. 3) to a second state (FIG. 4). In the first state, the base 70 may extend in a first direction (or length direction) to define a first length L_1 and in a second direction (or width direction) to define a first width W_1 . In the second state the base 70 may extend in the first direction to define a second length L_2 and in the second direction to define a second width W_2 . From the shape change, one of the first length and width L_1 , W_1 may be greater or smaller than a corresponding one of the second length and width L_2 , W_2 . As shown in FIGS. 3 and 4, the first width W_1 is greater than the second width W_2 and the first and second lengths L_1 , L_2 are the same as each other.

As shown in FIGS. 5 and 6, in one embodiment, each perimeter segment 110-140 may have a radial inner portion 200 (the above noted inner surface 54) and a radial outer

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portion **210** (the above noted outer surface **52**). It is to be appreciated that the use of the term radial in this context does not require a circular cross section but rather references a distance from a center of the bead **90**. The inner portion **200** of the first and second perimeter segments **110**, **120** may be formed to have a first CTE and the outer portion **210** of the first and second perimeter segments **110**, **120** may be formed to have a second CTE. As indicated, this may be obtained from different metals (e.g., first and second materials corresponding to first and second metals) or from plastic, fillings, or fibers. The inner portion **200** of the third and fourth perimeter segments **130**, **140** may be formed to have the second CTE and the outer portion **210** of the third and fourth perimeter segments **130**, **140** may be formed to have the first CTE. FIG. 5 shows the bead **90** in a first state when the thermoelectric junction **150** (FIG. 2) is not providing thermal input and FIG. 6 shows the bead in a second state when thermoelectric junction **150** is providing thermal input. The embodiment shown in FIGS. 5 and 6 provides a radial CTE gradient that results in a tailored deformation of the beads **90** upon receiving thermal input from the thermoelectric junction **150**.

As shown in FIG. 7, the outer boundary **80** defines a first outer end **230** and a second outer end **240**. The first and second outer ends **230**, **240** are opposite each other. In one embodiment, a top elastomer layer **250** is disposed against the top end **230** of the outer boundary **80** and a bottom elastomer layer **260** is disposed against the bottom end **240** of the outer boundary **80**.

As shown in FIG. 8, in one embodiment, an elastomer segment **270** extends from each of the beads **90** disposed at the outer boundary **80** of the lattice of beads **90**. With this configuration, adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.

Turning to FIGS. 9 and 10, in one embodiment, the base **70** of the airfoil **10** may be manufactured with a support structure **280** that may define the outer boundary **80** of the base **70** and internal base voids **290** or cavities. Each of the base voids **290** may be lined with one of above disclosed beads **90** and thus have a cavity surface **300** defining a cross sectional shape that is complementary to the shape of the beads **90**. The support structure **280** may be formed of a support material that differs from the bead material. An exterior surface **85**, surrounding the outer boundary **80** of the base **70**, maybe be coated with the materials that form the bead **90**. The support material may be an elastomer, a metal, an alloy or a composite. A thermoelectric junction **150** may be provided around the outer boundary **80** or in one or more of the bead voids **100**.

FIGS. 9 and 10 show the base **70** in the first state, having a first length and width **L1**, **W1**, and the second state, having a second length and width **L2**, **W2**. As indicated above, from the shape change, one of the first length and width **L1**, **W1** may be greater or smaller than a corresponding one of the second length and width **L2**, **W2**. In the illustrated embodiment, the second width **W2** is smaller than the first width **W1** and the first and second lengths **L1**, **L2** are the same as each other.

FIGS. 11 and 12 show another embodiment in which the airfoil **10** may be additively manufactured to form a base **70** having a composition gradient. The composition gradient may define a first CTE, and a second CTE that differs from the first CTE. As indicated, this may be obtained from different metals (e.g., first and second materials corresponding to first and second metals) or from plastic, fillings, or fibers. The base **70** extends in a first direction (e.g., a length direction) from first end **310** to a second end **320** and in a

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second direction (e.g., a width direction) from a first side **330** to a second side **34**. The base **70** defines an outer boundary **80**. The first CTE may be formed from a first composition layer **350** that extends in the first direction between the first and second ends **310**, **320**, and in the second direction between the first side of the base **70** and a layer junction **370**. The second CTE may be formed in a second composition layer **360** that extends in the first direction between the first and second ends **310**, **320**, and in the second direction between the second side **340** and the composition junction **370**. That is, the first and second layers **350**, **360** extend alongside each other. With this configuration, a transverse CTE gradient is formed in the base **70**. A thermoelectric junction **150** may extend along the first direction at the layer junction **370**, between the first and second composition layers **350**, **360**, or along the boundary **80** of the base **70**.

The first and second composition layers each may be a bistable metal, alloy or composite. The base **70** may extend in the first direction by a first length **L1** and in the second direction by a first width **W1**. Due to the different coefficients of thermal expansion, when subjected to thermal input by the thermoelectric junction **150**, the base **70** may deform as shown in FIG. 11 to form an arcuate shape. When in the deformed state, a longer side of the base **70** may have a length **L2** that is greater than the first length **L1**, though projected along first direction the base **70** has a second length **L2x** that is shorter than the first length **L1**. The width may be unchanged.

As shown in FIGS. 13 and 14, between opposite ends **310**, **320**, in one embodiment the first and second layers form a chain of elements **380** connected at circumferential ends **390**, **400**. The elements **380** are illustrated as having a semicircular shape, though that is not intended on limiting the scope of the embodiments. FIG. 13 shows the base **70** is in a normal state, having a first length **L1**. FIG. 14 shows the base **70** in a deformed state, from thermal input from the thermoelectric junction **150**, having a second length **L2** which is smaller than the first length **L1**.

FIG. 15 shows an oval shaped bead **90**, which may be formed as indicated above, in a normal state having a first width **W1**. FIG. 16 shows the oval bead **90** in a deformed state having a second width **W2** that is less than the first width **W1**. As indicated, the beads **90** do not need to be arcuate in shape. FIG. 17 shows a diamond shaped bead **90** in a normal state having a first width **W1**. FIG. 18 shows the diamond shaped bead **90** in a deformed state having a second width **W2** that is less than the first width **W1**. FIG. 19 shows a random shaped bead **90** in a normal state having a first width **W1**. FIG. 20 shows the random shaped bead **90** in a deformed state having a second width **W2** that is less than the first width **W1**. The desired deformation shape may determine the shape of the bead **90**.

FIGS. 21 and 22 show an equivalent structure **405** to the structures shown above and for example in FIGS. 11-12. Specifically, the first and second composition layers **350**, **360** are at a temperature **T1** in FIG. 21, and **T2** that is greater than **T1** in FIG. 22. The controlled thermal expansion shown in FIG. 22 results from the composition layers being integrally connected. That is, the first and second composition layers **350**, **360** bend together in a predictable and controlled way. That is, the controlled thermal expansion of the first and second composition layers **350**, **360** in the disclosed embodiments provides for controlled manipulation of the airfoil disclosed herein.

As can be appreciated, utilizing the above disclosed configurations to form the airfoil **10**, the camber of the

airfoil may be selectively increased or decreased to change flow characteristics around it, e.g., to modify lift and drag, by applying thermal input to the materials, e.g., along the outer boundary **80** of the base **70** or, within one or more of the bead voids **100**. That is, driving current across the thermoelectric junction **150** in a first direction may increase camber and driving the current across the thermoelectric junction **150** in a second direction may decrease camber. Thus, a controllable airfoil may be obtained without the need for a movable part.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the present disclosure. As used herein, the singular forms “a”, “an” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms “comprises” and/or “comprising,” when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or airfoils, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element airfoils, and/or groups thereof.

Those of skill in the art will appreciate that various example embodiments are shown and described herein, each having certain features in the particular embodiments, but the present disclosure is not thus limited. Rather, the present disclosure can be modified to incorporate any number of variations, alterations, substitutions, combinations, sub-combinations, or equivalent arrangements not heretofore described, but which are commensurate with the scope of the present disclosure. Additionally, while various embodiments of the present disclosure have been described, it is to be understood that aspects of the present disclosure may include only some of the described embodiments. Accordingly, the present disclosure is not to be seen as limited by the foregoing description, but is only limited by the scope of the appended claims.

What is claimed is:

1. An airfoil comprising:

a composition gradient defining a first coefficient of thermal expansion (CTE) and a second (CTE) that differs from the first coefficient of thermal expansion; and

a thermoelectric junction operationally coupled to the composition gradient,

wherein the composition gradient is formed of either of a plurality of dissimilar metals or of plastic with fillings or fibers;

a base formed by the composition gradient defining the first coefficient of thermal expansion and the second coefficient of thermal expansion that differs from the first coefficient of thermal expansion, so that:

the base defines an outer boundary and beads within the outer boundary,

each of the beads has a bead void, and each of the beads includes:

first and second perimeter segments that are opposite each other and formed to define the first CTE; and

third and fourth perimeter segments that are opposite each other, adjacent to the first and second perimeter segments, and formed to define the second CTE; and

the thermoelectric junction is provided around the outer boundary or in one or more of the bead voids.

2. The airfoil of claim 1, wherein:

each perimeter segment has a radial inner portion and a radial outer portion;

the radial inner portion of the first and second perimeter segments is formed to define the first CTE and the radial outer portion of the first and second perimeter segments is formed to define the second CTE; and

the radial inner portion of the third and fourth perimeter segments is formed to define the second CTE and the radial outer portion of the third and fourth perimeter segments is formed to define of the first CTE.

3. The airfoil of claim 1, wherein:

adjacent ones of the beads are interconnected to form a lattice.

4. The airfoil of claim 1, wherein:

the outer boundary defines a first outer end and a second outer end, wherein the first and second outer ends are opposite each other, and

the base includes a top elastomer layer that is disposed against the first outer end of the outer boundary and a bottom elastomer layer that is disposed against the second outer end of the outer boundary.

5. The airfoil of claim 1, wherein

the base includes an elastomer segment that extends from each of the beads that are located along the outer boundary of the base, so that adjacent ones of the elastomer segments overlap each other to define a flexible outer boundary cover.

6. The airfoil of claim 1, wherein:

the base includes a support material that forms a support structure that defines the outer boundary of the base and a plurality of base voids, wherein each of the plurality of base voids is lined with one of the beads.

7. The airfoil of claim 6, wherein:

the support material differs from the bead.

8. The airfoil of claim 1, wherein:

the beads define an oval or diamond shape.

9. The airfoil of claim 1, wherein:

the thermoelectric junction is a Peltier airfoil.

10. The airfoil of claim 1, wherein the composition gradient is formed of a first material having the first CTE and a second materials having the second CTE, and one or both of the first and second materials is a bistable metal, alloy or composite.

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