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(54) Title: A TIP CAP FOR A FAN BLADE

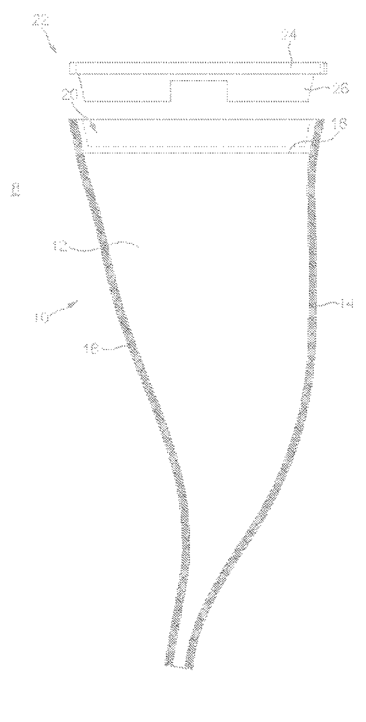

FIG. 2

(57) Abstract: A tip cap (22), (32), (44), (52), (62), (70) for a fan blade (8) of a gas turbine engine comprises: a tip portion (24); and an insert portion (26), (34), (46), (54), (64), (72) arranged to be received in a recess (20) of an aerofoil (10) of a fan blade (8), wherein the insert portion comprises regions of different density. An alternative fan blade 8 for a gas turbine engine comprises: an aerofoil (10) having a tip recess (20) for receiving an insert portion of a tip cap; a tip cap (22), (32), (44), (52), (62), (70) having a tip portion (24) and an insert portion (26), ((34), 46), (54), (64), (72), the insert portion having at least one cut-out (28), (36), (38), (48), (80); wherein the insert portion of the tip cap is disposed within the tip recess of the aerofoil, and wherein a void is defined by the cut-out within the recess.

WO 2015/015207 A1

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A TIP CAP FOR A FAN BLADE

This invention relates to a fan blade for a gas turbine engine. In particular, the invention relates to a tip cap for such a fan blade, a fan blade having a tip cap, a method of manufacturing a tip cap and a method of designing a tip cap.

A turbofan engine has a fan comprising a plurality of fan blades towards its upstream end. Modern fan blades typically have a complex highly swept and twisted shape optimised for aerodynamic performance.

In use, the fan is driven to rotate by a turbine of the engine so that each fan blade accelerates air into the engine and provides propulsive thrust. The performance of the gas turbine engine is improved by having a close fit between the fan blade tips and the inner gas-washed surface of the containment arrangement surrounding the fan. Known containment arrangements comprise an inner abradable layer which defines the gas-washed surface, so as to achieve a close fit between the tips of the fan blades and the gas-washed surface.

For fan blades comprising composite material, it is known to provide a metallic tip cap forming a tip section of the blade which may abrade the abradable layer of the containment arrangement. The tip cap is typically received within and bonded to a recess in the end of the fan blade. A composite material generally comprises two or more constituent materials having different material properties, for example, strength and ductility. A composite material may comprise a matrix material and a fibre reinforcement material.

In use, the aerodynamic load on the fan blade typically acts on the blade in a direction which tends to increase the twist of the blade. In contrast, the centrifugal load on the blade due to the rotation of the blade introduces forces which tend to decrease the twist of the blade. The centrifugal load distribution depends on the mass distribution of the fan blade. The twist and/or untwist forces acting on a fan blade typically influence the radial position of the tip of the fan blade. In other words, the radial tip displacement from the design condition is influenced by the aerodynamic forces and centrifugal forces acting on the blade.

It is known for fan blades to exhibit flutter under certain operating conditions of the turbofan engine in which they are installed. Owing to the shape of modern fan blades, known flutter modes include a leading edge and trailing edge tip flap mode, in which a portion of the blade towards the tip may oscillate or flap around a notional flap axis which is inclined to the spanwise and chordwise directions of the blade. Where flutter is known to occur under certain operating conditions, it may be necessary for the control system of the engine to limit the operation of the engine to avoid those conditions. Such limitations reduce the allowable operational envelope of the engine, and may require complicated control and safety procedures to ensure that the engine is operated within the allowable envelope.

According to a first aspect of the invention there is provided a tip cap for a fan blade of a gas turbine engine, the tip cap comprising: a tip portion; and an insert portion arranged to be received in a recess of an aerofoil of a fan blade; wherein the insert portion comprises regions of different density. The regions of different density may be provided by different materials

The regions of different density may comprise first and second materials respectively. The second material may be denser than the first material. The insert portion may predominantly comprise the first material.

A region comprising the second material may be disposed substantially at a central chord-wise portion of the insert. Alternatively, or in addition, a region comprising the second material may be disposed substantially at a leading edge chord-wise position and/or a region comprising the second material may be disposed substantially at a trailing-edge chord-wise position.

The insert portion may be a monolithic structure. That is to say, the insert portion may be a unitary body in which the regions of different density are not separable from each other without destroying the body.

The insert portion may comprise a support structure comprising the first material to which at least one body comprising the second material may be mounted.

The first aspect of the present invention also provides a fan blade for a gas turbine engine comprising a tip cap in accordance with the first aspect of the invention.

According to a second aspect of the invention there is provided a fan blade for a gas turbine engine comprising: an aerofoil having a tip recess for receiving an insert portion of a tip cap; a tip cap having a tip portion and an insert portion, the insert portion having at least one cut-out; wherein the insert portion of the tip cap is disposed within the tip recess of the aerofoil, and wherein a void is defined by the cut-out within the recess.

The cut-out or at least one of the cut-outs may be formed in a central chord-wise portion of the insert portion. Alternatively, or in addition, the cut-out or at least one of the cut-outs may be formed in a leading-edge chord-wise portion of the insert portion and/or the cut-out or at least one of the cut-outs may be formed in a trailing-edge chord-wise portion of the insert portion. The cut-out or at least one of the cut-outs may extend span-wise or transverse to the chord of the blade. The void may be unfilled with any solid or liquid material.

In a fan blade in accordance with the first or second aspect of the invention, the aerofoil may be hollow. The fan blade may be made from a metallic material such as titanium or a titanium alloy.

Alternatively, at least the aerofoil of the fan blade may be made from a composite material. The fan blade may comprise leading edge and/or trailing edge metalwork and/or tip metalwork. The tip metalwork may define the recess for the insert portion of the tip cap.

The tip cap of a fan blade in accordance with the second aspect of the invention may be in accordance with the first aspect of the invention.

According to a third aspect of the invention there is provided a method of manufacturing a tip cap comprising: a tip portion; and an insert portion arranged to be received in a recess of an aerofoil of a fan blade; wherein the insert portion comprises regions of different density; the method comprising a stereo lithographic process in which the regions of different density are produced from different materials. The different materials may be different metal compositions.

The stereo lithographic process may, for example, be an Additive Layer Manufacturing (ALM) process.

At least one region of low density may be produced from aluminium or titanium, and at least one region of high density may be produced from depleted uranium, nickel or tungsten. For example, the respective materials may be deposited at different regions of the workpiece during the manufacturing process.

According to a fourth aspect of the invention there is provided a method of designing a tip cap of a fan blade for a gas turbine engine, the fan blade comprising: an aerofoil having a tip recess for receiving an insert portion of a tip cap; a tip cap having a tip portion and an insert portion, wherein the insert portion of the tip cap is disposed within the tip recess of the aerofoil, the method comprising the steps of: defining at least a first tip cap and a second tip cap, the insert portions of the tip caps having different chord-wise mass distributions; determining at least one of the flutter characteristics and the tip displacement characteristics of fan blades comprising the respective tip caps; and selecting one of the tip caps based on the flutter characteristics and/or tip displacement characteristics.

At least one of the first and second tip caps may be in accordance with the first aspect of the invention.

A fan blade comprising at least one of the first and second tip caps may be in accordance with the second aspect of the invention.

The method may be a computer implemented method.

The second tip cap may be defined based on the flutter characteristics and/or the tip displacement characteristics of at least a first tip cap as part of an iterative process.

The invention may comprise any combination of the features and/or limitations referred to herein, except combinations of such features as are mutually exclusive.

Embodiments of the invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 schematically shows in cross-sectional view a turbofan engine having a fan disposed within a fan casing;

Figure 2 schematically shows in exploded view a fan blade of the fan of Figure 1, comprising an aerofoil provided with a tip cap;

Figure 3 schematically shows in perspective view a first embodiment of a tip cap;

Figure 4 schematically shows in perspective view a second embodiment of a tip cap;

Figure 5 schematically shows in perspective view a third embodiment of a tip cap;

Figure 6 schematically shows in cross section view the insert portion of the tip cap of Figure 5;

Figure 7 schematically shows a side view of a fourth embodiment of a tip cap;

Figure 8 schematically shows in cross-sectional view the tip cap of Figure 7.

Figure 9 schematically shows a side view of a fifth embodiment of a tip cap;

Figure 10 schematically shows in cross-sectional view the tip cap of Figure 9;

Figure 11 schematically shows a side view of a sixth embodiment of a tip cap;

Figure 12 schematically shows a cross-sectional view of the tip cap of Figure 11; and

Figure 13 is a flowchart representing a tip cap design process.

The engine 6 shown in **Figure 1** has a fan 2 housed within a fan casing comprising a containment 4. The fan 2 comprises a plurality of fan blades 8, which extend from a fan disc 11 to the radially inner gas-washed surface of the containment 4. The gas-washed surface of the containment arrangement 4 is provided by a radially inner abradable layer 9 of the containment arrangement 4.

As shown in **Figure 2**, the fan blade 8 comprises an aerofoil 10 and a tip cap 22 which, in the assembled fan blade 8, is fixedly secured to the aerofoil 10.

The aerofoil 10 has a twisted, swept, wide-chord form. The aerofoil 10 predominantly comprises a composite body 12 which is bounded by leading edge, trailing edge and tip metalwork 14, 16, 18.

The leading edge and trailing edge metalwork 14, 16 is in the form of titanium alloy sheaths protecting the leading edge and trailing edge of the aerofoil 10. The leading edge and trailing edge metalwork 14, 16 is bonded to the composite body 12 within corresponding recesses (not shown) such that the gas-washed surface of the aerofoil 10 is continuous over the metalwork 14, 16 and the composite body 12.

The leading edge and trailing edge metalwork 14, 16 is integrally formed with the tip metalwork 18 which is thus made from the same titanium alloy. The tip metalwork 18 is also bonded to the composite body 12 such that the gas-washed surface of the aerofoil 10 is continuous over the composite body 12 and the tip metalwork 18. The tip metalwork 18 occupies the radially outer portion of the aerofoil 10 of the fan blade 8, and defines a tip recess 20 having a radially outer opening for receiving an insert portion 26 of the tip cap 22, as will be described in detail below. The tip recess 20 is of substantially uniform depth within the tip metalwork 18 (i.e. in a radial direction), and has a substantially uniform chordwise cross-section throughout its depth. The chordwise cross-section of the recess is defined by the internal surfaces of the tip metalwork 18, so that in this embodiment the tip metalwork 18 provides a wall of substantially uniform thickness around the recess. Accordingly, the chordwise cross-section of the tip recess 20 is similar to the outer profile of the aerofoil 10 towards its tip.

The tip cap 22 comprises a tip portion 24 and an insert portion 26. The tip portion comprises a coating of a thermally insulating material, for example, cobalt boron nitrate, so as to prevent transfer of heat generated by the tip portion 24 rubbing against the abradable layer 9 of the containment arrangement 4 to the insert portion 26, the tip recess 20 and the composite body 12 of the aerofoil 10. In this embodiment, the coating is electrodeposited The tip portion 24 is integrally formed with the insert portion 26, and the insert portion 26 is fixedly secured to the tip metalwork 18, for example, by bonding or by a mechanical connection.

A notional benchmark insert portion may be defined as an insert portion of uniform density which fills the tip recess 20 defined by the inner walls of the tip metalwork 18. Consequently, the mass distribution of the benchmark insert portion is solely a function of the general profile of the tip recess. In contrast to such a notional benchmark insert portion, insert portions according to the invention are configured to have particular mass distributions along their length (i.e. chordwise of the fan blade 8) which differ from the mass distribution of such a notional benchmark insert portion. The mass distributions of such insert portions are configured to influence the flutter characteristics and/or the displacement of the fan blade 8 under centrifugal load.

For example, a tip cap comprising an insert portion having increased mass towards the leading edge and/or trailing edge may give a fan blade more favourable flutter characteristics when compared with the same fan blade comprising the notional benchmark insert portion. For example, the onset frequency of fan blade flutter may be increased when compared with a fan blade having the notional benchmark insert portion.

As shown in **Figure 3**, in one embodiment of the invention the tip cap 22 comprises an insert portion 26 having a cut-out 28 located over a substantially central chord-wise length of the insert portion and extending transverse to the chord of the insert portion 26. When the insert portion 26 is received in the substantially uniform tip recess 20 of the aerofoil 10, the cut-out 28 defines a void within the recess 20, which is left unfilled, and so the mass of the insert portion 26 is concentrated at the leading and trailing ends of the insert portion 26.

The tip cap 32 of **Figure 4** differs from the tip cap 22 shown in Figure 3 in that the insert portion 34 has two cut-outs 36, 38 located respectively in leading and trailing edge chordwise lengths of the insert portion. The cut-outs 36, 38 extend transverse to the chord of the insert portion 34. When the insert portion 34 is received in the substantially uniform tip recess 20 of the aerofoil 10, the cut-outs 36, 38 define voids within the recess 20,which is left unfilled, and so the mass of the insert portion 34 is concentrated at the central region of the insert portion.

In the embodiments of Figures 3 and 4, the cut-outs 28, 36, 38 may extend fully or partially across the thickness of the respective insert portions 26, 34.

The tip cap 44 of **Figures 5 and 6** differs from the tip cap 22 of Figure 3 in that the insert portion 46 has a cut-out 48 located over a substantially central chordwise length of the insert portion 46 and extending in a substantially spanwise direction of the insert portion. In other words, the cut-out 48 is formed in the radially inner base of the insert portion 46 and projects radially outwardly into the insert portion 46. When the insert portion 44 is received in the substantially uniform tip recess 20 of the aerofoil 10, the cut-out 48 defines a void within the recess 20, which is left unfilled, and so the mass of the insert portion 46 is concentrated at the leading and trailing ends of the insert portion 46.

In the embodiments shown in Figures 3 to 6, the insert portions 26, 34, 46 of the tip caps 22, 32, 44 respectively are monolithic components having a substantially uniform composition and density. The effect of the unfilled voids defined within the tip recess 20 is that a fan blade 8 comprising either one of the tip caps 22, 32, 44 has a different mass distribution at its tip when compared with the mass distribution of the same fan blade 8 having a tip cap provided with the notional benchmark insert portion as described above. In other words, providing at least one cut-out extending over a chord-wise length of the insert portion over of a tip cap can be used to achieve a particular desired mass distribution of the tip cap.

The tip cap 52 shown in **Figures 7 and 8** comprises an insert portion 54 of substantially uniform depth along its chord. In this embodiment, the insert portion 54 does not comprise any cut-outs. Instead, the insert portion 54 comprises a low density region 56 composed of a low density material and two high density regions 58, 60 composed of a high density material. In this embodiment, the low density region 56 forms the predominant part of the insert portion 54 in that the entire insert portion 54 is entirely composed of the low density material except for two substantially cuboid high density regions 58, 60 embedded within the low density material and extending over a substantially leading edge chordwise length and a substantially trailing edge chordwise length of the insert portion 54 respectively.

The tip cap 62 shown in **Figures 9 and 10** differs from the tip cap 52 shown in Figures 7 and 8 in that the insert portion 64 comprises a single high density region 68 embedded within a low density region 66 forming the predominant part of the insert portion 64. The high density region 68 is embedded within and extends over a substantially central chord-wise length of the insert portion 64.

In the embodiments shown in Figures 7 to 10, the tip caps 52, 62 comprise regions of different density which comprise different materials respectively. For example, the low density regions may be composed of aluminium, titanium, an aluminium alloy or a titanium alloy. Further, the high density regions may be composed of depleted uranium, tungsten, nickel, or alloys thereof.

The effect of providing regions of different density is that a fan blade 8 comprising either one of the tip caps 52, 62 has a different mass distribution at its tip when compared with the mass distribution of the same fan blade 8 having a tip cap with a notional benchmark insert portion as described above. In other words, providing regions of high density and low density in the insert portion can be used to achieve a particular desired mass distribution of a tip cap.

The insert portion of a tip cap may comprise any combination of cut-outs, low density regions and high density regions as illustrated above. For example, as shown in **Figures 11 and 12**, a tip cap 70 according to an embodiment of the invention comprises an insert portion 72 having a predominant low density region 74 and high density regions 76, 78 embedded within the low density region 74 and extending over a substantially leading edge chord-wise length and a substantially trailing edge chord-wise length of the insert portion 72 respectively. The insert portion 72 also comprises a cut-out 80 extending transverse to the chord of the insert portion 72 over a substantially central chord-wise length of the insert portion 72.

In use, tip caps according to the invention are fixedly secured to tip metalwork 18 of the aerofoil section 10. One method of securing a tip cap to the tip metalwork 18 of the aerofoil section 10 is to apply an adhesive to the insert portion of the tip cap and/or to the tip recess 20, insert the insert portion of the tip cap into the tip recess 20 and cause or allow the adhesive to cure so as to form a bond. Alternatively, the insert portion may be fixedly secured within the tip recess 20 defined within the tip metalwork 18 by a mechanical connection.

The insert portion and tip portion of a tip cap may be manufactured separately and subsequently secured together, or may be integrally formed. Insert portions having a substantially uniform composition, such as the insert portions 26, 34, 46 of the tip caps 22, 32, 44 shown in Figures 3 to 6, may be manufactured in a two-step process in which the insert portion is first formed without any cut-outs, for example by a casting process, and in which a cut-out is subsequently machined in the insert portion. Alternatively, the insert portion may be formed with one or more cut-outs, for example by a casting process.

Tip caps may also be manufactured using an additive manufacturing or direct metal deposition process, which is sometimes referred to as 3D printing or stereolithography.

In an additive manufacturing process for creating insert portions having regions of different density, two different materials are used. The materials, which may be in powder or granular form at the start of the additive manufacturing process, are selectively deposited in appropriate locations over successive layers to build up the low density regions and high density regions respectively. The material deposited in each layer is bonded to the material of the previous layer or layers, for example, by laser sintering or electron beam melting. An insert portion manufactured in this way has a monolithic structure, despite comprising distinct regions of different material. In other words, the high density regions and low density regions are integrally formed.

The invention also relates to a method of designing a tip cap for a fan blade, and in particular to a method of designing the insert portion of the tip cap so as to achieve a mass distribution which provides favourable flutter characteristics and/or tip displacement characteristics of the fan blade under centrifugal load.

The method may be an automated or semi-automated method implemented in a computer, in which a plurality of fan blade models having different tip caps are defined, simulation conditions are set, static and/or dynamic optimisation criteria are set, static and/or dynamic analysis of the blade model is performed, and a suitable tip cap is selected, either as a final design or as a basis for a new variant design in an iterative process.

The fan blade model simulates a fan blade 8 as defined herein, and correspondingly comprises an aerofoil including a standard tip recess. The tip recess is referred to as standard since it does not change during the automated method.

The fan blade model also includes a tip cap model comprising a tip portion and an insert portion. The insert portion is defined by a number of variables which include: the number, shape, size and location of any low density regions, high density regions and cut-outs; and the material and/or density of the low density regions and high density regions. For insert portions having a uniform composition, the insert portion may be modelled as a single low density region or as a single high density region.

Static and/or dynamic simulation conditions are set which define the operating conditions at which static and/or dynamic analysis of the fan blade model is to be performed. For example, for a fan blade of a turbofan engine for an aircraft, the simulation conditions may include all or a part of the flight envelope of the aircraft. The simulation conditions may include air temperature, pressure, fan revolutions per minute and airflow characteristics (e.g. turbulence). In a further example, the simulation conditions may relate to only a part of the flight envelope of an aircraft, for example, a part in which it is known for fan blade flutter to occur.

Static and/or dynamic optimisation criteria are set depending on the desired static or dynamic performance of the fan blade. For example, it may be desirable to ensure that the tip displacement of the fan blade under static centrifugal load is reduced to a minimum. Further, it may be desirable that the dynamic response of the fan blade is such that flutter does not occur over a part or all of the operational envelope of the turbofan engine.

Static optimisation criteria may therefore be defined as a desired or a minimum tip displacement. Dynamic optimisation criteria may be defined as a specific flutter onset frequency, or a safety threshold for the flutter onset frequency defined relative to the frequency of aerodynamic loading which the fan blade is subjected to at the associated simulation conditions. The optimisation criteria may comprise multiple optimisation criteria for a multiobjective optimisation process.

Complex optimisation criteria may be defined based on desirable flutter and/or tip displacement characteristics at a plurality of different simulation conditions, as is known in the art of multiobjective optimisation. For example, for a gas turbine engine for an aircraft, it may be necessary to optimise the tip cap such that the flutter onset frequency remains above the aerodynamic loading frequency of a fan over all or a part of the flight envelope of the aircraft.

As shown in Figure 13, one embodiment of the automated method is an iterative method. A user or an automated process first defines the standard design criteria 202, the optimisation criteria 214 (as described above), termination criteria 210, and the static and/or dynamic simulation conditions 204 (as described above). The standard design criteria 202 are constraints to which the tip cap models 170 must adhere, such as the size of the tip recess in the aerofoil 110 of the fan blade model 108 and materials which may be used. The termination criteria 210 may be set by a user or selected from a predetermined set of termination criteria. For example, for an iterative process, the termination criteria may be a number of iterations to perform, or a minimum threshold between the flutter and/or tip displacement characteristics for the two most favourable tip cap models 170. There may also be a minimum number of iterations that must be performed (e.g. 100 iterations).

In the iterative process, an initial tip cap model 170 is defined by a tip cap definition process 200, taking into account the standard design criteria 202. The aerofoil model 110 is then combined with the tip cap model 170 to define a fan blade model 108.

Static and/or dynamic modelling 206 of the fan blade model 108 is performed based on the static and/or dynamic simulation conditions 204, to calculate the flutter and/or tip displacement characteristics of the fan blade model 108 having the respective tip cap model 170.

The tip cap model 170 and/or its design variables (e.g. cut-out location and size, location and size of high density and/or low density regions) are sent to a database 208 where they are correlated with the corresponding flutter and/or tip displacement characteristics of the fan blade model 108 having the respective tip cap model 170.

The termination criteria 210 are evaluated in an evaluation step 211. If the termination criteria 210 are not met, a new tip cap model 170 is defined in a definition process 212, based on the optimisation criteria 214 set or selected by the user, the standard design criteria 202 and the previous tip cap models 170 and their associated flutter and/or tip displacement characteristics, retrieved from the database 208. The new tip cap model 170, having a different mass distribution from previous tip cap models 170, is defined by adjusting the variables that define the insert portion, as described above.

A new fan blade model 108 is then created and the process is repeated until the termination criteria 210 are met. Once the termination criteria 210 are met, the optimum tip cap model 170 is selected in a selection step 216. The design of the optimum tip cap model 170 may then be implemented in a manufacturing process and installed in an aerofoil 10 to form an optimum fan blade 8.

The definition of the plurality of tip caps 170, the performance of the static and/or dynamic analysis of fan blade models 108 comprising the respective tip caps 170, and the selection of an optimum tip cap 170 may proceed based on any number of simulation and selection procedures as are known in the art.

For example, the simulation and selection procedure may be a brute force process in which a plurality of tip cap models 170 are initially defined, a corresponding plurality of fan blade models 108 comprising the tip cap models 170 are subsequently analysed, and a suitable tip cap model 170 is selected based on the optimisation criteria.

Alternatively, the simulation and selection procedure may use a design of experiments method, a Monte Carlo method, or any simulation and selection methodology as is known in the art.

Although embodiments of the invention have been described in which an insert portion comprises one or more regions of high density material which are wholly embedded within low density material, it will be appreciated that in other embodiments a region of high density material may constitute a section of the insert portion adjacent to, but not embedded within, a region of low density material.

Although embodiments of the invention have been described in which an insert portion comprises regions of high and low density material which are integrally formed, for example by an additive manufacturing process, it will be appreciated that in other embodiments regions of one material may be mechanically connected to regions of another material. For example, discrete regions may be mechanically connected by rivets, bolts, or any other suitable fastener. Discrete regions may be bonded together.

Although embodiments of the invention have been described in which the tip metalwork is of substantially constant thickness, it will be appreciated that in other embodiments the tip metalwork may be of non-uniform thickness. For example, the tip metalwork may be provided with reinforcement projections, or castellations, projecting into the tip recess and the insert portion of the tip cap may be provided with corresponding channels, such that the insert portion of the tip cap keys with the tip recess. The insert portion may be mechanically connected to the tip metalwork defining the tip recess with at least one fastener.

Although embodiments of the invention have been described in which the insert portion predominantly comprises regions of low density material with further regions of high density material, it will be appreciated that in other embodiments the insert portion may predominantly comprise regions of high density material, with further regions of low density material.

For the avoidance of doubt, references in above disclosure to regions of low and/or high density material, or to regions having different densities, relate to regions of solid material, and are not intended to refer to cut-outs, voids, or gas-filled or liquid-filled regions.

Although embodiments of the invention have been described in which cut-outs are formed which project partially or fully through the insert portion from one side of the insert portion, it will be appreciated that in other embodiments the tip cap may comprise enclosed voids, for example, when the tip cap is manufactured by an additive manufacturing process.

CLAIMS:

1. A tip cap for a fan blade of a gas turbine engine, the tip cap comprising:

a tip portion; and

an insert portion arranged to be received in a recess of an aerofoil of a fan blade, wherein the insert portion comprises regions of different density, and wherein the regions of different density are provided by different materials.

2. A tip cap according to claim 1, wherein the regions of different density comprise first and second materials respectively.

3. A tip cap according to claim 2, wherein the second material is denser than the first material.

4. A tip cap according to claim 3, wherein the insert portion predominantly comprises the first material.

5. A tip cap according to any one of claims 2 to 4, wherein a region comprising the second material is disposed substantially at a central chord-wise portion of the insert.

6. A tip cap according to any one of claims 2 to 5, wherein a region comprising the second material is disposed substantially at a leading edge chord-wise position and/or wherein a region comprising the second material is disposed substantially at a trailing-edge chord-wise position.

7. A tip cap according to any one of the preceding claims, wherein the insert portion is a monolithic structure.

8. A tip cap according to any one of claims 2 to 6, wherein the insert portion comprises a support structure comprising the first material to which at least one body comprising the second material is mounted.

9. A fan blade for a gas turbine engine comprising a tip cap in accordance with any one of the preceding claims.

10. A method of manufacturing a tip cap comprising:

a tip portion; and

an insert portion arranged to be received in a recess of an aerofoil of a fan blade, wherein the insert portion comprises regions of different density;

the method comprising a stereolithographic process in which the regions of different density are produced from different materials.

11. A method of manufacturing a tip cap according to claim 10, wherein the different materials are different metal compositions.

12. A method of manufacturing a tip cap according to claim 10 or 11, wherein at least one region of low density is produced from aluminium or titanium or alloys thereof, and wherein at least one region of high density is produced from depleted uranium, nickel or tungsten or alloys thereof.

13. A method of designing a tip cap of a fan blade for a gas turbine engine, the fan blade comprising:

an aerofoil having a tip recess for receiving an insert portion of a tip cap;

a tip cap having a tip portion and an insert portion;

wherein the insert portion of the tip cap is disposed within the tip recess of the aerofoil;

the method comprising the steps of:

defining at least a first tip cap and a second tip cap, the insert portions of the tip caps having different chord-wise mass distributions;

determining at least one of the flutter characteristics and the tip displacement characteristics of fan blades comprising the respective tip caps; and selecting one of the tip caps based on the flutter characteristics and/or the tip displacement characteristics.

14. A method according to claim 13, wherein at least one of the first and second tip caps is in accordance with any one of claims 1 to 8.

15. A method according to claim 13 or 14, wherein a fan blade comprising at least one of the first and second tip caps is in accordance with any one of claims 9 to 15.

16. A method according to any one of claims 13 to 15, wherein the method is a computer implemented method.

17. A method according to any one of claims 13 to 16, wherein the second tip cap is defined based on the flutter characteristics and/or the tip displacement characteristics of at least a first tip cap as part of an iterative process.

18. A fan blade for a gas turbine engine comprising:

an aerofoil having a tip recess for receiving an insert portion of a tip cap;

a tip cap having a tip portion and an insert portion, the insert portion having at least one cut-out;

wherein the insert portion of the tip cap is disposed within the tip recess of the aerofoil, and wherein a void is defined by the cut-out within the recess.

19. A fan blade according to claim 18, wherein the cut-out or at least one of the cut-outs is formed in a central chord-wise portion of the insert portion.

20. A fan blade according to claim 18, wherein the cut-out or at least one of the cut-outs is formed in a leading-edge chord-wise portion of the insert portion and/or wherein the cut-out or at least one of the cut-outs is formed in a trailing-edge chord-wise portion of the insert portion.

21. A fan blade according to any one of claims 18 to 20, wherein the cut-out or at least one of the cut-outs extends span-wise or transverse to the chord of the blade.

22. A fan blade according to any one of claims 18 to 21, wherein the void is unfilled with any solid or liquid material.

23. A fan blade according to any one of claims 18 to 22, wherein the tip cap is in accordance with any one of claims 1 to 9.

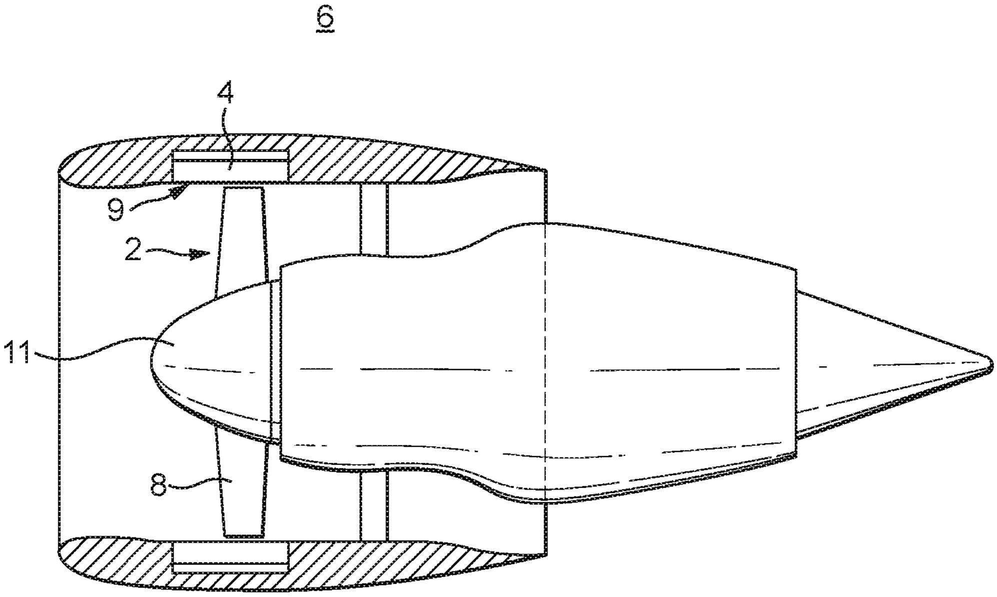

FIG. 1

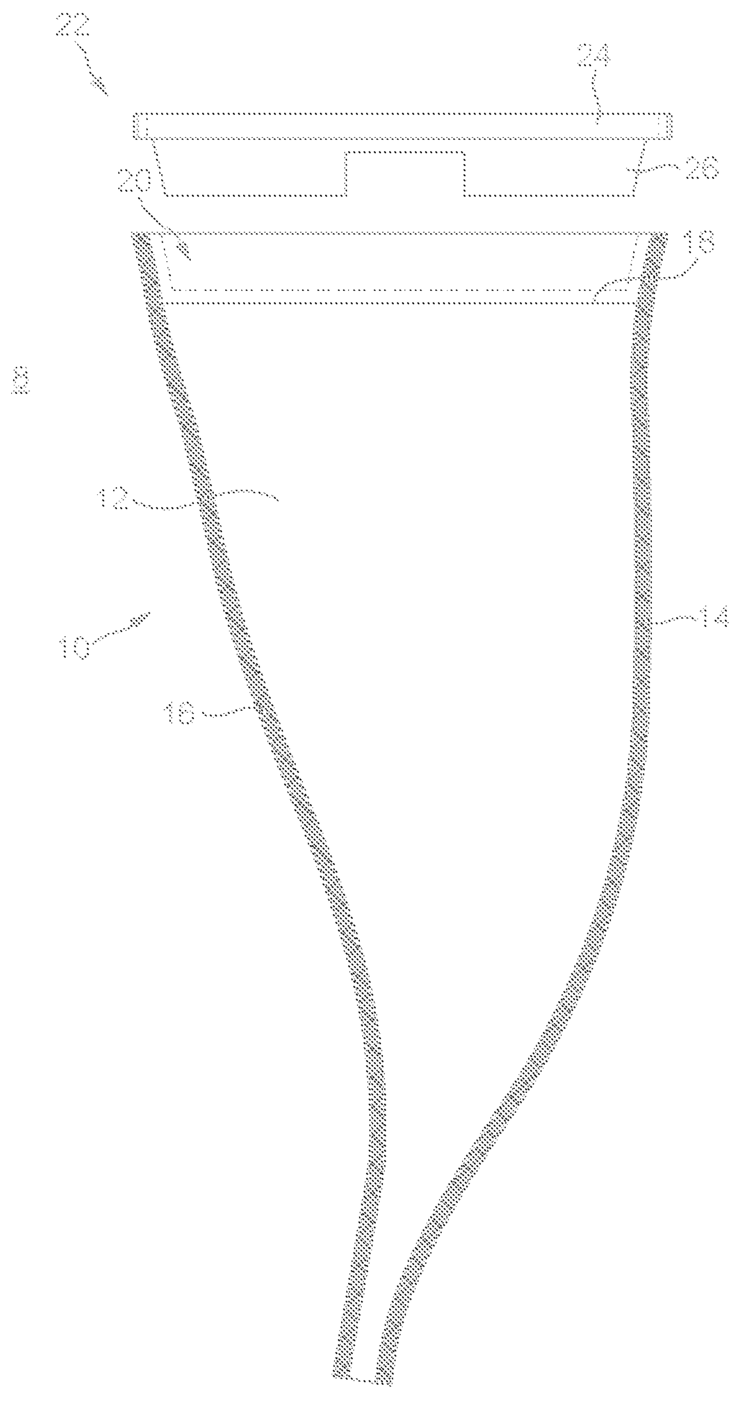

FIG. 2

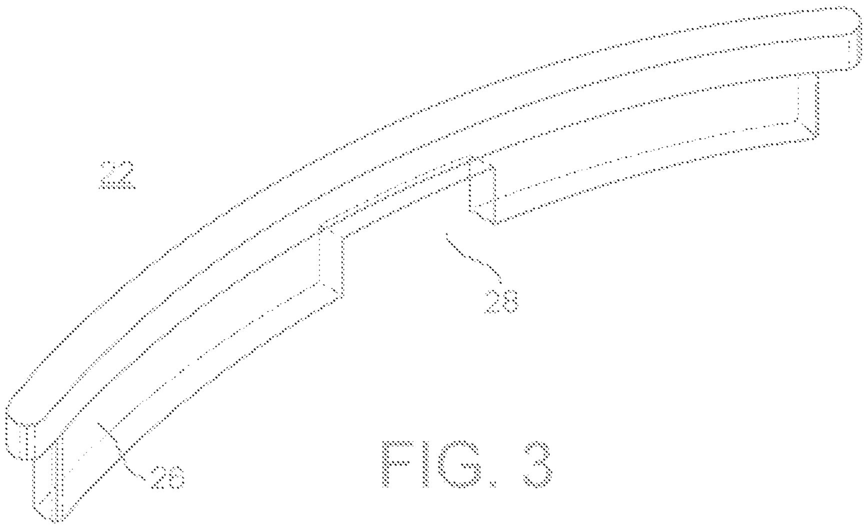

FIG. 3

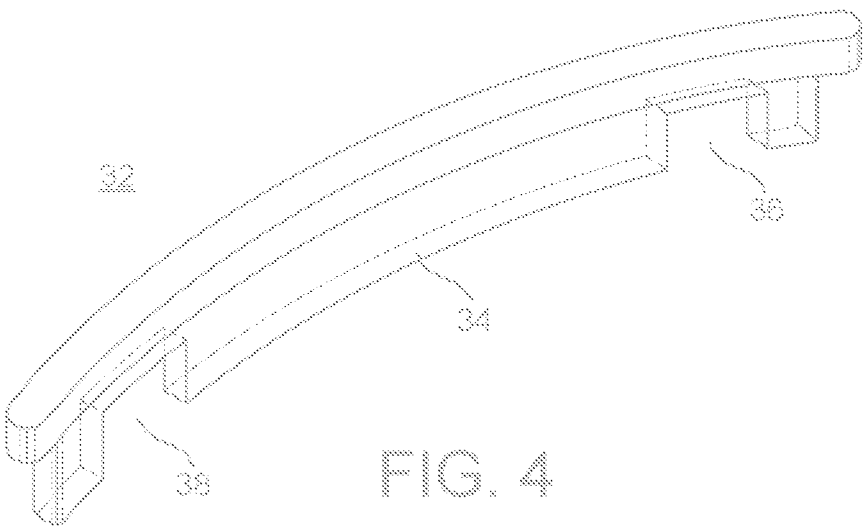

FIG. 4

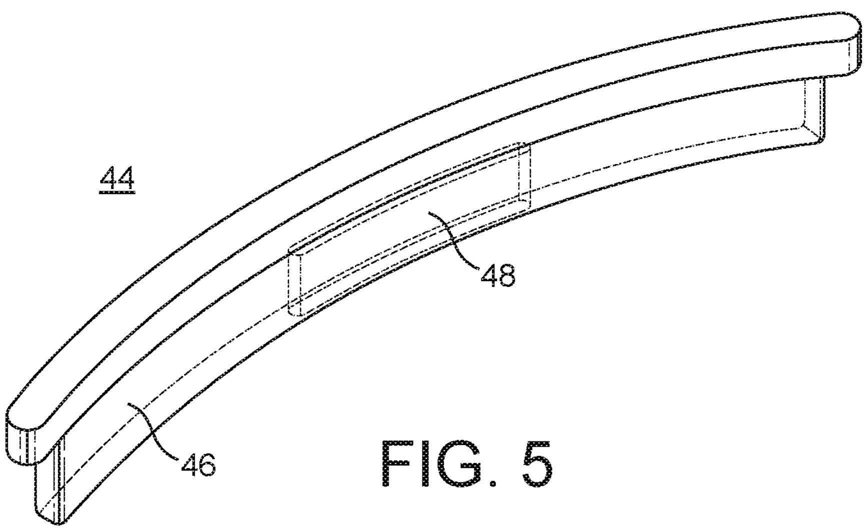

FIG. 5

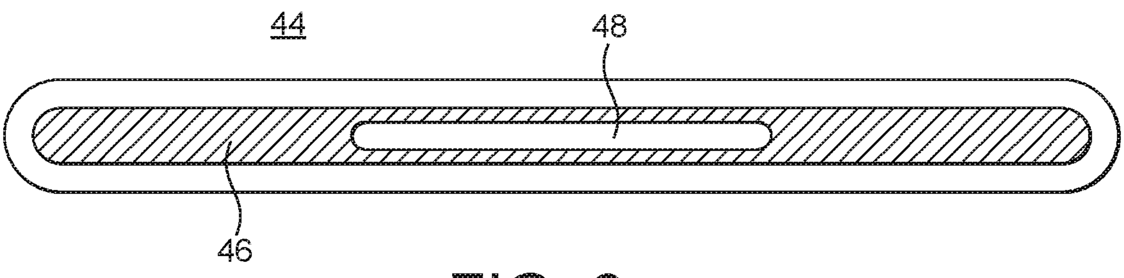

FIG. 6

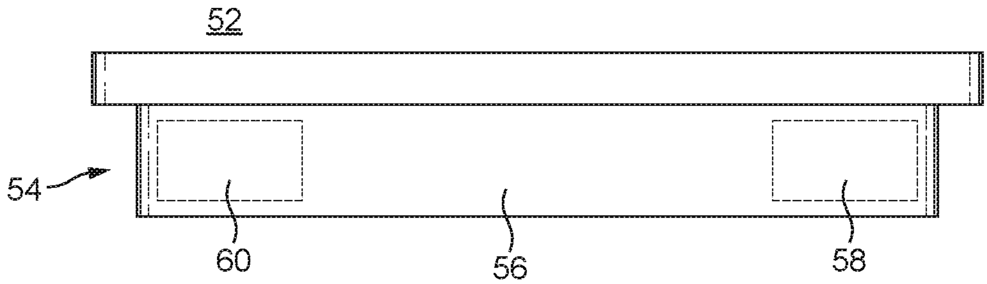

FIG. 7

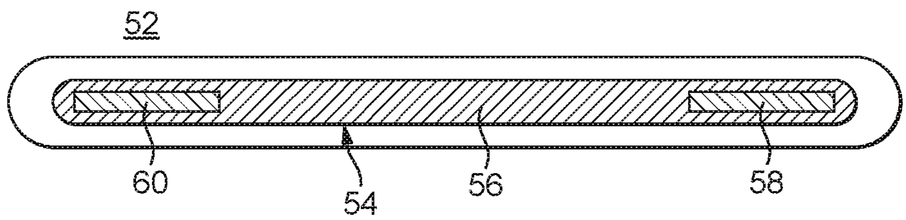

FIG. 8

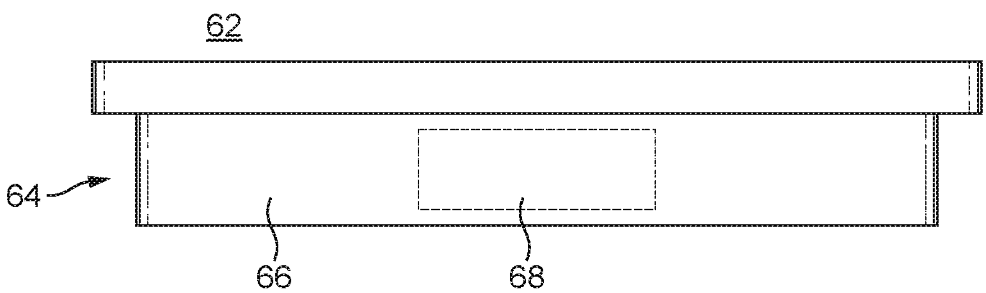

FIG. 9

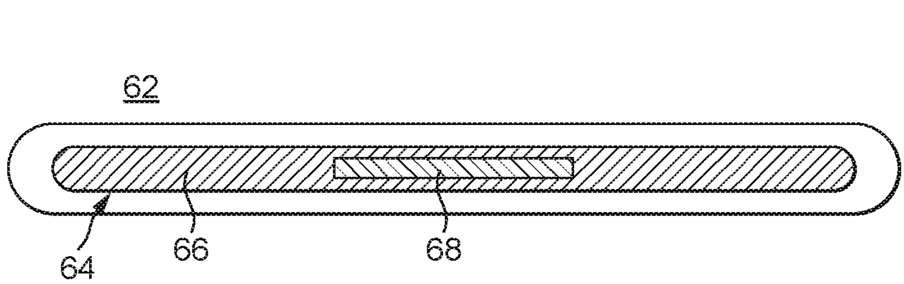

FIG. 10

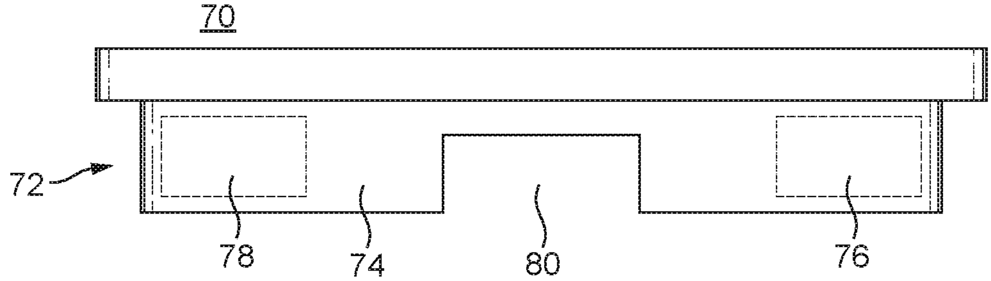

FIG. 11

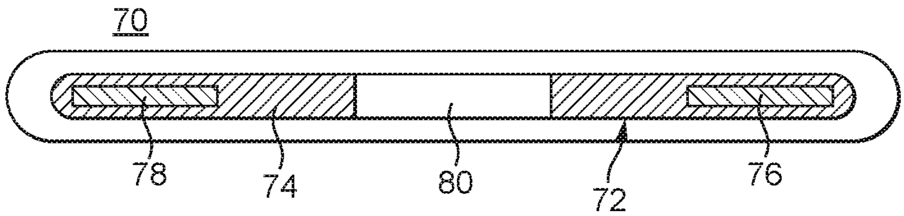

FIG. 12

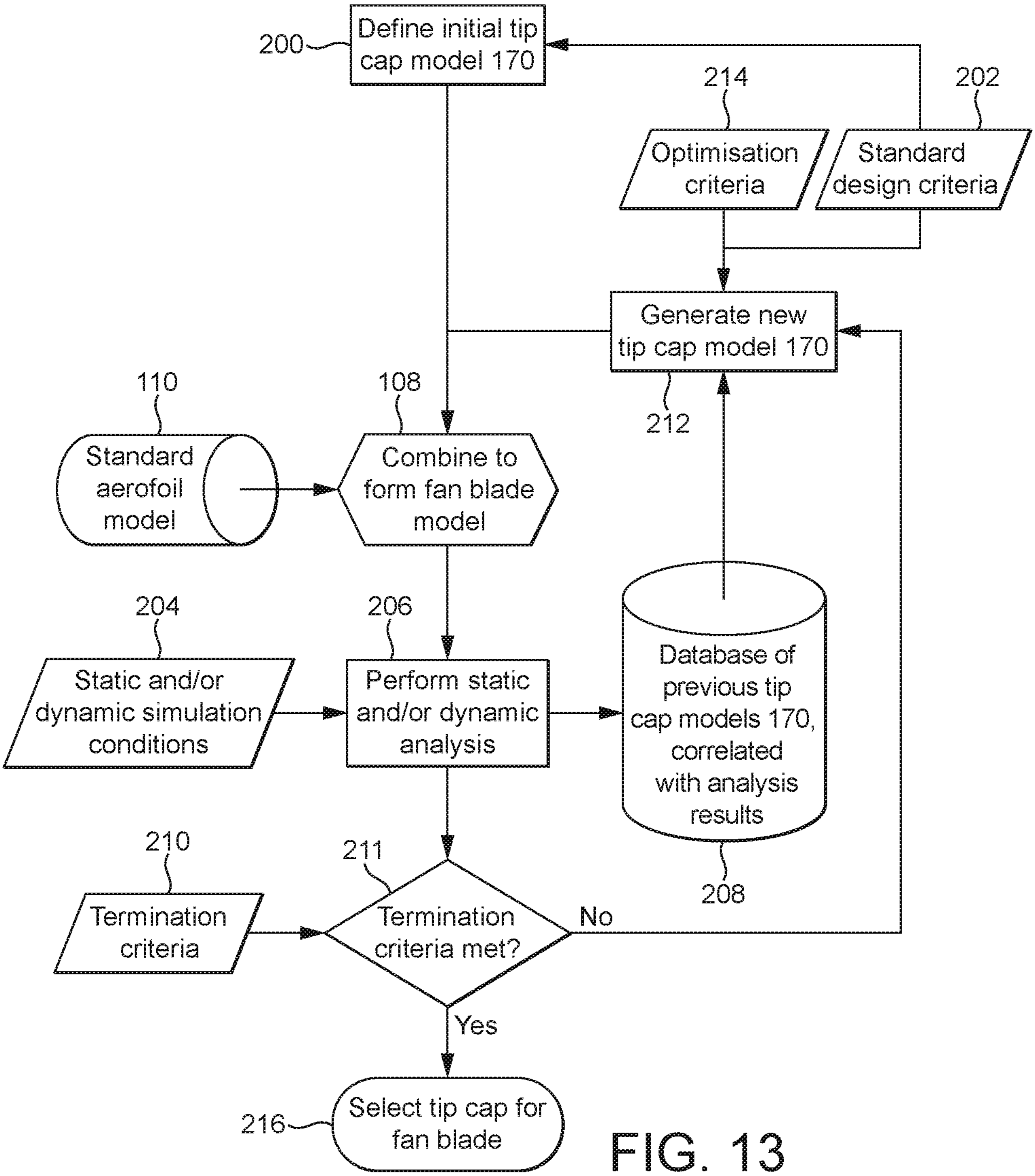
200
Define initial tip cap model 170
214
202
Optimisation criteria
Standard design criteria
Generate new tip cap model 170
212
110
108
Standard aerofoil model
Combine to form fan blade model
204
206
Static and/or dynamic simulation conditions
Perform static and/or dynamic analysis
Database of previous tip cap models 170, correlated with analysis results
208
210
211
Termination criteria
Termination criteria met?
No
Yes
216
Select tip cap for fan blade

FIG. 13

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2014/052342

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01D5/20 F01D5/16 F01D25/06
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F01D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	EP 1 772 593 A2 (GEN ELECTRIC [US]) 11 April 2007 (2007-04-11) column 4 - column 7 column 11 - column 19; claims 1,3,5; figures 1-3	1-6,8,9 7,10-12
X A	FR 2 502 242 A1 (GEN ELECTRIC [US]) 24 September 1982 (1982-09-24) page 2 - page 8; claims 1,19; figures 1-4	1-6,8,9 7,10-12
A	CA 2 696 274 A1 (GEN ELECTRIC [US]) 11 September 2011 (2011-09-11) page 9, line 22 - page 10, line 26; claims 1,3,6,7,12,13,14; figures 1,7,8,12,14,15	1-12
A	EP 2 028 342 A2 (UNITED TECHNOLOGIES CORP [US]) 25 February 2009 (2009-02-25) the whole document	1-12

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
28 November 2014	14/01/2015

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Balice, Marco

3

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 7 967 565 B1 (KIMMEL KEITH D [US] ET AL) 28 June 2011 (2011-06-28) the whole document	1-12
A	DE 10 2009 032549 A1 (MTU AERO ENGINES GMBH [DE]) 13 January 2011 (2011-01-13) paragraph [0039] - paragraph [0076]	13-17
A	US 2007/258825 A1 (SHADBOLT SIMON [GB] ET AL) 8 November 2007 (2007-11-08) paragraph [0013] - paragraph [0018]; claims 1,8; figures 1-3	13-17
A	EP 2 096 652 A1 (ANSALDO ENERGIA SPA [IT]) 2 September 2009 (2009-09-02) the whole document	13-17

3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB2014/052342

Box No. II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

1-17

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. claims: 1-12

   Tip cap for a fan blade of a gas turbine with an insert portion with regions made of different materials, fan blade comprising said tip cap and manufacturing method of the tip cap

   ---

2. claims: 13-17

   Method of designing the tip cap of a fan blade by determining the flutter characteristics and the tip displacemente characteristics depending on the tip caps

   ---

3. claims: 18-23

   Fan blade for a gas turbine with a tip cap inserted in a tip recess of the airfoil, the tip cap being provided with cut-outs

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2014/052342

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
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