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(71) Applicant: **Goodrich Corporation**
Charlotte, NC 28217-4578 (US)

(72) Inventors:
- **HEIN, Brandon**
  Kent, OH, 44220 (US)
- **SLANE, Casey M.**
  Tallmadge, OH, 44278 (US)
- **WERBELOW, Jeffrey M.**
  Phoenix, AZ, 85048 (US)
- **BOTURA, Galdemir C.**
  Copley, OH, 44321 (US)
- **HAMMAN, Matthew**
  Fairview Park, OH, 44126 (US)
- **KESTLER, Steven**
  San Diego, CA, 92104 (US)
- **LACALLE, Javier**
  San Diego, CA, 92131 (US)

(74) Representative: **Dehns**
St. Bride's House
10 Salisbury Square
London EC4Y 8JD (GB)

(54) A MULTILAYER STRUCTURE WITH CARBON NANOTUBE HEATERS

(57) A multilayer heating structure for controlling ice accumulation on a surface of an aircraft includes a carbon nano-tube (CNT) heater. The heater includes: a CNT layer; a first encapsulation layer (304) disposed on a first side of the CNT layer formed of a first encapsulation layer thermoplastic material; and a second encapsulation layer (306) disposed on a second side of the CNT layer formed of a second encapsulation layer thermoplastic material. The structure further includes for and aft composite structures (402, 404). The first and second encapsulation layer thermoplastic materials have higher melting temperatures that one or both the fore composite structure thermoplastic material and the aft composite structure thermoplastic material.

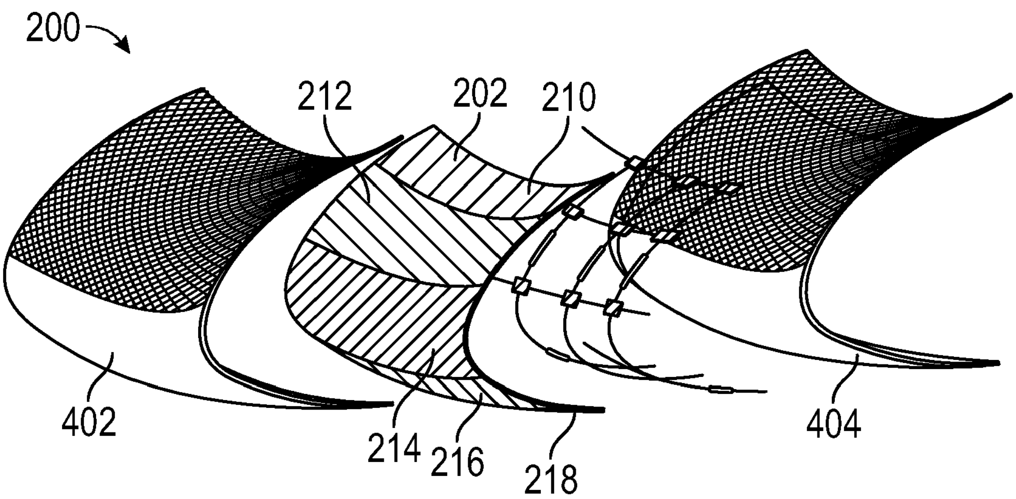

FIG. 2

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Description

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation in part of U.S. Application No. 17/568,402 filed January 4, 2022, which claims the benefit of U.S. Provisional Application No. 63/256,673 filed October 18, 2021.

BACKGROUND

[0002] The present invention relates to ice protection systems, and more specifically, an ice protection device that includes carbon nanotubes integrated into a thermoplastic composite structure.

[0003] Aircraft can be exposed to weather conditions that allow ice to form on its surfaces. Ice can be formed on the surfaces of the aircraft such as the windscreen, wings, tail, and air intake components before or during flight. The build up of ice can lead to adverse operation such as blocking needed engine airflow or inhibiting the operation of the wings or other components. In addition, damage to other components and the safety of the aircraft and passengers can result. Aircraft equipped with heating components can include electric heaters to protect the aircraft. There may be a need to ensure the proper operation of the heating components over the life of the aircraft.

[0004] Carbon nanotubes (CNT) are allotropes of carbon having a generally cylindrical nanostructure, and have a variety of uses in nanotechnology, electronics, optics and other materials sciences. CNT is both thermally and electrically conductive. Due to these properties, CNT can be used as a heating element to prevent icing on aircraft or other vehicles.

[0005] CNT heater mats or other more standard etched metallic foil or wire-wound heater mats are typically manufactured with thermoset materials. This construction typically leads to a multi-step curing process leading to high manufacturing costs. Typical materials also have lower temperature limits which can lead to design limitations. This construction is typically thicker than needed which requires a higher power demand. These materials also do not allow for heater mat repair and require replacement.

BRIEF DESCRIPTION

[0006] Disclosed in one embodiment is a multilayer heating structure for controlling ice accumulation on a surface of an aircraft. The structure includes: a carbon nano-tube (CNT) heater comprising: a CNT layer; a first encapsulation layer disposed on a first side of the CNT layer formed of a first encapsulation layer thermoplastic material; and a second encapsulation layer disposed on a second side of the CNT layer formed of a second encapsulation layer thermoplastic material.

[0007] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the structure can also include: a fore composite structure that includes a fore composite structure thermoplastic material disposed on the first side of CNT heater; and an aft composite structure that includes an aft composite structure thermoplastic material disposed on the first side of CNT heater.

[0008] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the fore and aft composite structure thermoplastic materials are the same thermoplastic material.

[0009] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the fore and aft composite structure thermoplastic materials are the same as thermoplastic material of the first and second encapsulation layer thermoplastic materials.

[0010] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the aft composite structure can directly contact the second encapsulation layer. Alternatively, the aft composite structure can be spaced from and not directly contact the second encapsulation layer.

[0011] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the CNT layer includes carbon nanotubes.

[0012] In addition to one or more of the features described above, or as an alternative to any of the foregoing embodiments, the CNT layer can further include one or more metal layers.

[0013] Also disclosed is second multilayer heating structure for controlling ice accumulation on a surface of an aircraft that includes: a carbon nano-tube (CNT) heater; a fore composite structure that includes a composite structure thermoplastic material disposed on the first side of CNT heater; and an aft composite structure that includes an aft composite structure thermoplastic material disposed on the second side of CNT heater.

[0014] In addition to one or more of the features described above related to the second structure, or as an alternative to any of the foregoing embodiments, the fore and aft composite structure thermoplastic materials can be the same thermoplastic material.

[0015] In addition to one or more of the features described above related to the second structure, or as an alternative to any of the foregoing embodiments, the fore and aft composite structure thermoplastic materials can be the same as thermoplastic material of the first and second encapsulation layer thermoplastic materials.

[0016] In addition to one or more of the features described above related to the second structure, or as an alternative to any of the foregoing embodiments, the CNT heater includes a CNT layer that includes carbon nanotubes.

[0017] In addition to one or more of the features described above related to the second structure, or as an alternative to any of the foregoing embodiments, the CNT layer further includes one or more metal layers.

[0018] Also disclosed is method of forming either the two above embodiments. The method can include: receiving a carbon nano-tube (CNT) heater comprising: a CNT layer, a first encapsulation layer disposed on a first side of the CNT layer formed of a first encapsulation layer thermoplastic material a second encapsulation layer disposed on a second side of the CNT layer formed of a second encapsulation layer thermoplastic material; receiving a fore composite structure that includes a fore composite structure thermoplastic material; disposing the fore composite structure on the first side of CNT heater; receiving an aft composite structure that includes an aft composite structure thermoplastic material; disposing the aft composite structure disposed on the second side of CNT heater to form an assembly that includes the CNT heater, the fore composite structure and the aft composite structure; and heating the assembly to at least partially melt the fore and aft composite structure thermoplastics and the first and second encapsulation layer thermoplastic bond to them assembly together.

[0019] In addition to one or more of the features described above related to the method, or as an alternative to any of the foregoing embodiments, heating includes providing heat with the CNT heater.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020] The following descriptions should not be considered limiting in any way. With reference to the accompanying drawings, like elements are numbered alike:

FIG. 1 is a perspective view of an aircraft showing different locations where a de-icing assembly to embodiments herein can be utilized;

FIG. 2 shown an exploded view of a structure with embedded CNT heating elements according to one embodiment;

FIG. 3 shows a sectional view of a portion of the CNT heater shown in FIG. 2;

FIG. 4 shows a sectional view of a portion of the assembly shown in FIG. 2;

FIG. 5 shows an exploded view of a structure with embedded CNT heating elements according to one embodiment that includes addition layers relative to FIG. 2;

FIG. 6 shows a sectional view of a portion of assembly shown in FIG. 5;

FIG. 7 shows an exploded view of a structure with embedded CNT heating elements according to one embodiment that includes only one of the additional layers of FIG. 5;

FIG. 8 shows an exploded view of a structure with embedded CNT heating elements according to one embodiment that includes only a different one of the additional layers of FIG. 5; and

FIG. 9 shows an example sensor layer according to one embodiment.

DETAILED DESCRIPTION

[0021] 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.

[0022] According to an embodiment, a heater mat is disclosed. The mat includes carbon nanotube heating elements in a mat that is bonded internally within a thermoplastic structure.

[0023] FIG. 1 is a perspective view of aircraft 10 including wings 12, horizontal stabilizers 14, and fuselage 16. Wings 12 include leading edges 18 and horizontal stabilizers 14 include leading edges 20. Of course, the aircraft could also include vertical stabilizers and the teachings herein are also applicable to them.

[0024] In the illustrated configuration of FIG. 1, aircraft 10 is of a fixed-wing design. Fuselage 16 extends from nose section 22 to tail section 24, with wings 12 fixed to fuselage 16 between nose section 22 and tail section 24. Horizontal stabilizers 14 are attached to fuselage 16 on tail section 24. Wings 12 and horizontal stabilizers 14 function to create lift and to prevent pitching, respectively, for aircraft 10. Wings 12 and horizontal stabilizers 14 include critical suction surfaces, such as upper surfaces 26 of wings 12 and lower surfaces 28 of horizontal stabilizers 14, where flow separation and loss of lift can occur if icing conditions form on any of the surfaces of wings 12 and horizontal stabilizers 14. FIG. 1 also shows structures with embedded CNT heating elements 30 mounted onto leading edges 18 of wings 12 and onto leading edges 20 of horizontal stabilizers 14. In other non-limiting embodiments, structures with embedded CNT heating elements 30 can be mounted onto any leading edge or non-leading edge surface of aircraft 10. Structures with embedded CNT heating elements 30 function generating heat so as to prevent ice from forming on or shed ice formed on any of the above noted surfaces. Further, it should be noted that the assemblies could be mounted to an engine lip and engine induction deicers generally shown by reference number 31.

[0025] In more detail, and as shown in FIG. 2, there is provided in one embodiment, a multilayer structure 200 that includes a heater mat 202. In one embodiment, the heater mat is formed as a carbon nano-tube (CNT) heater.

[0026] With reference also to FIG. 3, which shows a more detailed version of the CNT heater 202 of structure of FIG. 2. As illustrated, the CNT heater 202 includes a heating layer 300.

[0027] In a non-limiting example, the heating layer 300 includes at least one sheet of a carbon allotrope material, such as carbon nanotubes (CNT), which have a generally cylindrical structure. A CNT sheet can be formed from CNT suspended in a matrix, a dry CNT fiber, or a CNT yarn, to name a few non-limiting examples. In other embodiments, the carbon allotrope material of the CNT heater 202 includes graphene, graphene nanoribbons (GNRs), or other suitable carbon allotropes. Graphene has a two-dimensional honeycomb lattice structure, and GNRs are strips of graphene with ultrathin widths.

[0028] Further, it should be noted that the heating layer 300 can be a heating assembly that includes several layers. The layer 300 can include, for example, the structure as disclosed in U.S. Patent No. 11,167,856 that includes a composite of CNT and silicon surrounded by metal layers.

[0029] As illustrated, the CNT heater 202 also includes first and second (or fore and aft) encapsulation layers 304, 306. The encapsulation layers are formed of a thermoplastic material. Examples of such materials include materials that become molten when heated, solid when cooled, and can be re-melted or molded after cooling. The curing process is completely reversible, and doing so will not compromise the material's physical integrity.

[0030] Prior art CNT heaters typically utilize thermoset materials. In contrast to the encapsulation layers 304, 306 show in FIG. 3, using thermoset materials will create irreversible chemical bonds during curing. As such, a thermoset material cannot be melted/reversed, and this current state of the art makes repairing a heater or assembly difficult if not impossible.

[0031] Examples of materials that can be used as thermoplastic dielectric encapsulation layers 304, 306 include, but are not limited to polyether ether ketone (PEEK), thermoplastic polyimide, or Polyaryletherketone (PAEK).

[0032] It shall be understood that because the thermoplastic encapsulation layers 304, 306 can be heated and reformed, if there is damage to either them or the heating layer 300, the combination thereof can be heated and separated.

[0033] With reference now to FIGs. 2 and 4 an embodiment of a multilayer structure that includes a CNT heater 202 is illustrated. In this embodiment, the CNT heater 202 is surrounded by composite structures 402, 404. The composite structures 402, 404 can be formed of a thermoplastic in one embodiment. In one embodiment, the composite structures 402, 404 are formed of same thermoplastic as thermoplastic encapsulation layers 304, 306. In another, the composite structures 402, 404 are formed of a different thermoplastic than thermoplastic encapsulation layers 304, 306.

[0034] In one embodiment, encapsulation layers 304, 306 are formed of a thermoplastic that has a higher melting temperature than the composite structures 402, 404. To form the heating layer 300, the thermoplastic material of the encapsulation layers 304, 306 can be melted so that the material infuses between the carbon nanotubes of the heating layer 300. Then the composite structures 402, 404 are added as described elsewhere herein. Such a version may result in smaller heating layer 300 and, thus, reduce the amount of material needed in the full assembly structure which will lead to less power required from the CNT heater for ice protection. The heating layer 300 (or CNT layer) thermoplastic material can, thus, be different than one or both of the composite structures 402, 404 thermoplastic materials. In one example, the encapsulation layers 304, 306 can be formed of PEEK resin and layers 402/404 may be formed of a PAEK resin

[0035] The CNT heater 202 can be provided and then bonded to the composite structures 402, 404 by adding heat. In one embodiment, some or all of the heat can be provided by the CNT heater.

[0036] Embodiments herein may reduce manufacturing complexity/costs and decrease power required from the heater mat during operation. This will also allow for the heater mat to be repaired or replaced instead of having to discard the entire structural component thus decreasing repair and maintenance costs. The use of a thermoplastic structure will also provide higher temp limits the heater mat can operate which could decrease design constraints. These features can apply to any of the following examples that are discussed.

[0037] It should be noted that while shown as being directly contacting one another, additional layers or adhesive materials can be disposed between the composite structures 402, 404 and the thermoplastic encapsulation layers 304, 306. Thus, the aft composite structure can directly contact the encapsulation layer 306 in some cases and be separated from (e.g., not in direct contact) it.

[0038] As shown in FIG. 2 and applicable to all embodiments herein, the composite structures 402, 404 can be formed to have a shape such they can be applied to any of the surfaces of an aircraft as shown above. The CNT heaters 202 can be formed into a flat or shaped mat and then place on one of the structures 402, 404 and then other of the structures 402, 404 is provided to encapsulate the CNT heater 202. The structure so formed can then be heated to at least partially melt them to bond the assembly together. Thus, one embodiment, a method of forming a structure that includes receiving a carbon nanotube (CNT) heater as disclosed herein. The method can also include receiving a fore composite structure 402 that includes a fore composite structure thermoplastic material and an aft composite structure 404 that includes an aft composite structure thermoplastic material. The two structures 402, 404 can be placed on opposing sides of the CNT heater 202. OF course, as shown below, other layers or material could be placed between the CNT heater 202 and the structures 402, 404. Heat can then be applied to bond the assembly together.

[0039] FIG. 5 shows another embodiment of an assembly. This assembly includes additional optional layers/elements. The elements include sensors located in a sensor layer 501 and the layer includes a low ice adhesion coating layer 520. It shall be understood that one embodiment is an assembly 700 that only includes the sensor layer 501 (see FIG. 7) and another assembly 800 can include only the low ice adhesion coating layer 520 (FIG. 8).

[0040] As illustrated in FIGs. 5-7, the sensor layer 501 includes sensors 502 are between the CNT heater 202 and the back or aft composite structure 404. Of course, the sensors elements 502 could alternatively be place between the CNT heater 202 and the fore or front composite structure 402.

[0041] In one embodiment, the sensors 502 are an array of fiber optic sensors that can detect one or both temperature and stress/strain on the assemblies 500, 600, 700.

[0042] As shown in FIGs. 5 and 9, the sensors 502 of the sensor layer 501 can include a plurality of temperature sensors 504 and a plurality strain gauge sensors 506. The sensors 504, 506 can be apart of a fiber optic cable 508 in one embodiment. Each fiber optic cable 508 can include both types of sensors 504, 506 which reduces the amount of additional wires that are needed to install the different type of sensors.

[0043] In one or more embodiments of the disclosure, the plurality of sensors 504, 506 is apart of each fiber optic cable 508, and the individual readings from sensors 504, 506 on the same fiber optic cable 508 can be processed by, for example, a controller 550 in a variety of ways.

[0044] For example, the controller 550 can process each signal from corresponding sensors 504, 506 using a known time delay or wavelength. Each of the sensors 504, 506 can be associated with a particular location of the aircraft for mapping. FIG. 5 illustrates a fixed number of sensors, however, it should be understood that any number of sensors and placement of the sensors can be used. In addition, although the arrangement of fiber optic-based sensors is on a surface of a substrate 550, it can be appreciated the sensors can be placed directly on the for or aft composite structure 402, 404. Thus, in one embodiment the sensor layer includes a substrate 550 that supports the sensors and in another it does not.

[0045] As shown, the cables 508 extend in the horizontal direction in FIG. 9 and the vertical direction in FIGs. 5 and 7 to illustrate that either orientation is possible. In the non-limiting example, the sensors 504, 506 can be arranged in a manner that they line up with a plurality of zones 210-218 of the heater 202 for monitoring the various zones. The zones in the heater 202 are shown in FIG. 2 but can apply to all CNT heaters disclosed herein and the orientation can be vertical or horizontal as shown. Example correspondence to the zones in FIG. 2 is shown in FIG. 9.

[0046] The low ice adhesion coating layer 520 of FIGs. 5, 6 and 8 can be any type of coating on which it is difficult for ice to adhere. The low ice adhesion coating layer may comprise polydimethylsiloxane (PDMS), at least one of nanoscale amorphous silica and super hydrophobic nanoparticles, and at least one of a non-reactive hydrophobic additive and a non-reactive hydrophilic additive. The coating may further comprise fluoride. An example of such a layer is more fully described U.S. Patent Application Publication No.US20210179276A1 which is incorporated herein by reference.

[0047] In addition, the low ice adhesion coating layer 520 could be an Ice Phobic Material where any water that runs across it does not turn to ice due to the low ice adhesion. An example of such a material may have low ice adhesion, at least below 200 psi (pounds per square inch), preferably below 100 psi, and typically below 45 psi. Such materials includes multiscale crack initiator promoted super-low ice adhesion surfaces, Slippery Liquid-Infused Nanostructured Surfaces (SLIPS), HygraTek , HybridShield0 by NanoSonic ice phobic coatings, PPG IcePhobic Coating, NANOMYTE SuperAi by NEI Corporation, or other materials/coatings with low ice adhesion.

[0048] The low ice adhesion coating layer 520 can include health monitoring capabilities as well.

[0049] The term "about" is intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application.

[0050] 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 components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, element components, and/or groups thereof.

[0051] While the present disclosure has been described with reference to an exemplary embodiment or embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the scope of the present disclosure. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present disclosure without departing from the essential scope thereof. Therefore, it is intended that the present disclosure not be limited to the particular embodiment disclosed as the best mode contemplated for carrying out this present disclosure, but that the present disclosure will include all embodiments falling within the scope of the claims.

Claims

1. A multilayer heating structure for controlling ice accumulation on a surface of an aircraft, the structure comprising:

   a carbon nano-tube, CNT, heater comprising:

a CNT layer;
a first encapsulation layer (304) disposed on a first side of the CNT layer; and
a second encapsulation layer (306) disposed on a second side of the CNT layer;
a fore composite structure (402) that includes a fore composite structure thermoplastic material disposed on the first side of CNT heater; and
an aft composite structure (404) that includes an aft composite structure thermoplastic material disposed on the second side of CNT heater;
wherein the first and second encapsulation layer thermoplastic materials have higher melting temperatures than one or both the fore composite structure thermoplastic material and the aft composite structure thermoplastic material.

2. The structure of claim 1, wherein the fore and aft composite structure thermoplastic materials are the same thermoplastic material.

3. The structure of claim 1 or 2, wherein the aft composite structure (404) directly contacts the second encapsulation layer (306).

4. The structure of claim 1 or 2, wherein the aft composite structure (404) does not directly contact the second encapsulation layer (306).

5. The structure of any preceding claim, wherein the CNT layer includes carbon nano-tubes.

6. The structure of any of claims 2-5, wherein the CNT layer further include one or more metal layers.

7. A multilayer heating structure for controlling ice accumulation on a surface of an aircraft, the structure comprising:

a carbon nano-tube, CNT, heater encased in a CNT heater thermoplastic material;
a fore composite structure (402) that includes a composite structure thermoplastic material disposed on the first side of CNT heater; and
an aft composite structure (404) that includes an aft composite structure thermoplastic material disposed on the second side of CNT heater;
wherein the CNT heater thermoplastic material has a higher melting temperatures than one or both the fore composite structure thermoplastic material and the aft composite structure thermoplastic material.

8. The structure of claim 7, wherein the fore and aft composite structure thermoplastic materials are the same thermoplastic material.

9. The structure of claim 7 or 8, wherein the CNT heater includes a CNT layer that includes carbon nanotubes.

10. The structure of claim 9, wherein the CNT heater further includes one or more metal layers.

11. A method of forming a multilayer heating structure for controlling ice accumulation on a surface of an aircraft, the structure comprising:

receiving a carbon nano-tube, CNT, heater comprising: a CNT layer, a first encapsulation layer (304) disposed on a first side of the CNT layer formed of a first encapsulation layer thermoplastic material a second encapsulation layer (306) disposed on a second side of the CNT layer formed of a second encapsulation layer thermoplastic material;
receiving a fore composite structure (402) that includes a fore composite structure thermoplastic material;
disposing the fore composite structure (402) on the first side of CNT heater;
receiving an aft composite structure (404) that includes an aft composite structure thermoplastic material;
disposing the aft composite structure (404) disposed on the second side of CNT heater to form an assembly that includes the CNT heater, the fore composite structure (402) and the aft composite structure (404); and
heating the assembly to at least partially melt the fore and aft composite structure thermoplastics and the first and second encapsulation layer thermoplastic bond to them assembly together;
wherein the first and second encapsulation layer thermoplastic materials have higher melting temperatures that one or both the fore composite structure thermoplastic material and the aft composite structure thermoplastic material.

12. The method of claim 11, wherein heating includes providing heat with the CNT heater.

13. The method of claim 11 or 12, wherein the fore and aft composite structure thermoplastic materials are the same thermoplastic material.

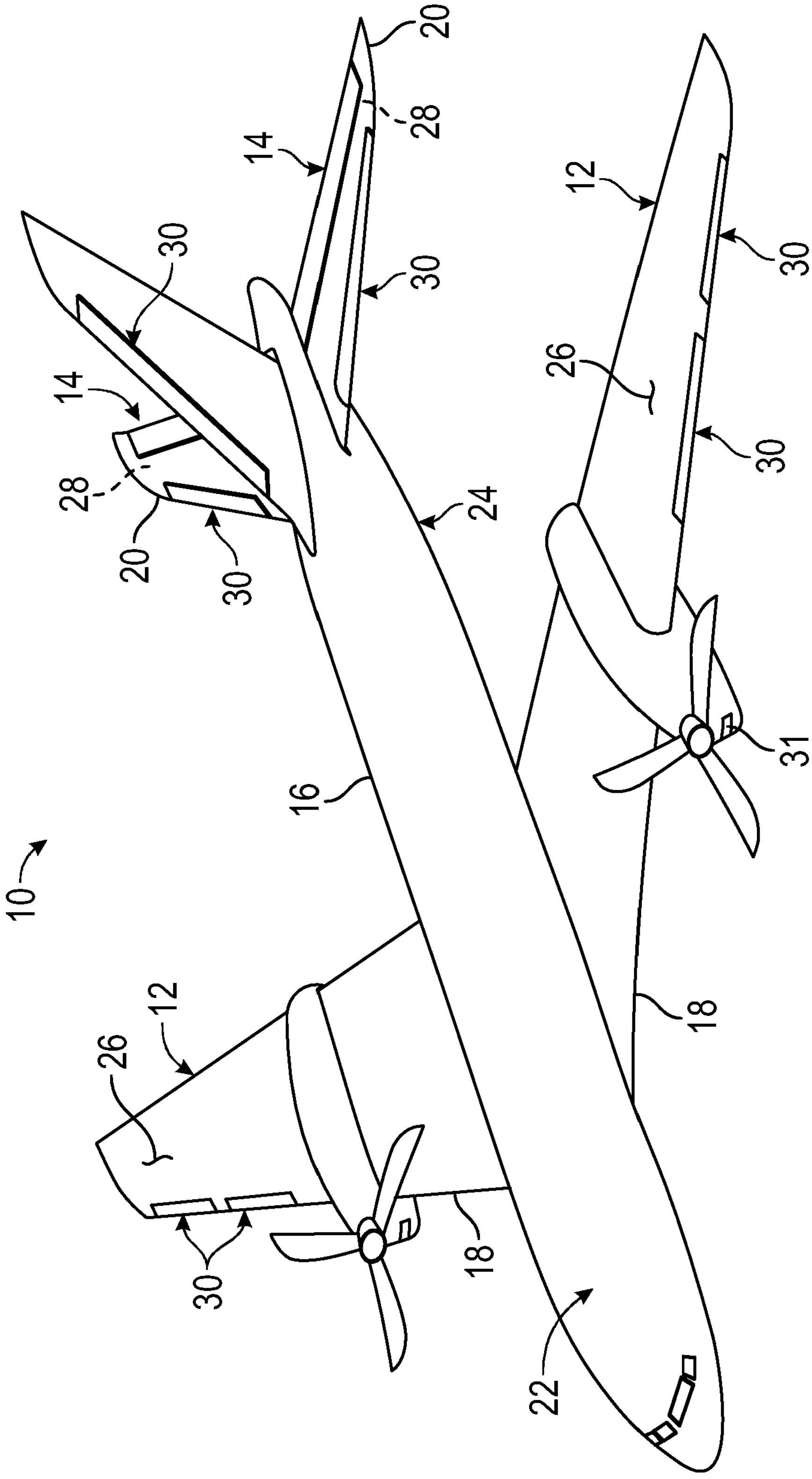

FIG. 1

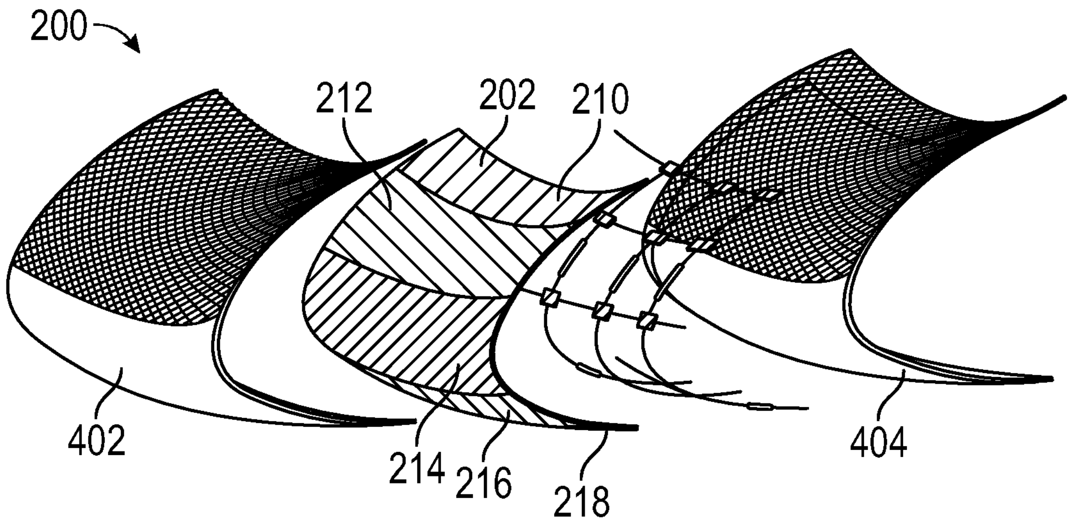

FIG. 2

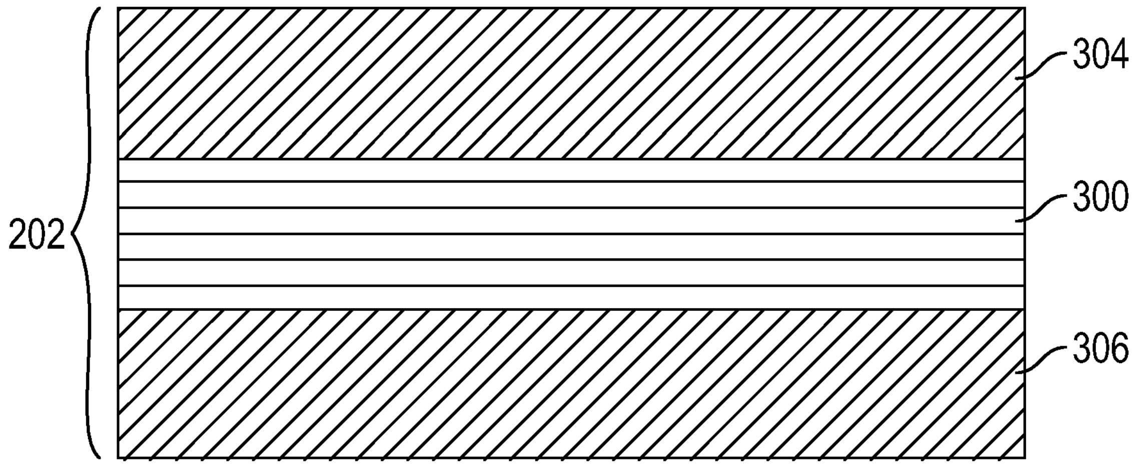

FIG. 3

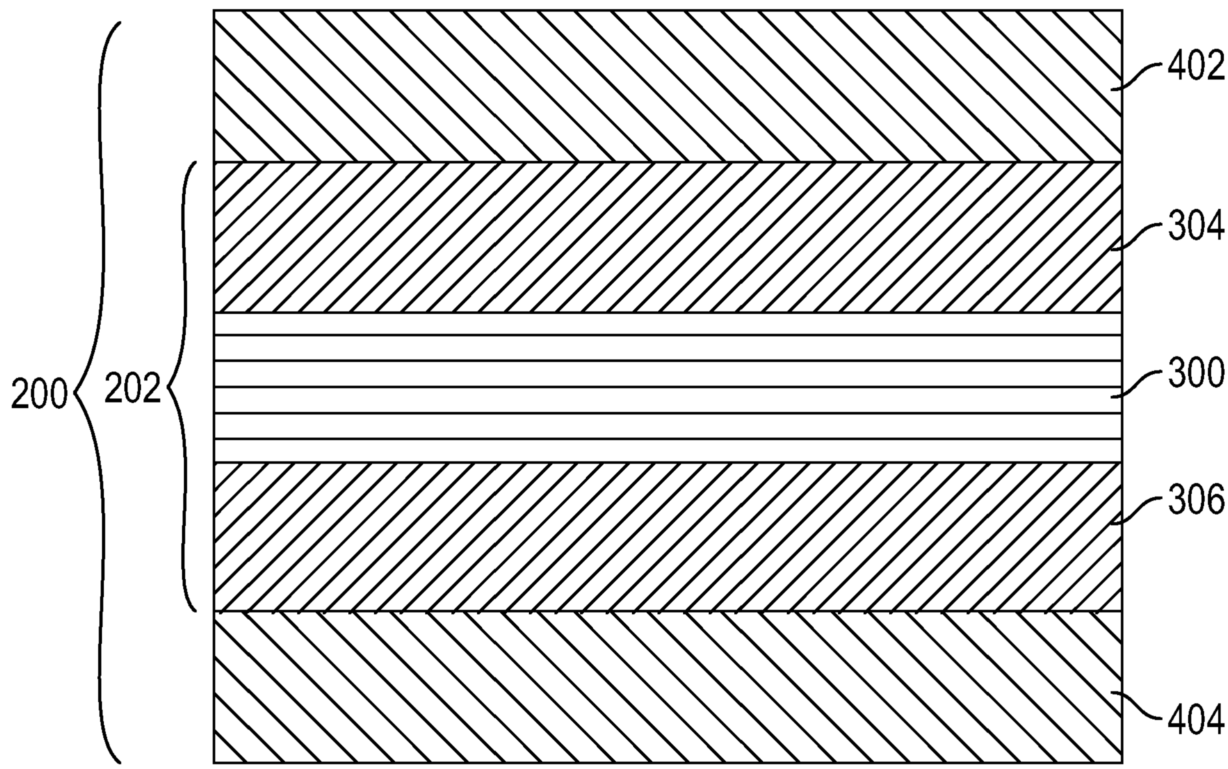
402
304
300
306
404
200
202

FIG. 4

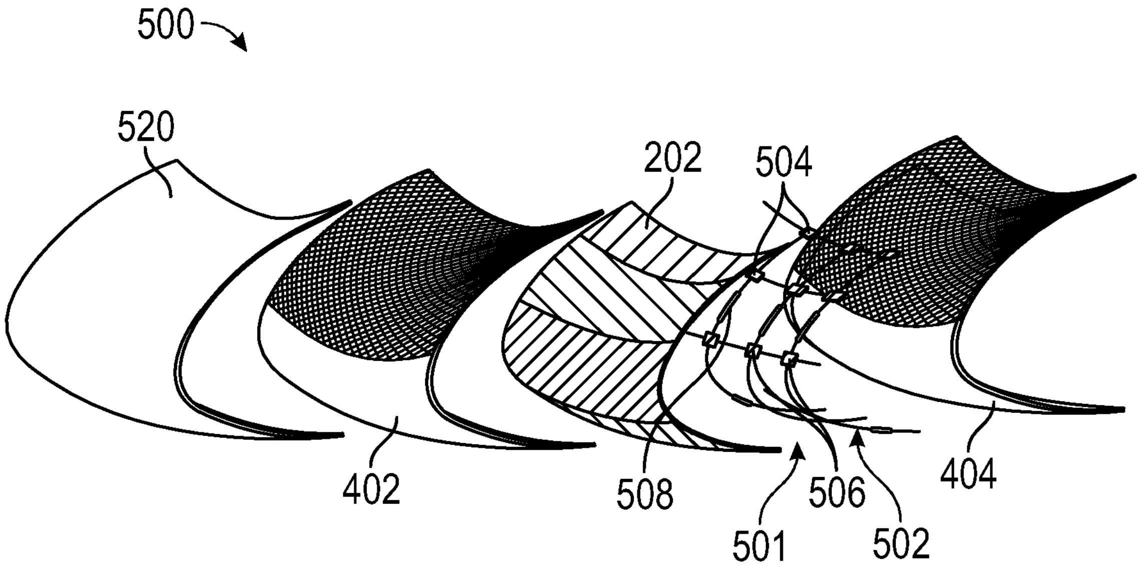
500
520
202
504
402
508
506
404
501
502

FIG. 5

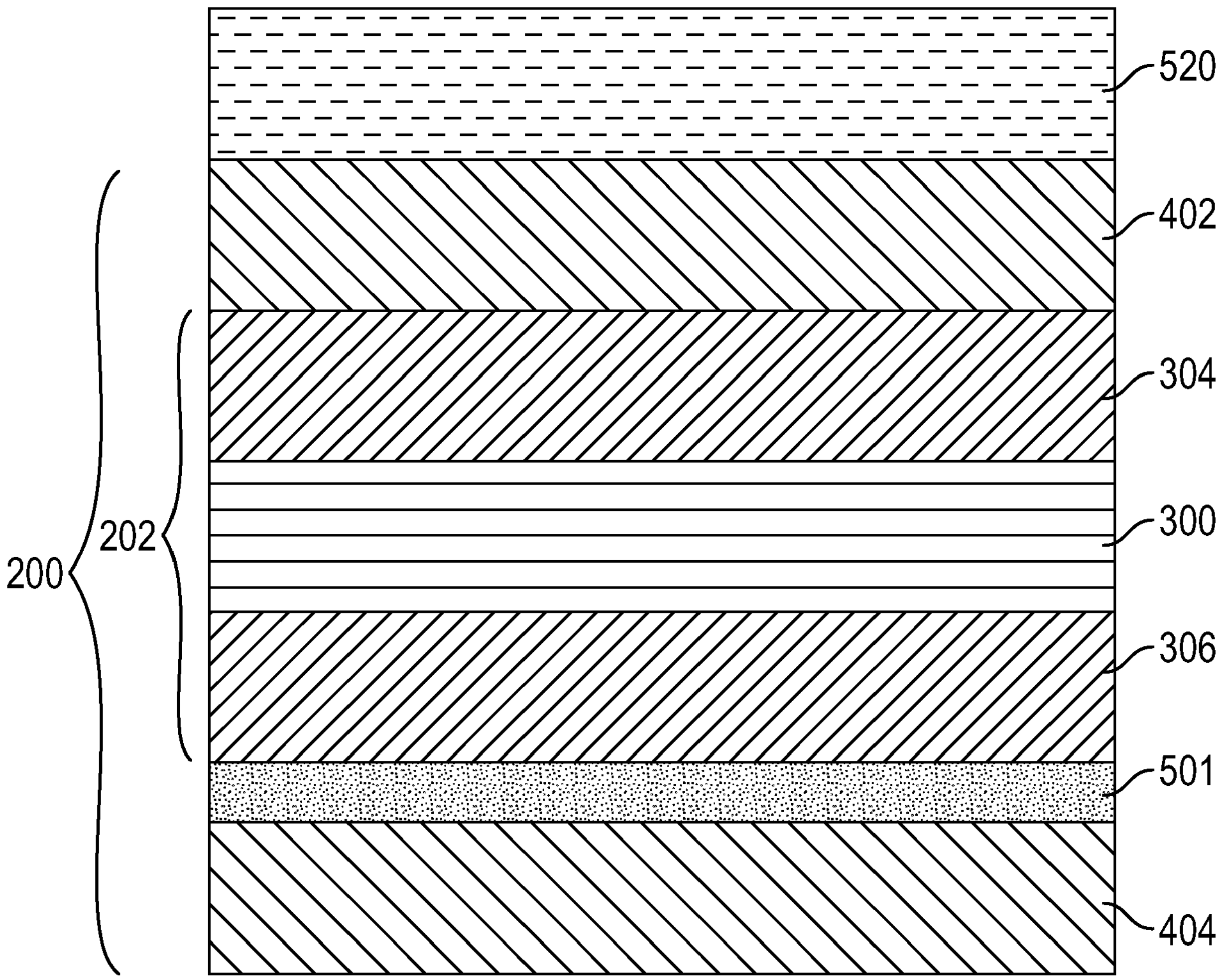

FIG. 6

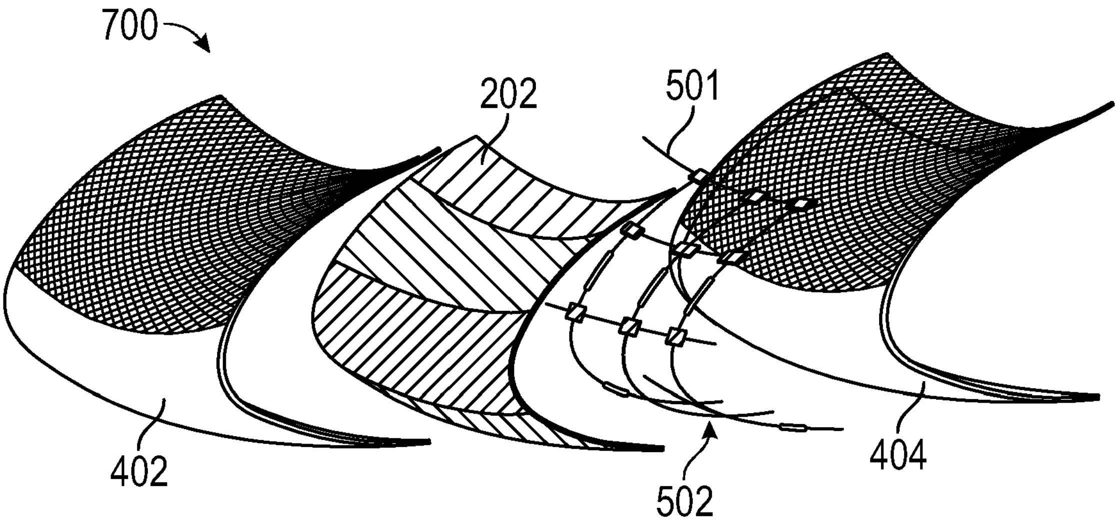

FIG. 7

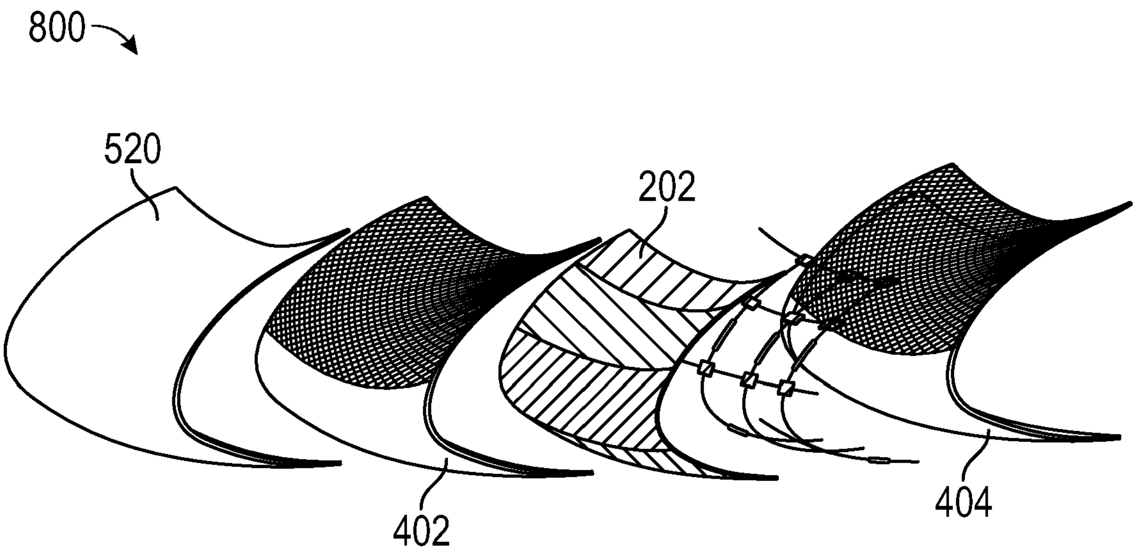
800
520
202
402
404

FIG. 8

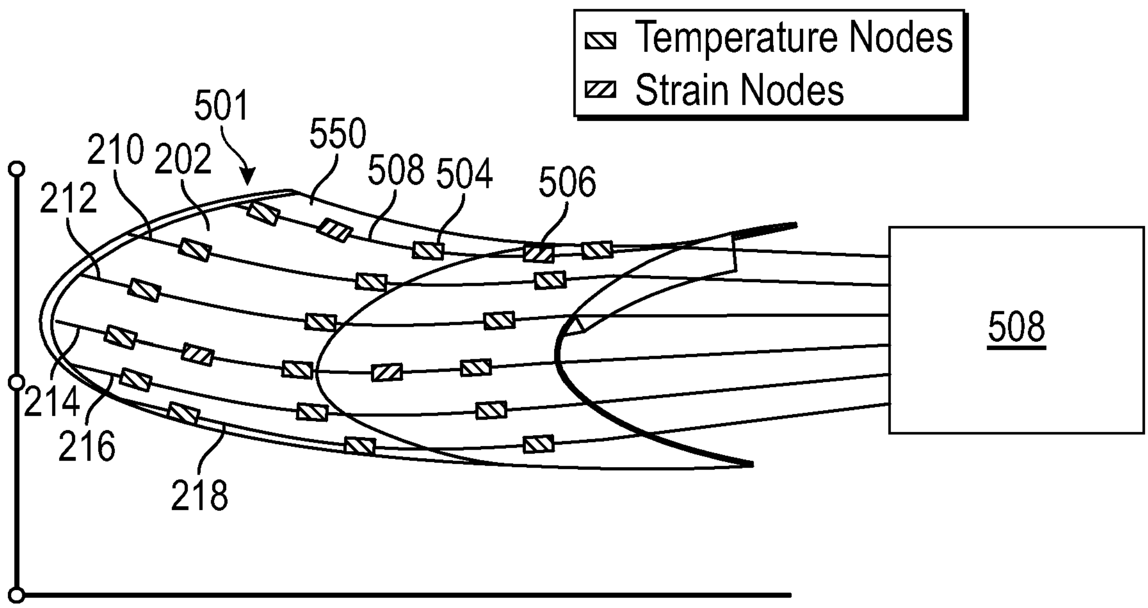
Temperature Nodes
Strain Nodes
501
550
210
202
212
508
504
506
214
216
218
508

FIG. 9

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- US 63256673 **[0001]**
- US 11167856 B **[0028]**
- US 20210179276 A1 **[0046]**