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(54) Title: ROTOR BLADE FOR A ROTORCRAFT

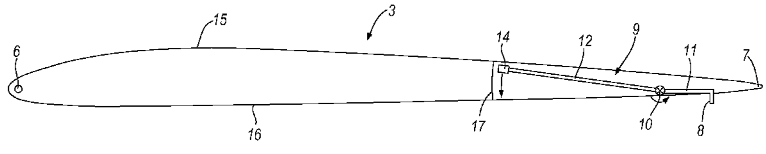

Fig.2

(57) Abstract: A rotor blade (31) for a rotorcraft includes a variable aerodynamic element (8), transformable between a first arrangement and a second arrangement and a drive (9,14,17) for transforming the variable aerodynamic element from the first arrangement to the second arrangement, wherein the drive comprises a linear electric motor (14,17).

WO 2011/124908 A1

Rotor blade for a rotorcraft

Technical Field

This invention relates generally to rotor blades of rotorcraft, in particular but not exclusively to the case where the rotorcraft is a helicopter, and to a rotorcraft including such a rotor blade.

Background of the Invention

The design of rotor blades for rotorcraft, especially helicopters is very challenging. The main rotor of a helicopter of standard design may be mounted for rotation about an approximately vertical axis passing close to the centre of mass of the helicopter. When the helicopter is not moving forwards through the air, the blades on the helicopter may experience approximately constant conditions as they rotate through an entire revolution about the vertical axis. As is well known, however, at other times, for example when the helicopter is moving forwards through the air, the conditions for a blade, especially its airspeed, may be very different when the blade is moving forwards on one side of the helicopter from when it is moving rearwardly on the other side of the helicopter. In order to take account of this problem a swashplate may be provided in the region of the connection of the rotor blades to the swashplate and, through a mechanical camming action, may alter a characteristic of each blade as it rotates; for example, the pitch of the blades may be varied.

In order to provide a control via a swashplate of the kind just described relatively large loads must be applied and this leads both to high energy consumption levels and to an increase in the mass of the helicopter. Similar situations arise with other forms of rotorcraft for example autogyros.

In an attempt to avoid such disadvantages it has been proposed to provide adjustable aerodynamic elements on a rotor blade in a manner somewhat similar to that in which elements might be provided on a fixed wing of an aircraft. There are, however, substantial additional complications if such an approach is adopted in respect of a rotor of a rotor craft: a first principal difference is that the rotor rotates in use at considerable speed relative to the body of the rotorcraft making transmission of power from the body of the rotorcraft to the rotor more difficult; the second principal difference is that the rotor rotates at a high speed so that, especially towards the tip of the rotor blade, there may be high g forces. For example, it is not unusual for there to be g forces of 700 g in the region of a tip of a rotor blade.

In an attempt to mitigate these difficulties, WO2008/048279 proposes that a brushless direct current motor be used. The rotation of the motor shaft is used to drive an aerodynamic element through a transmission system which may comprise either a screw linkage for converting rotary motion to linear motion or a set of gears to generate a rotary motion of sufficient torque. The provision of such drive transmissions in the environment of a rotor blade gives rise to various difficulties, however, principally because of the high g forces generated in normal operation.

It is an object of the invention to provide an improved rotor blade for a rotorcraft.

Summary of the Invention

According to the invention there is provided a rotor blade for a rotorcraft, the blade including:

a variable aerodynamic element, transformable between a first arrangement and a second arrangement; and

a drive for transforming the variable aerodynamic element from the first arrangement to the second arrangement;

wherein the drive comprises a linear electric motor.

By providing a linear electric motor it becomes possible to provide a simple but reliable drive for an aerodynamic element in a rotor blade.

The first and second arrangements of the aerodynamic element may for example represent different shapes of a deformable element with the element staying centred in the same position, but preferably the variable aerodynamic element is mounted for movement relative to the remainder of the blade between a first position corresponding to the first arrangement and a second position corresponding to the second arrangement.

The drive preferably includes a drive member. The drive member is preferably mounted for pivotal movement. It is within the scope of the invention for the pivotal mounting to be provided by a conventional bearing; in that case there may be a requirement that the bearing is kept adequately lubricated. It is preferred, however, to avoid an arrangement in which surfaces are required to move over one another at the pivotal mounting. More particularly the pivotal movement may be allowed by flexing of a pivotal mounting. For example, the pivotal mounting may comprise a wire that is twisted about its longitudinal axis during the pivoting; another possibility is that the pivotal mounting is provided by flexing of a generally lamellar member.

The drive member preferably extends from the linear motor to the aerodynamic element. Preferably the drive member extends generally in a direction approximately aligned with a wing chord extending between the leading and trailing edges of the blade. It is within the scope of the invention for there to be a plurality of drive members which may for example be coupled in series between the motor and the aerodynamic element, and it is also within the scope of the invention for the drive member to be integral with the armature of the linear electric motor and/or for the drive member to be integral with the aerodynamic element. In a preferred embodiment of the invention described below, a single member provides an armature of the motor, the drive member and the aerodynamic element. Such an arrangement has the advantage of reducing the number of moving parts and mountings for those parts. It should be understood that where reference is made to a single member that should not be taken as implying that the member is fabricated in a single piece; indeed it will usually be advantageous for such a member to be fabricated from several pieces that are fixed together.

The linear electric motor is preferably disposed at a location that is more than 25% of the distance along a wing chord extending from the trailing edge of the rotor blade to the leading edge. In an embodiment of the invention described below it is about one third of the distance along the wing chord.

The flexing of the aerodynamic element preferably involves resilient deformation of a member, but it is also possible for the deformation to be plastic deformation. The variable aerodynamic element may be resiliently biased into the first arrangement, into the second arrangement or into an intermediate state between the first and second arrangements. Preferably the aerodynamic element is resiliently biased into its safest position; in that case in the event of failure of the linear motor, the aerodynamic element will adopt its safest position.

The aerodynamic element may be disposed in the region of the tip of the blade.

In an embodiment of the invention described below the aerodynamic element is disposed in the region of the trailing edge of the blade; in that case the element may be mounted for pivotal movement about an axis approximately aligned with the longitudinal axis of the rotor blade. The aerodynamic element may be a Gurney flap. Another possibility is for the aerodynamic element to project radially outwardly from the tip of the blade; in that case the element may be mounted for pivotal movement about an axis approximately aligned with the longitudinal axis of the rotor blade.

The linear electric motor may include a permanent magnet armature. The permanent magnet armature may comprise a rare earth magnet, which may for example be a neodymium magnet. Such a magnet may be made from an alloy comprising mainly, by weight, an alloy of neodymium, iron and boron. It provides an especially strong and lightweight magnet. Another possibility is that the linear electric motor includes a coil on the armature to provide the desired magnetisation of the armature.

The linear electric motor may include a stator comprising a multiplicity of coils. The coils may be disposed in series along a linear path. Whilst the linear path may be straight, at least in the case where the drive member is pivotally mounted, there is advantage in the path being curved and, preferably, matching the curvature of the path of movement of the drive member in the region of the coils. In that way the spacing between the armature and the stator of the motor may be maintained substantially constant throughout its range of movement. Thus the linear motor may include an arcuate stator. The linear motor may be a limited angle torque motor.

Linear electric motors are known in a variety of forms involving different arrangements of stator coils and the present invention is not directed to any particular arrangement of stator coils. For example, electrical connections to the stator coils may be made via a commutator, or without a commutator. It is also possible, if desired, to provide two or more sets of coils each independently capable of operating the aerodynamic element. Such redundancy may be desirable for safety reasons. In such a case there may be two or more armatures; there may also be two or more drive members and there may be two or more pivotal mountings.

In the case where the linear electric motor includes a coil on the armature to provide the desired magnetisation of the armature, the stator may comprise a multiplicity of permanent magnets, or a multiplicity of coils as described above.

The stator of the linear motor may also provide a structural member of the rotor blade. By arranging the stator also to serve as a structural member, the need for a separate structural member in the region of the stator can be avoided and therefore the additional mass introduced by including the linear motor very significantly reduced.

According to the invention there is also provided a rotorcraft including a rotor blade as defined above. The rotorcraft may be a helicopter, although it should be understood that the invention is also applicable to other rotorcraft, such as autogyros.

Brief Description of the Drawings

By way of example embodiments of the invention will now be described with reference to the accompanying schematic drawings, of which:

Fig. 1 is a side view of a helicopter including a main rotor having four rotor blades;

Fig. 2 is a cross-sectional view of a rotor blade towards the tip of the blade; and

Fig. 3 is a more detailed view of a portion of the view of Fig. 2.

Detailed Description of Embodiments

The helicopter 1 shown in Fig. 1 includes a main rotor 2 comprising four rotor blades 3 rotatable on a shaft 4. When the helicopter is at rest on the ground the shaft 4 is disposed along an approximately vertical axis. Apart from the rotor blades the design of the helicopter may be entirely conventional and the pitch of each of the blades may for example be controlled by a swashplate in the region of the top of the shaft 4, in a manner that is well known.

Each of the rotor blades 3 is also of generally conventional design but includes a special additional feature as will now be described. On the trailing edge of each rotor blade, in the region marked G in Fig.1, which is about 80% of the distance along the rotor blade 3 from the shaft 4 towards the tip of the blade, a Gurney flap is provided on the underside of the trailing edge of the blade.

Referring now to Fig. 2 there is shown a cross-section through a blade 3 in the region G. The blade 3 has a leading edge 6 and a trailing edge 7. Close to the trailing edge 7 and on the underside of the blade 3, a Gurney flap 8 is shown projecting through an aperture in the skin of the blade in a direction approximately perpendicular to the surface of the blade. In Fig. 2 the Gurney flap is shown projecting out to its maximum extent, which in this particular example amounts to a projection of about 10 mm. Typically the projection is 1% to 2% of the length of the wing chord of the blade 3 in the region of the Gurney flap.

The Gurney flap 8 is fixed to one end of a drive member 9 pivotally mounted at a mounting 10. The drive member 9 is cranked at the mounting 10 to define a first portion 11 on the free end of which the Gurney flap 8 is fixed and a second portion 12 on the end of which a motor armature 14 of a linear motor is fixed. The armature 14 is spaced from the trailing edge of the blade 3, being about one third of the distance along the length of the wing chord from the trailing edge to the leading edge. An arrow in Fig.2 shows that the drive member 9 is movable between the position shown in Fig. 2 and one in which the motor armature 14 has moved downwardly from a position in the region of the top skin 15 of the blade 3 to a position in the region of the bottom skin 16 of the blade 3. When the armature is in its lowermost position the Gurney flap is retracted to a position in which it is entirely contained within the blade 3. Movement of the drive member 9 is controlled by the interaction of the armature 14 on the end of the drive member 9 with an arcuate stator 17 as will be described below with reference to Fig. 3. The arcuate stator 17 extends from the top skin 15 of the blade 3 to the bottom skin 16 and acts as a structural member of the blade maintaining the cross-sectional profile of the blade.

The mass of the drive member 9, including the Gurney flap 8 and the armature 14 is balanced about the pivot mounting 10 to reduce loads arising from high g forces.

Referring now to Fig. 3, the armature 14 is provided with a permanent magnet 15, which in this particular example is a neodymium magnet. As shown in Fig. 3 in this example it is arranged with its south pole at its radially outermost end closest to the stator 17.

The stator 17 comprises a series of coils some of which, referenced 18A to 18E are visible in Fig.3. The coils are each independently connectible to a power supply controller 19 via connections shown schematically by dotted lines 20 in Fig.3. The controller 19 is able to energise a selected one or more of the stator coils with a selected polarity of voltage (typically 28V) and thus generate a north pole or south pole at the end of the coil. In the example shown in Fig. 3, the coil 18A is energised to create a north pole in the region of the end of the coil 18A adjacent to the armature 14 and the armature is thus held in the position shown. As will be well understood, the armature could be moved one step clockwise by connecting the coil 18B as the coil 18A had been connected, while disconnecting or even reversing the connection to the coil 18A. If it is desired to move the armature more than one step, then the connection of the coil 18B may be momentary and superseded by connection of the coil 18C. Thus, in a manner that is well known per se, the position of the armature 14 may be controlled by appropriate energisation of the coils of the stator 17. Commonly a position sensing feedback system will also be provided, for example using Hall sensors connected to the controller 19 to indicate the position of the armature 14 at any instant. The controller 19 may be located at the stator or at a location separate from the stator.

The linear motor described above may readily be designed to be capable of reciprocating the drive member 9 between two chosen positions at a frequency up to 40 Hz. Of course the frequency can be adjusted to match the speed of rotation of the blade 3 and indeed it will usually be desirable to do that, although some additional control of perhaps smaller amplitude but higher frequency may desirably be superimposed.

Referring again to Fig. 2, the drive member 9 is formed from several parts fixed together so that they behave as a single member pivoted at a mounting 10. Because of the substantial g forces in the region of the mounting 10, this mounting is preferably formed without parts having surfaces that move over one another as for example in a traditional bearing. The mounting may for example take the form of a torsion wire or some other deformable element.

From the description above it will be seen how a very simple, lightweight system may be employed to control a Gurney flap 8 on a rotor blade 3 of a helicopter.

In the description above a system has been described that does not have any inherent redundancy, but of course it is possible to build redundancy into some or all of the parts of the design if desired. For example, there may be two armatures 14 which may interact with respective coils of the stator 17; the two sets of coils may have separate power supply controllers 19; the two armatures may be mounted on separate drive members which may have separate pivotal mountings; in such a case the two sets of parts may be spaced from one another slightly along the length of the rotor blade (along the axis of pivoting of the drive member(s). For the purpose of introducing redundancy or for other reasons, the drive member 12 may carry a first armature 14 in the position shown in the drawings and a second armature on an extension that passes over the stator 17 and mounts the second armature in a position that is adjacent to the opposite face of the stator 17 from that which is adjacent to the armature 14.

In the examples of the invention described above it is a Gurney flap that is controlled. It should be understood, however, that the invention may be applied to control other elements of a rotor blade, for example a control tab (servo, mini-flap or the like) or a leading edge slat. The control of the invention may replace control provided conventionally by a swash plate or may supplement that control.

Where in the foregoing description, integers or elements are mentioned which have known, obvious or foreseeable equivalents, then such equivalents are herein incorporated as if individually set forth. Reference should be made to the claims for determining the true scope of the present invention, which should be construed so as to encompass any such equivalents. It will also be appreciated by the reader that integers or features of the invention that are described as preferable, advantageous, convenient or the like are optional and do not limit the scope of the independent claims.

Claims

1. A rotor blade for a rotorcraft, the blade including:

a variable aerodynamic element, transformable between a first arrangement and a second arrangement; and

a drive for transforming the variable aerodynamic element from the first arrangement to the second arrangement;

wherein the drive comprises a linear electric motor.

2. A rotor blade according to claim 1, in which the variable aerodynamic element is mounted for movement relative to the remainder of the blade between a first position corresponding to the first arrangement and a second position corresponding to the second arrangement.

3. A rotor blade according to claim 1 or 2, in which the drive includes a drive member mounted for pivotal movement.

4. A rotor blade according to claim 3, in which the drive member extends from the linear motor to the aerodynamic element.

5. A rotor blade according to claim 4, in which there is a single drive member.

6. A rotor blade according to any preceding claim, in which the aerodynamic element is disposed in the region of the trailing edge of the blade.

7. A rotor blade according to any preceding claim, in which the aerodynamic element is disposed in the region of the tip of the blade.

8. A rotor blade according to any preceding claim, in which the aerodynamic element is a Gurney flap.

9. A rotor blade according to any preceding claim, in which the linear electric motor includes a permanent magnet armature.

10. A rotor blade according to any preceding claim, in which the linear electric motor includes a stator comprising a multiplicity of coils.

11. A rotor blade according to any preceding claim, in which the linear electric motor includes an arcuate stator.

12. A rotor blade according to any preceding claim, in which the linear motor includes a stator that also provides a structural member of the rotor blade.

13. A rotor blade substantially as herein described with reference to the accompanying drawings.

14. A rotorcraft including a rotor blade according to any preceding claim.

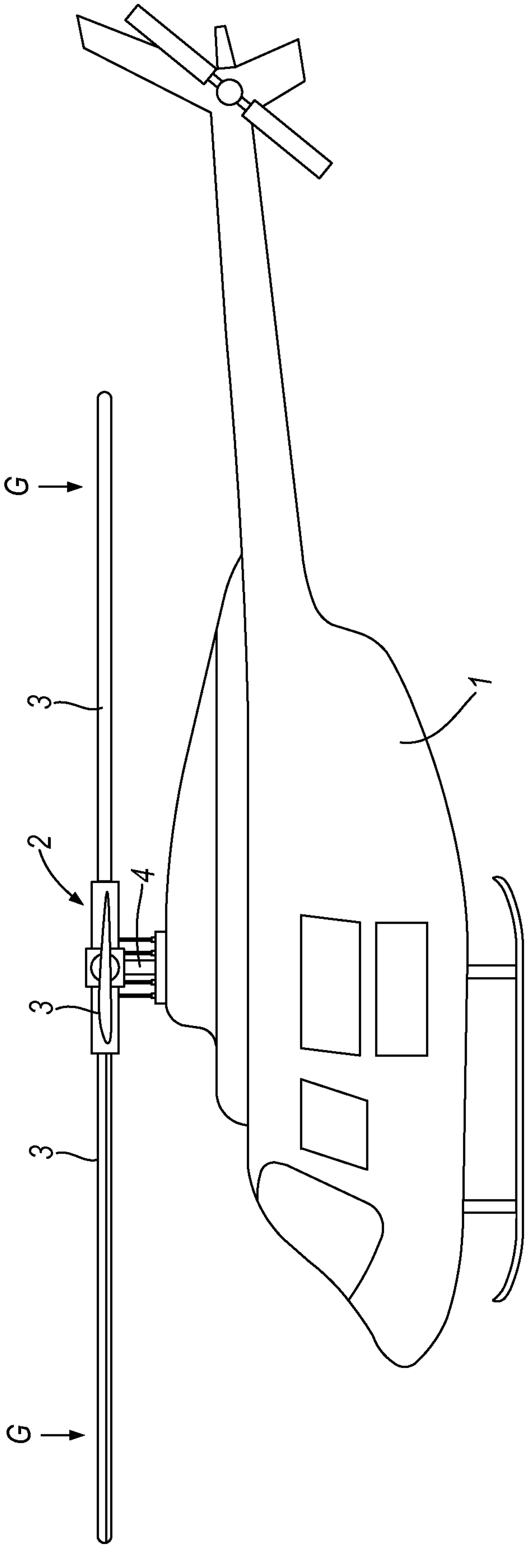

Fig.1

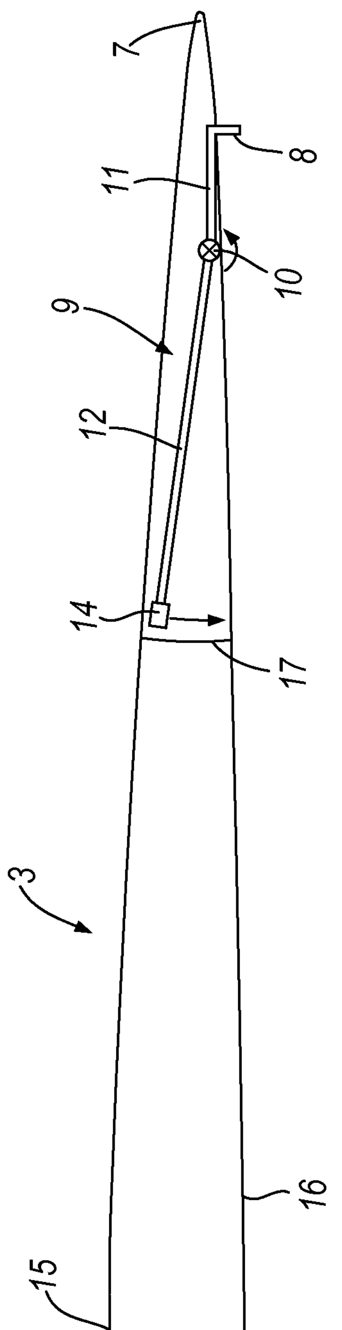

Fig.2

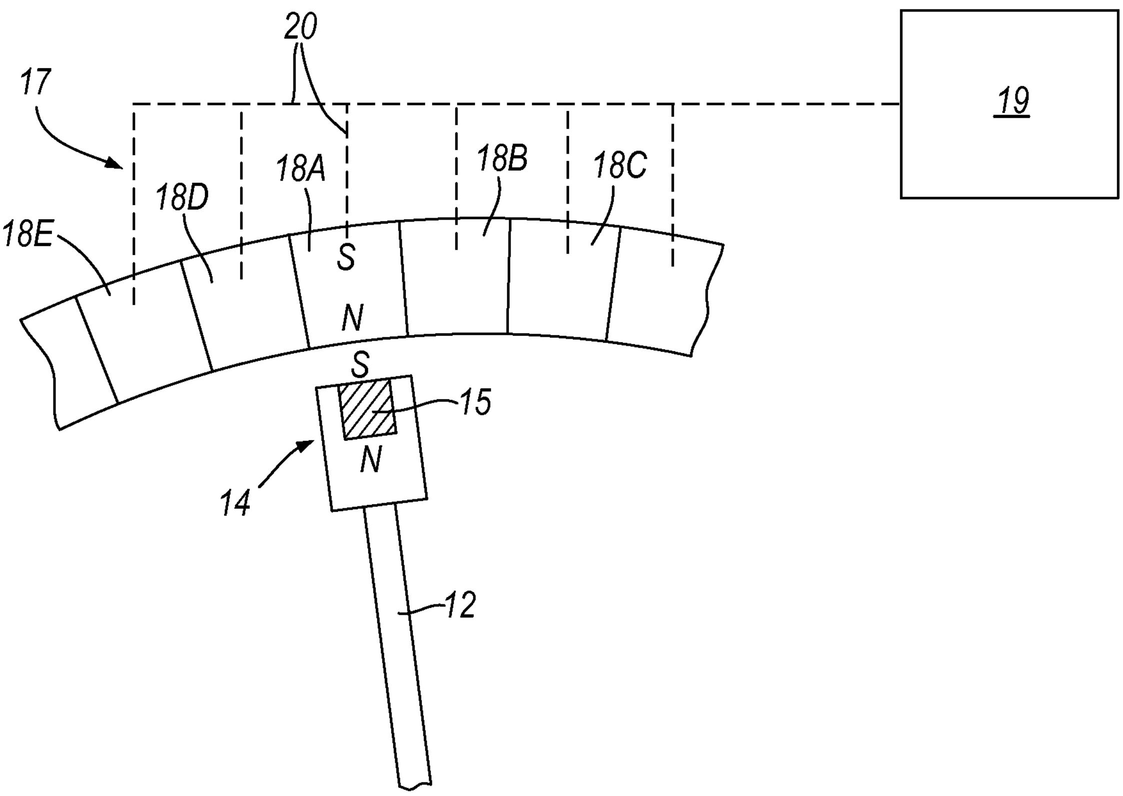

Fig.3

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/050669

A. CLASSIFICATION OF SUBJECT MATTER
INV. B64C27/615 B64C27/68
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)
B64C

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 practical, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 2009/302168 A1 (HETRICK JOEL A [US] ET AL) 10 December 2009 (2009-12-10) paragraphs [0081], [0115], [0125], [0149], [0152], [0154]; figures 2-7,12,19,20,22 -----	1-7,9, 10,13,14 8 11,12
Y A	US 2003/218102 A1 (VAN DAM CORNELIS P [US] ET AL) 27 November 2003 (2003-11-27) paragraphs [0008], [0013], [0045], [0543], [0054]; figures 3-6 -----	8 1-7
A	WO 2008/051293 A2 (UNIV LELAND STANFORD JUNIOR [US]; EATON JOHN K [US]; MATALANIS CLAUDE) 2 May 2008 (2008-05-02) page 12, line 5 - page 13, line 8 page 15, lines 3,4; figure 3 -----	1-8
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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 :

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Date of the actual completion of the international search

14 September 2011

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2011/050669

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 2008/048279 A2 (SIKORSKY AIRCRAFT CORP [US]; CHAUDHRY ZAFFIR [US]; WAKE BRIAN E [US];) 24 April 2008 (2008-04-24) the whole document -----	1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/GB2011/050669

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