(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
3 September 2009 (03.09.2009)

PCT

(10) International Publication Number
WO 2009/105835 A1

(51) International Patent Classification:
F01D 5/12 (2006.01) *F03D 3/06* (2006.01)

(21) International Application Number:
PCT/AU2009/000250

(22) International Filing Date:
27 February 2009 (27.02.2009)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
2008900975 28 February 2008 (28.02.2008) AU

(71) Applicant *(for all designated States except US)*: **WIND-WORKS ENGINEERING LIMITED** [GB/CY]; 29, Theklas Lyssioti Street, Cassandra Centre, 2nd Floor, Limassol, 3731 (CY).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **BERTONY, Joseph** [AU/AU]; 59 Ida Street, Hornsby North, New South Wales 2077 (AU).

(74) Agent: **GRIFFITH HACK**; Level 19, 109 St George's Terrace, Perth, Western Australia 6000 (AU).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*
— *with amended claims (Art. 19(1))*

(54) Title: AN AIRFOIL FOR A VERTICAL AXIS WIND TURBINE

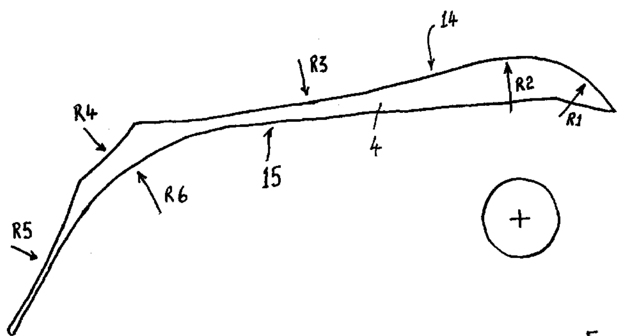

Fig. 3

(57) Abstract: The present disclosure provides an airfoil for a vertical axis wind turbine. The airfoil comprises an elongated member having a longitudinal axis and first and second ends. The airfoil has a longitudinal twist between the first and second ends and has a leading surface (14) and an opposite trailing surface (15) extending between the first and second ends. The trailing surface and also the leading surface of the airfoil have at least one concave longitudinally extending recess.

WO 2009/105835 A1

AN AIRFOIL FOR A VERTICAL AXIS WIND TURBINE

Field of the Invention

The present invention relates to an airfoil for a vertical axis wind turbine.

Background of the Invention

Airfoils for vertical axis wind turbines have a shape that differs from the propeller-like shapes of airfoils for horizontal axis wind turbines. The airfoils of horizontal axis wind turbine always face towards the wind during operation. This is different to vertical axis wind turbines; airfoils of the vertical axis wind turbine change their aspect relative to the prevailing wind as they rotate, and thus efficient designs have been challenging.

Summary of the Invention

According to a first aspect of the present invention there is provided an airfoil for a vertical axis wind turbine, the airfoil having a longitudinal axis and first and second ends and having a longitudinal twist between the first and second ends, the airfoil further having a leading surface and an opposite trailing surface extending between the first and second ends, the trailing surface having at least one longitudinally extending concave recess and the leading surface having at least one longitudinally extending concave recess.

The leading surface typically has a plurality of longitudinally extending concave recesses and the trailing surface typically has one longitudinally extending concave recess.

Conventional airfoils of vertical axis wind turbines typically are semi-cylindrical and have a semi-circular cross-sectional shape. These airfoils have a convex leading surface and a concave trailing surface. In contrast, the trailing surface of the airfoil in accordance with the embodiments of the present invention has a different shape that provides has significant advantages. The leading surface of the airfoil of the present invention also has at least one longitudinally extending concave recess. As a result, wind turbine having a plurality of such airfoils may generate a first torque produced by air incident upon the trailing surface of the airfoils and also an additional second torque produced by air incident on the at least one concave recess of the leading surface.

The longitudinally extending concave recesses of the leading surface may have cross-sectional shapes that correspond to a portion of a sphere having a radius that may be at least 2, 5, 10, 20 or even 50 times larger that a width of the airfoil.

In an embodiment, the airfoil has a cross-sectional shape that is substantially constant along the twist of the twisted airfoil.

In an embodiment, the leading surface of the airfoil has three longitudinal extending concave recesses, which may be adjacent each other and at least two of the concave recesses may have a cross-sectional shape that corresponds to a portion of a sphere, each having a differing radius.

In an embodiment, the leading surface of the airfoil also has a longitudinally extending convex portion. The convex portion may lead the at least one longitudinally extending concave recesses with respect to the direction of rotation of the airfoil. The convex portion may be adjacent the concave recesses. The convex portion may be part circular when viewed in transverse cross-section.

An axis about which the airfoil is twisted is outside the airfoil, typically offset relative to an inner face of the airfoil.

A wind turbine assembly may comprise a plurality of such airfoils and each axis about which a respective airfoil is twisted may coincide with a vertical axis of a wind turbine assembly, or may alternatively be parallel and spaced apart form the vertical axis of the wind turbine assembly. Positioning of the axis of each airfoil relative to the vertical axis of the wind turbine assembly allows modification of performance properties of the wind turbine assembly. For example, by shifting or rotating the airfoils about the axis of the wind turbine assembly by a small amount, an outside diameter of the wind turbine assembly may be varied so that the wind turbine assembly is "opened" or "closed" to airflow.

According to a second aspect of the invention there is provided an airfoil assembly comprising at least one, typically three, of the above-defined airfoils.

According to a third aspect of the invention there is provided a vertical axis wind turbine comprising the airfoil assembly in accordance with the second aspect of the present invention.

Brief Description of the Figures

An embodiment of the invention will now be described, by way of example only in order to achieve a better understanding of it, with reference to the accompanying drawings in which:

Fig. 1 is a side elevation of an embodiment of a wind turbine having three airfoils,

Fig. 2 is a plan view of the airfoils of Fig. 1,

Fig. 3 is a horizontal cross-section taken through one of the airfoils of Figs. 1 and 2,

Fig. 4 is a front elevation of one of the airfoils of Fig. 1, and

Fig. 5 - 7 are each a view similar to Fig. 3 but illustrating wind flow at different stages of the airfoil rotation.

Detailed Description of Embodiments of the Invention

An airfoil for a vertical axis wind turbine in accordance with embodiment of the present invention is now described with reference to Figs. 1-7. The vertical axis wind turbine 1 has a central mast 3 and three airfoils 4 which extend, in this embodiment, between an upper disc 6 and a lower disc 7. Each airfoil 4 has a leading surface 14 and a trailing surface 15. In addition each airfoil 4 has an upper edge 11 and a lower edge 12 as shown in Fig. 4. The lower edge 12 is twisted relative to the upper edge 11, by approximately 98 degrees, in this embodiment, so as to provide a twist for each of the airfoil 4. An axis about which the airfoil is twisted is outside the airfoil. Other degrees of twist may be employed as suitable. Because of this pitch wind which is incident on the leading surface 14 is directed downwardly and wind which is incident on the trailing surface 15 is directed upwardly. A 150kW turbine typically has a vertical extent between the discs 6, 7 of approximately 13 metres and a diameter of approximately 5-6 metres.

The leading surface 14 is shaped to produce a force when wind is incident upon it, this force being created by a pressure difference between the air adjacent the leading surface 14 and air adjacent the trailing surface 15. Similarly, the trailing surface 15 is shaped to create drag when air is incident upon it.

As a result of the above described arrangement the turbine 1 has a first torque produced by air incident upon the trailing surface 15 of one of the airfoils 4 and also experiences a second torque created by the drag produced by air incident on the leading surface 15 of an opposite airfoil 4. The torque causing rotation of the wind turbine 1 is the sum of the torques.

This is to be contrasted with a conventional Savionus vertical axis wind turbine, for example, having two semi-cylindrical opposed airfoils each of which when viewed in transverse cross-section is a semicircle. This conventional arrangement does not produce any airfoil effect on the leading surface. Instead, wind incident upon the leading surface creates a drag which tends to rotate the turbine in one direction whereas wind incident on the trailing surface creates a bigger drag which tends to rotate the wind turbine in the opposite direction. Thus the wind turbine rotates in the opposite direction but the net torque is the difference between the two drags and consequently is relatively small.

Turning now to Fig. 3, a transverse cross-section through any one of the airfoils 4 is illustrated. In this embodiment this transverse cross-section is constant irrespective of the distance between the upper edge 11 and the cross-section or the lower edge 12 and the cross-section. Thus the cross-section is the same irrespective of the height at which it is taken. In the preferred embodiment the leading surface 14 is formed by a first convex portion having a radius of curvature R1, a second convex portion having a radius of curvature R2, a first concave portion having a radius of curvature R3, a second concave portion having a radius of curvature R4 and a third concave region having a radius of curvature R5. The trailing surface 15 consists of two essentially flat surfaces interconnected by a curved portion having a radius of curvature R6. The configuration of the trailing surface 15 is not critical compared to that of the leading surface 14.

Dimensions for the various radii of curvature, for this embodiment, are as follows:

RADIUS OF CURVATURE	DIMENSION (mm)
R1	620
R2	10,000
R3	20,000
R4	12,000
R5	12,000
R6	1,279

Typical ratios of an airfoil width to an airfoil length are between 2.5 and 4.5 and the ratio of a single airfoil assembly for a vertical axis wind turbine can be between 3.3 and 6.

It will be appreciated that some embodiments may have a different number of radii and/or different dimensions. Some embodiments may be scaled up or down version of this embodiment.

Turning now to Fig. 4, a single airfoil 4 is illustrated. Hereafter for convenience, each of the six above regions will be referred to as R1-R6 respectively, so that region R3 has a radius of curvature R3, and so on. Thus the various regions extending across the leading surface 14 are indicated in sequence R1-R5 which respectively refer to the first convex region R1, the second convex region R2, the first concave region R3, the second concave region R4 and the third concave region R5.

The operational consequence of the above described shaped regions will now be described with reference to Figs. 5-7 which indicate an airfoil 4 with its leading surface 14 turning into the wind which in relation to Fig. 5 may be considered to have its horizontal component to be coming from the east (the right hand side of the page) and is indicated by three straight arrows 20A indicating an initially uniform air flow. The consequence of the first convex region R3 is to induce a vortex indicated by arrow 20B in Fig. 5. The pressure within the vortex 20B is less than the pressure behind the trailing surface 15 and thus the airfoil 4 experiences a net force which operates to turn the airfoil clockwise as seen in Fig. 5. As a result the airfoil 4 begins to rotate because of the incident air flow indicated by arrows 20A.

In Fig. 6, the situation is illustrated at a time just after the situation illustrated in Fig. 5. The wind continues to blow from the east but the airfoil 4 has turned slightly so that the angle between the air flow indicated by arrows 21A and the airfoil 4 illustrated in Fig. 6 is different than illustrated in Fig 5. The vortex 20B previously induced at region R3 is now substantially diminished (as indicated by broken lines in Fig. 6) and a new vortex 21B is induced at region R4. As a consequence, the air pressure at region R4 is reduced relative to the air pressure on the trailing surface 15 and so the airfoil 4 continues to experience a force turning the airfoil 4 clockwise as seen in Fig. 6.

Turning now to Fig. 7, the position of the airfoil 4 in Fig. 7 is further turned again from the position illustrated in Fig. 6. Thus the wind which still blows from the east is now illustrated by air flow 22A which results in a reduced or diminished vortex 21B and a new vortex 22B induced at region R5. Again, the pressure within the vortex 22B is reduced relative to the air pressure at the trailing surface 15 and thus again the airfoil 4 continues to experience a torque or turning force which maintains the clockwise rotation of the airfoil 4.

It should be born in mind in considering Figs. 5-7 that the air flow indicated by arrows 20A, 21A and 22A in addition to moving from right to left across the leading surface 14 of the airfoil 4, is also simultaneously moving downwardly from the upper edge 11 towards the lower edge 12 because of the vertical component of the flow induced by the pitch of the airfoil 4.

It will be understood to persons skilled in the art of the invention that many modifications may be made without departing from the spirit and scope of the invention. For example, some embodiments may comprise more or less than 3 concavities on the leading surface. The surface defining one or more of the recesses may define a volume which is part of an ovoid.

In the claims which follow and in the preceding description of the invention, except where the context requires otherwise due to express language or necessary implication, the word "comprise" or variations such as "comprises" or "comprising" is used in an inclusive sense, i.e. to specify the presence of the stated features but not to preclude the presence or addition of further features in various embodiments of the invention.

CLAIMS

1. An airfoil for a vertical axis wind turbine, the airfoil having a longitudinal axis and first and second ends and having a longitudinal twist between the first and second ends, the airfoil further having a leading surface and an opposite trailing surface extending between the first and second ends, the trailing surface having at least one longitudinally extending concave recess and the leading surface having at least one longitudinally extending concave recess.

2. The airfoil of claim 1 wherein the leading surface has a plurality of longitudinally extending concave recesses.

3. The airfoil of claim 2 wherein the longitudinally extending concave recesses of the leading surface have cross-sectional shapes that corresponds to a portion of a sphere.

4. The airfoil of claim 3 wherein a radius of at least one sphere is at least 5 larger that a width of the airfoil.

5. The airfoil of claim 3 wherein a radius of at least one sphere is at least 10 larger that a width of the airfoil.

6. The airfoil of claim 3 wherein a radius of at least one sphere is at least 20 larger that a width of the airfoil.

7. The airfoil of any one of the preceding claims having a cross-sectional shape that is substantially constant along the twist of the twisted airfoil.

8. The airfoil of any one of the preceding claims wherein the leading surface of the airfoil has three longitudinally extending concave recesses.

9. The airfoil of claim 8 wherein the longitudinally extending recesses are adjacent each other and at least two of the recesses have a cross-sectional shape that corresponds to portions of spheres having a differing radii.

10. The airfoil of any one of the preceding claims wherein the leading surface of the airfoil also has a longitudinally extending convex portion.

11. The airfoil of claim 10 wherein the convex portion leads the at least one longitudinally extending concave recesses with respect to the direction of rotation of the airfoil.

12. The airfoil of any one of the preceding claims wherein the axis about which the airfoil is twisted is outside the airfoil.

13. An airfoil assembly comprising at least one airfoil in accordance with claims 1- 12.

14. A vertical axis wind turbine comprising the airfoil assembly in accordance claim 13.

AMENDED CLAIMS
[received by the International Bureau on 26 May 2009 (26.05.2009); original claims 4-6 amended; remaining claims unchanged]

1. An airfoil for a vertical axis wind turbine, the airfoil having a longitudinal axis and first and second ends and having a longitudinal twist between the first and second ends, the airfoil further having a leading surface and an opposite trailing surface extending between the first and second ends, the trailing surface having at least one longitudinally extending concave recess and the leading surface having at least one longitudinally extending concave recess.

2. The airfoil of claim 1 wherein the leading surface has a plurality of longitudinally extending concave recesses.

3. The airfoil of claim 2 wherein the longitudinally extending concave recesses of the leading surface have cross-sectional shapes that corresponds to a portion of a sphere.

4. The airfoil of claim 3 wherein a radius of at least one sphere is at least 5 times larger that a width of the airfoil.

5. The airfoil of claim 3 wherein a radius of at least one sphere is at least 10 times larger that a width of the airfoil.

6. The airfoil of claim 3 wherein a radius of at least one sphere is at least 20 times larger that a width of the airfoil.

7. The airfoil of any one of the preceding claims having a cross-sectional shape that is substantially constant along the twist of the twisted airfoil.

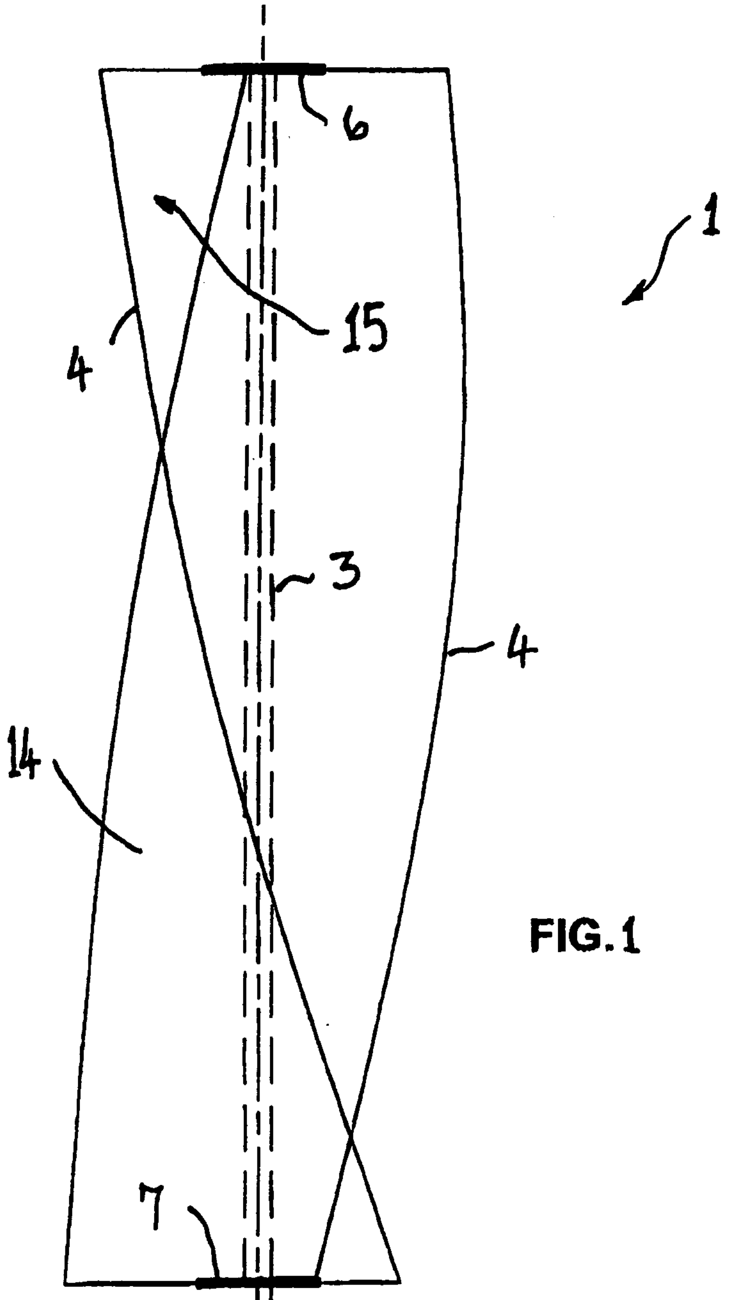

FIG.1

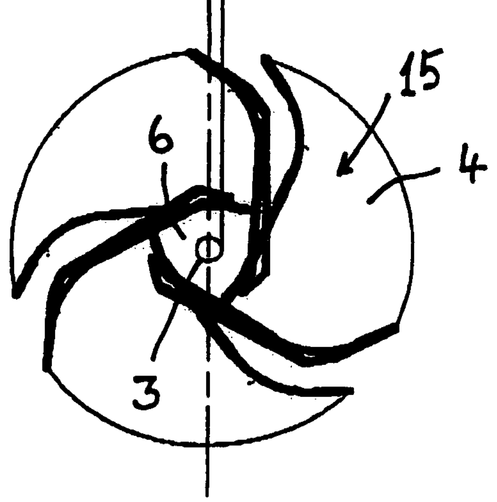

FIG.2

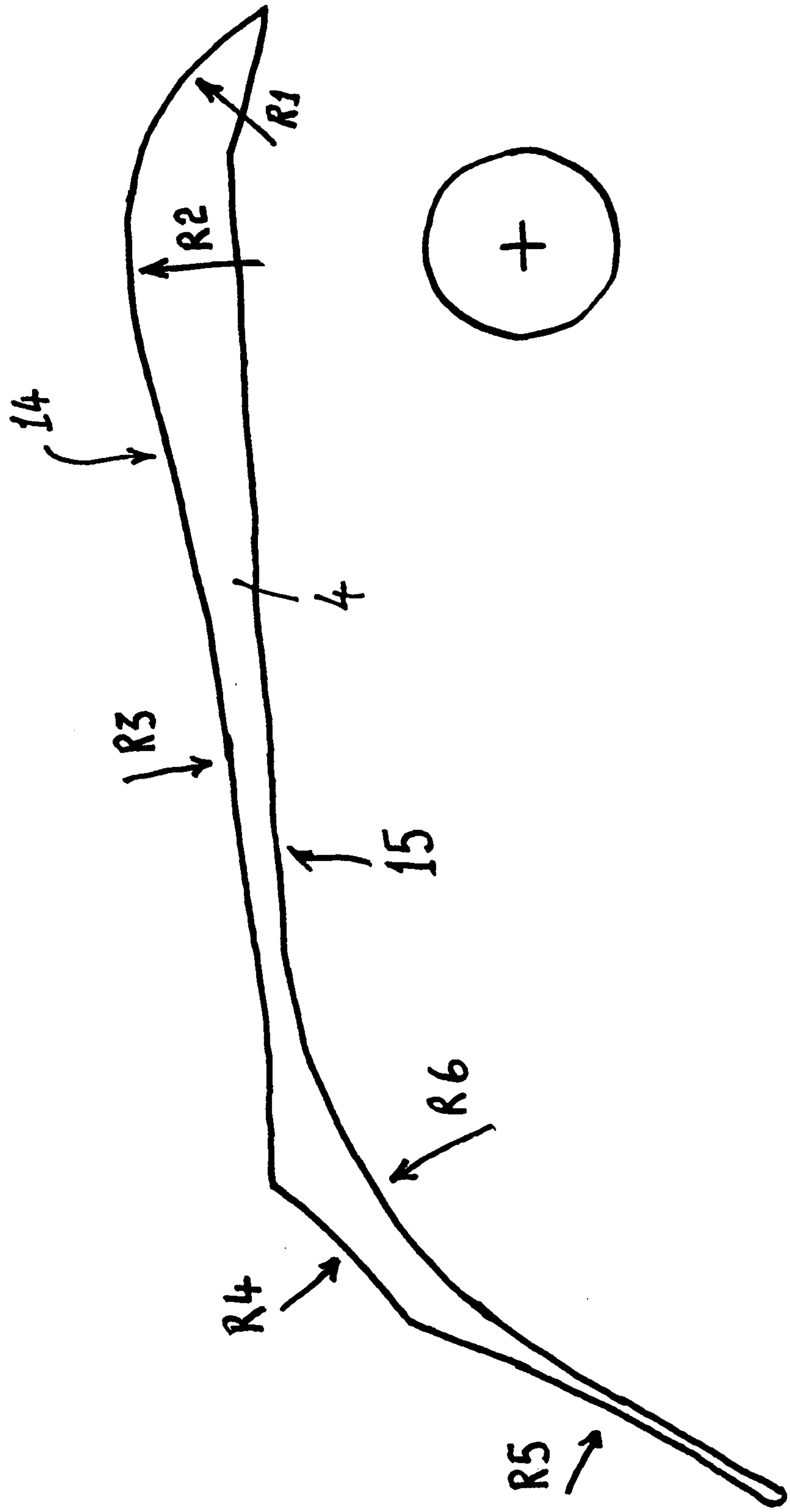

FIG. 3

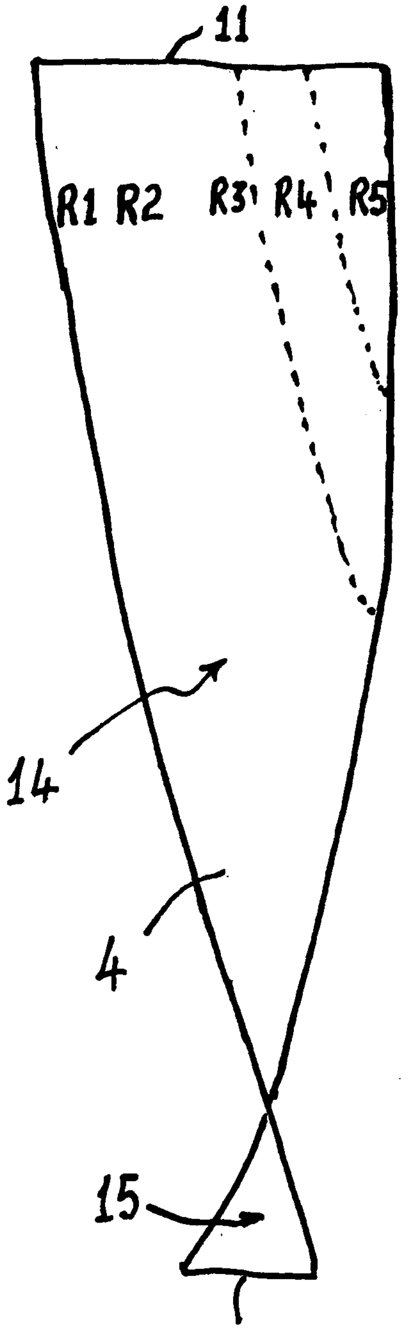

FIG. 4

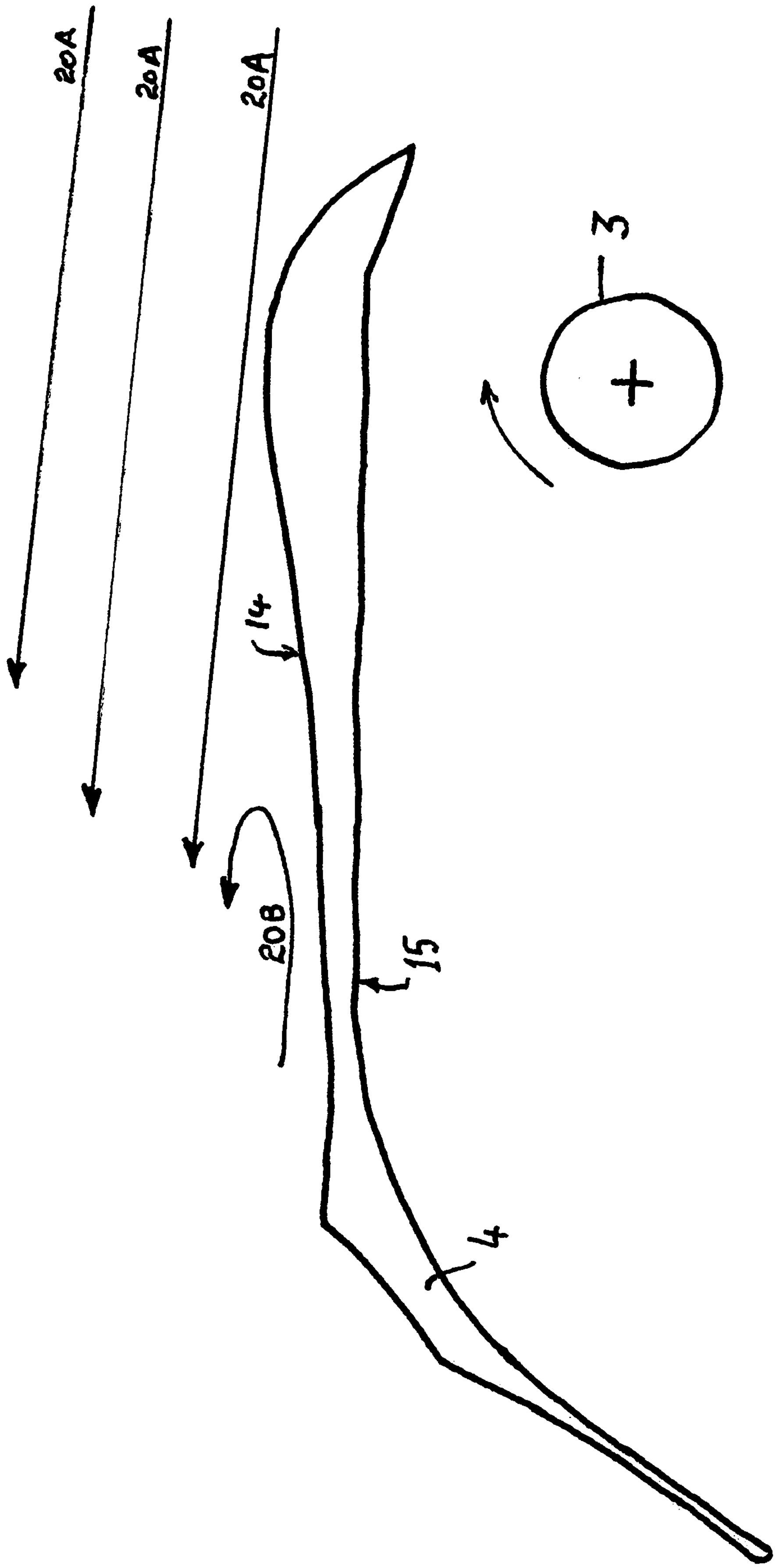

FIG. 5

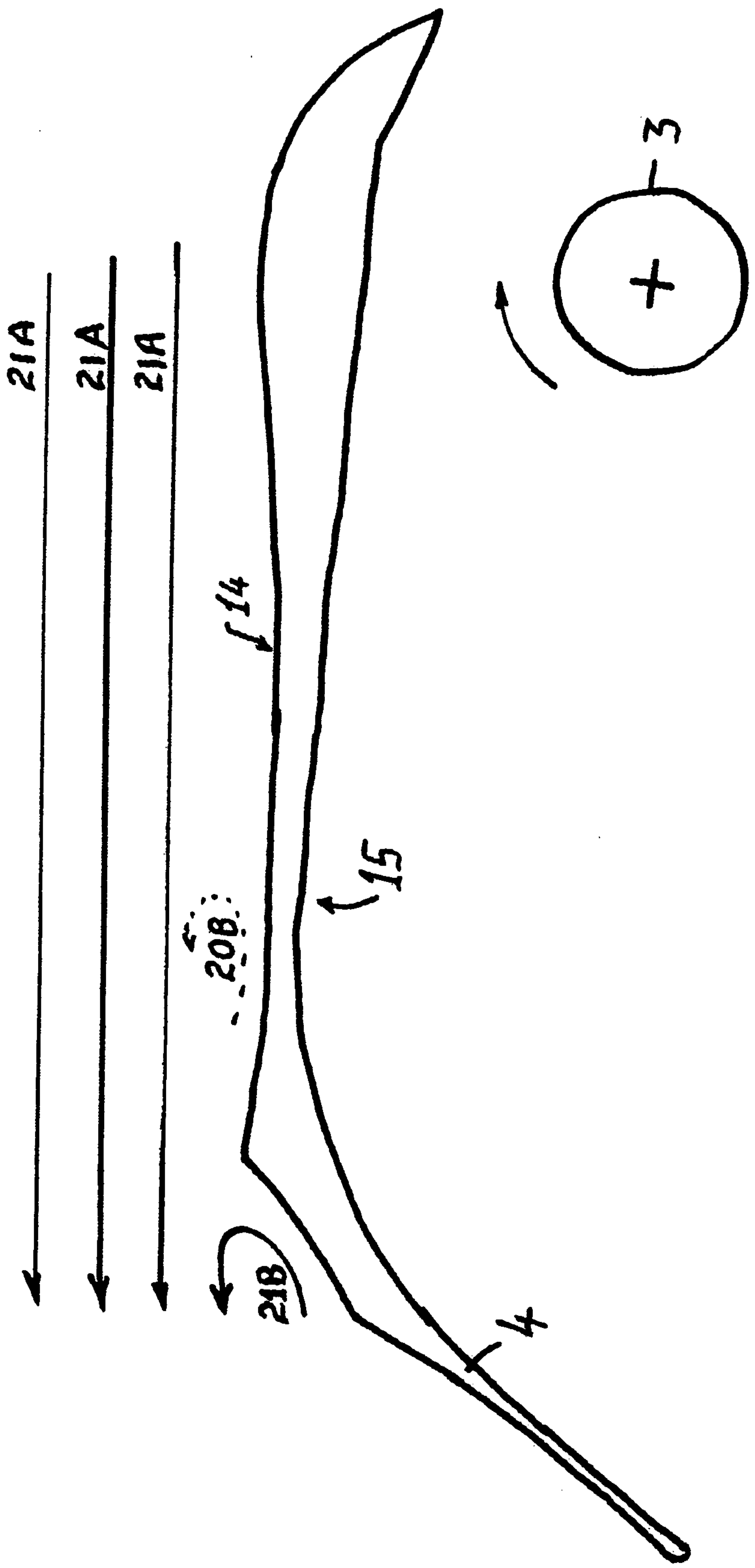

FIG. 6

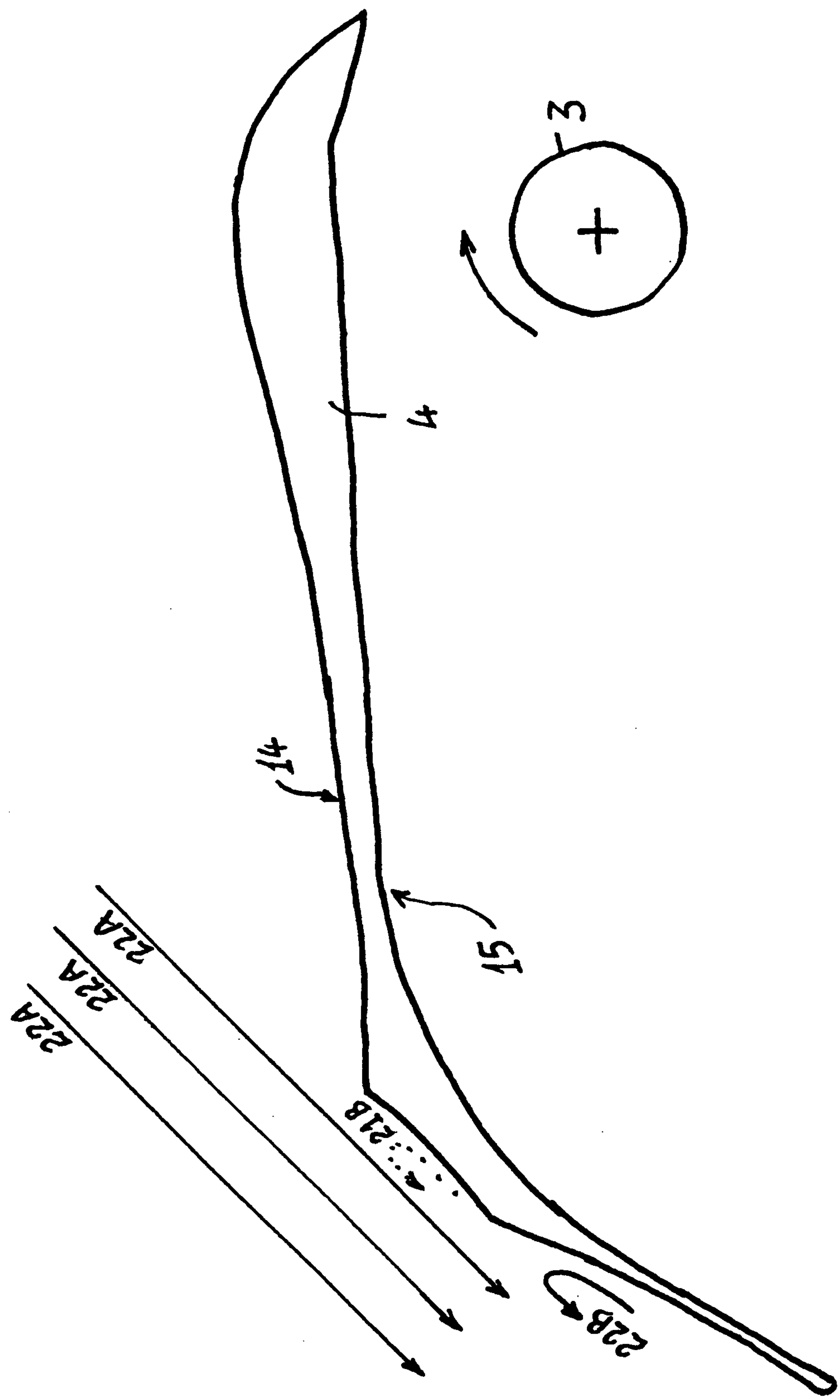

Fig. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU2009/000250

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl.

F01D 5/12 (2006.01) ***F03D 3/06*** (2006.01)

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)

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)
EPODOC & WPI: Classification Marks (F01D5/12/IC/EC, F03D3/IC/EC) & keywords (blade, rotor, airfoil, aerofoil, vane, twist, screw, helix, concave, convex, section and related words), Google Patents: Savonious and profile.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 2007/0104582 A1 (RAHAI ET AL.) 10 May 2007	
X	Entire Document, particularly Fig. 6	1-6, 8-11, 13, 14
Y	Entire Document, particularly Fig. 6	1-14
	WO 2005/010355 A1 (XCO2 CONISBEE LIMITED) 03 February 2005	
Y	Entire Document, particularly Fig. 2	1-14
	DE 2948060 A1 (ERNO RAUMFAHRTTECHNIK GMBH) 04 June 1981	
Y	Entire Document, particularly Fig. 1	1-14

☐ Further documents are listed in the continuation of Box C ☒ 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
23 April 2009	11 MAY 2009

Name and mailing address of the ISA/AU

AUSTRALIAN PATENT OFFICE
PO BOX 200, WODEN ACT 2606, AUSTRALIA
E-mail address: pct@ipaustralia.gov.au
Facsimile No. +61 2 6283 7999

Authorized officer
SARAVANA COIMBATORE
AUSTRALIAN PATENT OFFICE
(ISO 9001 Quality Certified Service)
Telephone No : +61 2 6222 3641

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/AU2009/000250

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	2007104582	US	7393177				
WO	2005010355	AU	2004259896	CA	2533426	CN	1826464
		EP	1649163	GB	2404227	GB	2415750
		RU	2006105624				
DE	2948060	NONE					

Due to data integration issues this family listing may not include 10 digit Australian applications filed since May 2001.

END OF ANNEX