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(84) Designated States (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, 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, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

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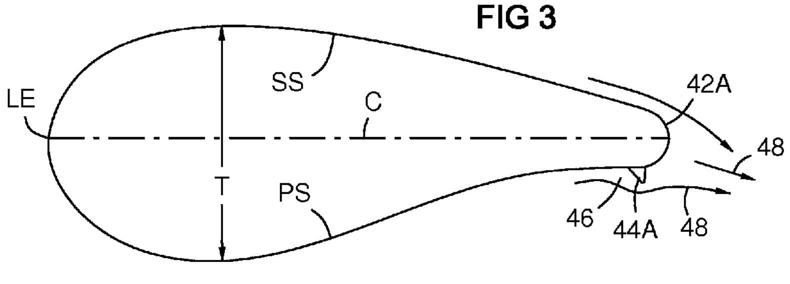
(54) Title: WIND TURBINE BLADE WITH TRAILING EDGE TAB

FIG 3



(57) **Abstract**: A wind turbine blade (20B-C) with a rounded trailing edge (42A-E) and an elongated tab (44A-J) extending from the pressure side (PS) within the aft 10% of the local chord (C) and generally parallel to the trailing edge to increase lift. The tab may have a height (H) that is greatest on the radially inboard end to maximize lift, and lower on the outboard end to minimize drag. It may have a base with a length of at least 60% of its height.

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WIND TURBINE BLADE WITH TRAILING EDGE TAB

FIELD OF THE INVENTION

The invention relates to airfoil efficiency, and particularly to a tab extending into the boundary layer on the pressure side of a wind turbine blade near the trailing edge to increase lift.

BACKGROUND OF THE INVENTION

Wind turbine designs have used thick trailing edges with a flat back on an inboard portion of the blades for structural strength and stiffness and increased lift. However, vortex shedding from flat-back trailing edges creates noise and drag. Also the sharp contours of flat-back airfoils cause blade molding problems, thus adding complexity to the blade structural design and blade manufacturing procedures and increasing the risk of non-conformance and repair hours. Vortex shedding has been reduced by devices such as splitter plates that extend aft from the flat-back trailing edge. However, this does not solve the manufacturing problem.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is explained in the following description in view of the drawings that show:

FIG. 1 illustrates the geometry of a prior wind turbine blade design.

FIG. 2 is a cross sectional profile of a prior flat-back airfoil.

FIG. 3 is a cross sectional profile of a round-back airfoil with a pressure side trailing edge tab.

FIG. 4 shows another tab embodiment.

FIG. 5 is a partial perspective view of an inboard portion of a wind turbine blade showing aspects of an embodiment of the invention.

FIG. 6 is a cross sectional profile of a right triangular tab.

FIG. 7 is a cross sectional profile of rounded isosceles tab.

FIG. 8 is a cross sectional profile of rounded asymmetric acute tab.

FIG. 9 is a cross sectional profile of a partly rounded asymmetric acute tab.

FIG. 10 is a cross sectional profile of an L-shaped tab.

FIG. 11 is a cross sectional profile of an L-shaped tab with fully filleted forward ramp.

FIG. 12 shows a cross section of a trailing edge with a built-in tab.

FIG. 13 shows a cross section of a trailing edge with an add-on cover with a tab and turbulators.

FIG. 14 shows a cross section of a trailing edge with an add-on cover with an extended tab.

FIG. 15 is a partial perspective view of an inboard portion of a wind turbine blade showing another embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG 1 shows the design of a prior wind turbine blade having a leading edge LE, a trailing edge, TE, and a radial span S from a root 22 to a tip 24. It has a cylindrical root region 26 with a radial length 27, a shoulder 28 at the position of maximum length of chord C, and a transition region 29 with a radial length 30 between the cylindrical root portion 26 and the shoulder 28. The transition region transitions in shape between a cylindrical profile 31 at the cylindrical region 26, through an intermediate egg-shaped blunt profile 32, to a lifting profile 33 with a pressure side PS and a suction side SS at the shoulder. “Radially" herein means spanwise S. "Radially inward" or "inboard" means toward or closer to the root 22. "Radially outward" or "outboard" means toward or closer to the tip 24. Outboard of the shoulder 28, the blade tapers to the tip 24. Portions 34 of the pressure side of the blade may be concave.

FIG 2 shows a profile of a flat-back airfoil with a relatively thick flat trailing edge 40. This design increases blade strength, stiffness, and lift in comparison to an otherwise similar airfoil with a sharp trailing edge and the same chord length C and maximum thickness T. However, it also increases drag and noise by vortex shedding, and is difficult to mold due to the sharp edges of the flat-back.

FIG 3 shows a profile of a round-back airfoil with a relatively thick rounded trailing edge 42A. It can be thought of as the flatback airfoil of FIG 1 but with a rounded trailing edge. This provides stiffness without sharp edges, and is thus practical to mold, but it does not increase lift as much as an otherwise similar flat-back airfoil. The inventors found that adding a tab 44A extending from the pressure side PS proximate the trailing edge 42A increases lift and can restore the original performance of the equivalent flatback airfoil. For example, the tab may be located in the aft 10% of the chord C. Airflow 48 slows in front 46 of the tab, increasing pressure and lift. The tab also directs the flow downward, further increasing lift.

FIG 4 shows another tab embodiment 44B with a concave front surface 50 that helps launch the airflow downward. The back surface 51 of the tab may also be concave or filleted onto the trailing edge, which increases the mounting surface area and structural strength. The tab may be mounted to the blade by adhesive or other means. The curvature of the rounded trailing edge may be generally circular with a radius R that varies with radial position along the blade. For example, the radius may be 50% of chord length at the cylindrical root portion (the chord being a diameter of the cylindrical root portion), tapering to 5 - 10% of chord length at the shoulder, and further tapering to 2 - 3% of local chord length at a position 30 - 50% of the blade span starting from the root 22. If the airfoil has a concave pressure side 34, there is an inflection point 52 where the concave pressure side transitions to the convex trailing edge 42A. In one embodiment, the tab 44B may follow this inflection point along at least a portion of the span of the blade, for example from the shoulder to at least one transition length 30B (FIG 5) past the shoulder, or from the shoulder to a radial position of 20-30% of the blade span starting from the root 22.

The tab may taper in height H from greatest at an inboard end of the tab to lesser at the outboard end. At the inboard end, increasing lift is more significant and drag is less significant for power production, while at the outboard end frictional and form drag become more significant, due to the local velocity of the blade relative to the air. If the tab has an inboard end at or proximate the inboard end of the transition region 29, the tab height at the inboard end of the tab may be for example 5-12% of chord length, and it may be inversely proportional to radial distance, which means tab height is reduced by half at twice the radial position of the inboard end of the tab. If the tab has an inboard end at or proximate the shoulder 28, the tab height may start for example at 3-6% of local chord length, and it may be inversely proportional to radial distance.

Alternately, the tab height may taper in proportion to local chord length. For example, if the tab starts at the shoulder, the tab height may taper from 3 - 6% of a local chord length at the inboard end of the tab to 0.5% - 2% or 0.5% - 1% of local chord length at the outboard end of the tab. The tab height may be measured normal to the pressure side to the tip or apex of the tab.

In one embodiment, the height of the tab may be set relative to a local boundary layer, which may be defined for example at reference ambient conditions of 15° C temperature, 1013 hPa pressure, 1.225 kg/m^3 density, and 10 m/s wind speed. Alternately, the reference conditions may be customized for a given site or elevation. Herein "boundary layer" means a layer of airflow contacting the blade surface and extending outward to a distance at which the air flows at 99% of the free-stream wind velocity relative to the blade. The height H of the tab may vary for example from 100% of the boundary layer thickness at the inboard end to 25% of the boundary layer thickness at the outboard end. Combinations of tab height limitations may be used, for example, the inboard end of the tab may have a height of 5-12% of local chord length, while the outboard end may be 25-100% or 50-100% of the local boundary layer.

FIG 5 is a partial perspective view of an inboard portion 20B of a wind turbine blade illustrating aspects of an embodiment of the invention. The blade may have a root 22, a cylindrical root region 26 with a radial length 27, a shoulder 28 at a radial position of maximum length of chord C, and a transition region 29 with a radial length 30A (transition length) spanning between the cylindrical root portion 26 and the shoulder 28. The transition region may transition in shape between a cylindrical profile 31 at the cylindrical region 26, through an intermediate egg-shaped profile 32, to a lifting profile 33B with a pressure side PS and a suction side SS at the shoulder 28. Portions 34 of the pressure side of the blade may be concave. The blade may have a rounded trailing edge 42A continuing from the egg-shaped profile 32 to a position past the shoulder 28, for example to a position at least one transition length 30B past the shoulder or alternately to at least 30% or 20% of the blade span starting from the root 22. An elongated tab 44B in accordance with an embodiment of the invention may extend from a pressure side of the blade or along at least most of a portion of the trailing edge from the shoulder to one transition length 30B (equal in length to 30A) past the shoulder or to 30% or 20% of the blade span starting from the root 22. The elongated tab may additionally extend over at least most of the transition region 29.

FIGs 6-17 show exemplary cross sectional shapes for tab embodiments with an apex 45, a base B, and a height H. FIG 6 is a cross sectional profile of a right triangular tab 44C. FIG 7 is a cross sectional profile of rounded isosceles tab 44D. FIG 8 is a cross sectional profile of rounded asymmetric acute tab 44E. FIG 9 is a cross sectional profile of a partly rounded asymmetric acute tab 44F. FIG 10 is a cross sectional profile of an L-shaped tab 44G. FIG 11 is a cross sectional profile of L-shaped tab G with a fully filleted concave forward ramp and filleted base. In all embodiments, the length of the base B may be at least 60% of the height H for structural strength and durability of the bond between the base and the pressure side.

FIG 12 shows a rounded trailing edge 42B that includes a tab 44H formed in the blade mold and integral with the trailing edge 42B. FIG 13 shows a rounded trailing edge 42C indented as formed to accept an add-on rounded trailing edge cover 42D that includes a tab 44I. It may further include turbulators 54 on the upper half of the trailing edge, such as ridges aligned with the trailing edge. "Upper half" means the half of the trailing edge toward the suction side SS. The turbulators increase turbulence production and this helps the flow stay attached to the rounded trailing edge surface longer than a laminar boundary layer, as known on some Frisbee® toy flying saucers and dimpled golf balls. This reduces pressure drag, and directs the trailing edge flow 48 downward in synergy with the tab 44I, increasing lift. The ridges only need to be 1-5 mm high or they may be higher at the inboard end of the trailing edge 42D to maximize lift, and lower at the outboard end to minimize frictional drag.

FIG 14 shows a tab 44J extending backward and downward from the molded trailing edge 42C, thus increasing chord length C by up to 20% over the molded chord length. This tab may be attached via an add-on trailing edge cover 42E with a rounded back. It may further include turbulators as in FIG 13. Different add on covers such as 42D, 42E, and others may be available to adapt a base blade design for different average ambient conditions at different installation sites and elevations.

FIG 15 shows an inboard portion of a wind turbine blade 20C with a downward curved corrugated flap 56 on the pressure side proximate the trailing edge over at least most of the length 30A of the transition region 29. The flap 56 may have a greatest height at the inboard end, such as 10% of chord, tapering to 5% at the shoulder 28. A tab 44B in any embodiment previously described may start at the shoulder 28 with a height such as 5% of chord, and taper to a lower height such as 2% of chord at a radial position one transition length 30B outboard of the shoulder. This provides increased lift inboard of the shoulder, and reduced frictional drag outboard of the shoulder.

While various embodiments of the present invention have been shown and described herein, it will be obvious that such embodiments are provided by way of example only. Numerous variations, changes and substitutions may be made without departing from the invention herein. Accordingly, it is intended that the invention be limited only by the spirit and scope of the appended claims.

CLAIMS

The invention claimed is:

1. A wind turbine blade comprising:

a cylindrical root portion;

a maximum chord position comprising a lifting airfoil cross sectional profile;

a transition region comprising a radial transition length between the root portion and the maximum chord position;

a trailing edge that is rounded in cross section from the root portion to at least one transition length radially outward of the maximum chord position; and

an elongated tab extending from a pressure side of the wind turbine blade over at least a portion thereof from the maximum chord position to said one transition length outward of the maximum chord position;

wherein the tab is located within an aft 10% of the chord length of the blade.

2. The wind turbine blade of claim 1, wherein the tab comprises a height normal to the pressure side, and the height gradually changes from 3 - 6% of local chord length at an inboard end of the tab to 0.5% - 2% of local chord length at an outboard end of the tab.

3. The wind turbine blade of claim 1, wherein the tab further extends along at least a portion of the transition region, and comprises a height normal to the pressure side, wherein the height gradually changes from 5 - 12% of local chord length at an inboard end of the tab to 0.5% - 2% of local chord length at an outboard end of the tab.

4. The wind turbine blade of claim 1, wherein the tab further extends along at least a portion of the transition region, and comprises a height normal to the pressure side, wherein the height is 5 - 12% of local chord length at an inboard end of the tab, and the tab height is inversely proportional to radial position along the radial span of the tab.

5. The wind turbine blade of claim 1, wherein the tab further extends along a portion of the transition region, and comprises a height normal to the pressure side, wherein the height tapers from 5 - 12% of local chord length at an inboard end of the tab to 25% - 100% of a local boundary layer at an outboard end of the tab.

6. The wind turbine blade of claim 1, wherein pressure side is concave over at least a portion thereof from the maximum chord position to said one transition length outward of the maximum chord position, and the elongated tab extends from and follows a concave/convex inflection point between the concave portion of the pressure side and the rounded trailing edge.

7. The wind turbine blade of claim 1, wherein the tab is generally triangular in cross section and comprises a concave front surface.

8. The wind turbine blade of claim 1, wherein the tab is generally L-shaped in cross section comprising a base portion facing forward and a fully filleted front ramp between the base portion and a height portion thereof.

9. The wind turbine blade of claim 1, wherein the tab is part of an add-on cover bonded to a molded trailing edge of the blade, the cover forming the rounded trailing edge of the blade and the tab, and further comprising turbulators on an upper half of the rounded trailing edge, the upper half being toward a suction side of the blade.

10. The wind turbine blade of claim 9, wherein the turbulators comprises a plurality of ridges parallel to the trailing edge.

11. The wind turbine blade of claim 9, wherein the turbulators decrease in height in proportion to radial position.

12. The wind turbine blade of claim 1, further comprising a downward curved corrugated flap on the pressure side proximate the trailing edge over a portion of the length of the transition region, wherein the corrugated flap comprises a first height at an inboard end thereof and a lesser second height at the maximum chord position, wherein the elongated tab has an inboard end at the maximum chord position starting with a third height that is not greater than the second height, and the elongated tab extends radially to at least one transition length outboard of the shoulder and tapers to a fourth height at the outboard end of the tab that is less than the third height.

13. A wind turbine blade comprising:

a root, a tip, and a span there between;

a cylindrical root portion extending radially outward from the root;

a maximum chord position comprising a lifting airfoil cross sectional profile at a radial position outboard of the cylindrical root portion;

a transition of airfoil profile shape over a spanwise transition length between the cylindrical root portion and the maximum chord position;

a rounded trailing edge with a radius of curvature of at least 2% of a local chord length as seen in cross section over an inboard 30% of the blade span; and

a tab extending from a pressure side of the wind turbine blade within an aft 10% of the local chord length over a portion of the blade from the maximum chord position to at least one transition length outward from the maximum chord position.

14. The wind turbine blade of claim 14, wherein the radius of curvature is 50% of local chord length at the cylindrical root portion, and reduces to 3-5% of local chord length at one transition length outward from the maximum chord position.

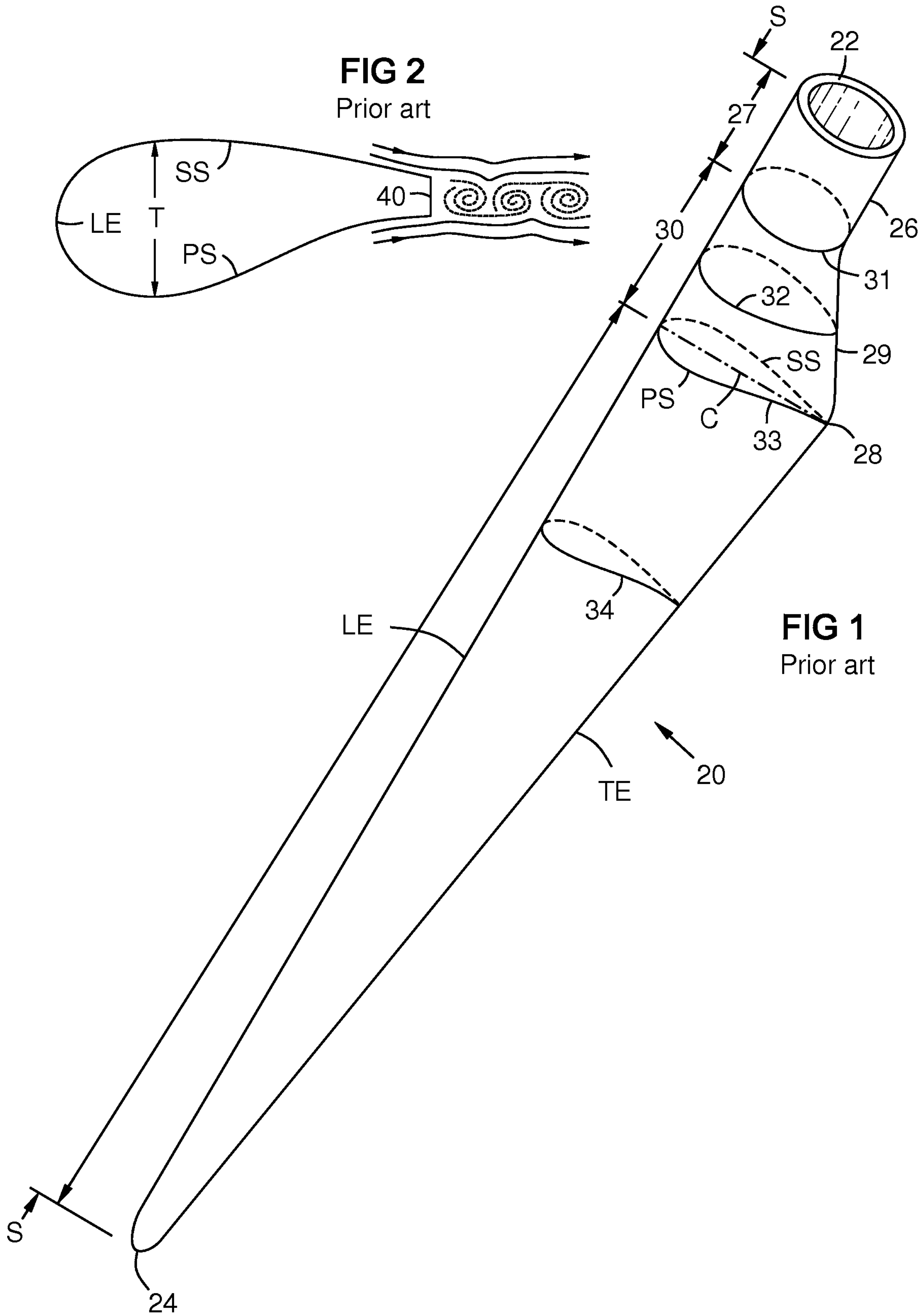


FIG 2
Prior art

FIG 1
Prior art

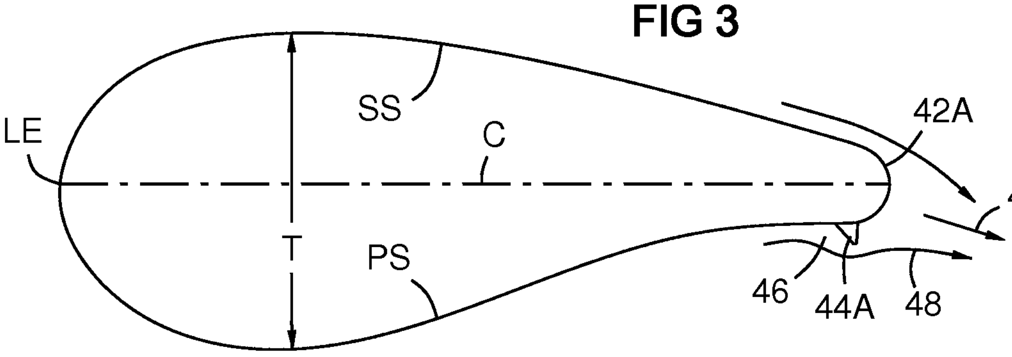


FIG 3

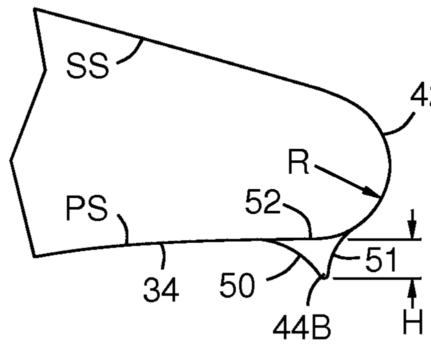


FIG 4

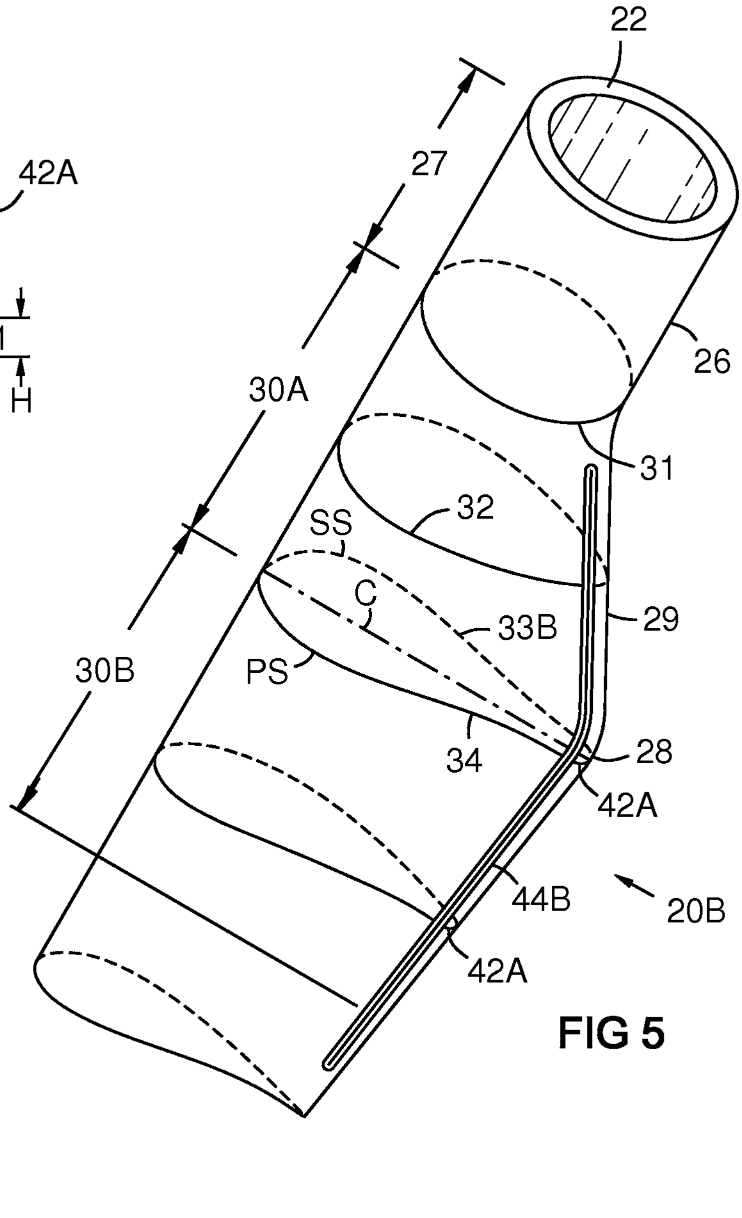


FIG 5

FIG 6

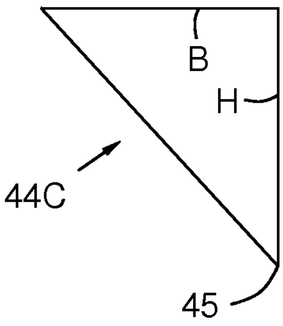


FIG 7

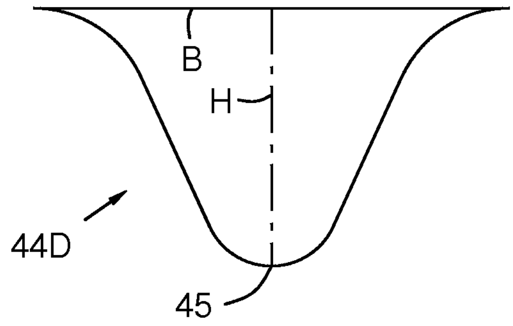
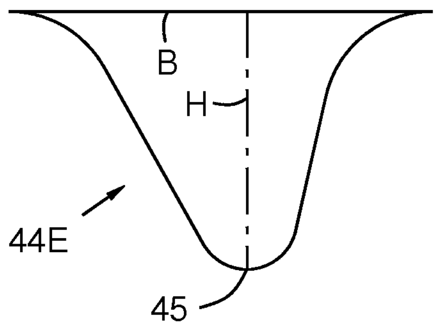


FIG 8



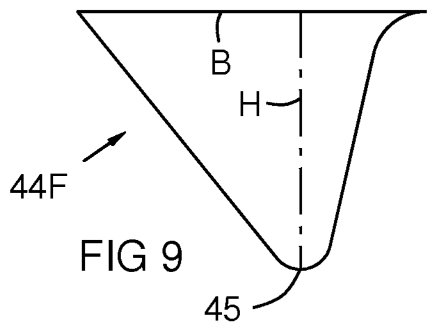


FIG 9

FIG 10

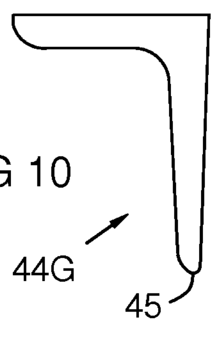


FIG 11

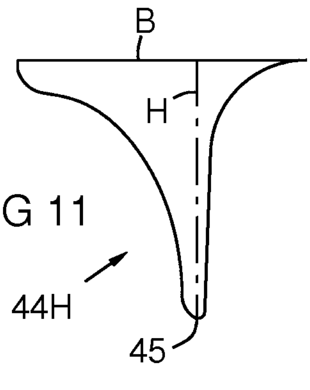


FIG 12

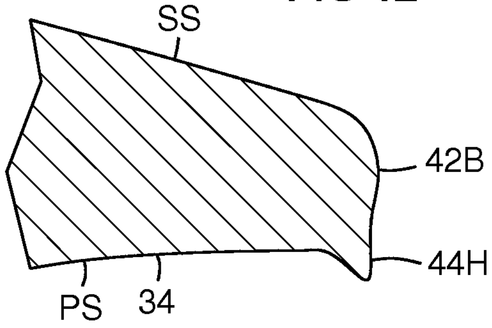
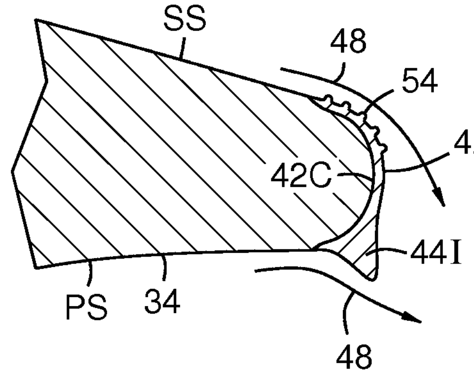


FIG 13



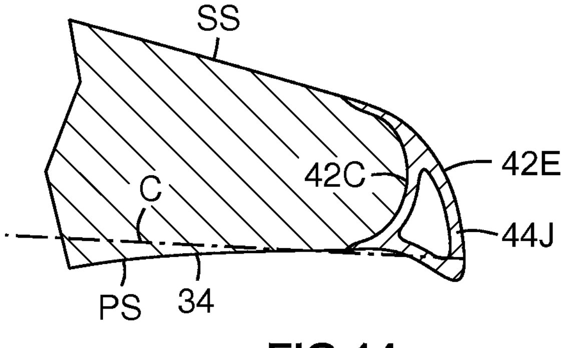


FIG 14

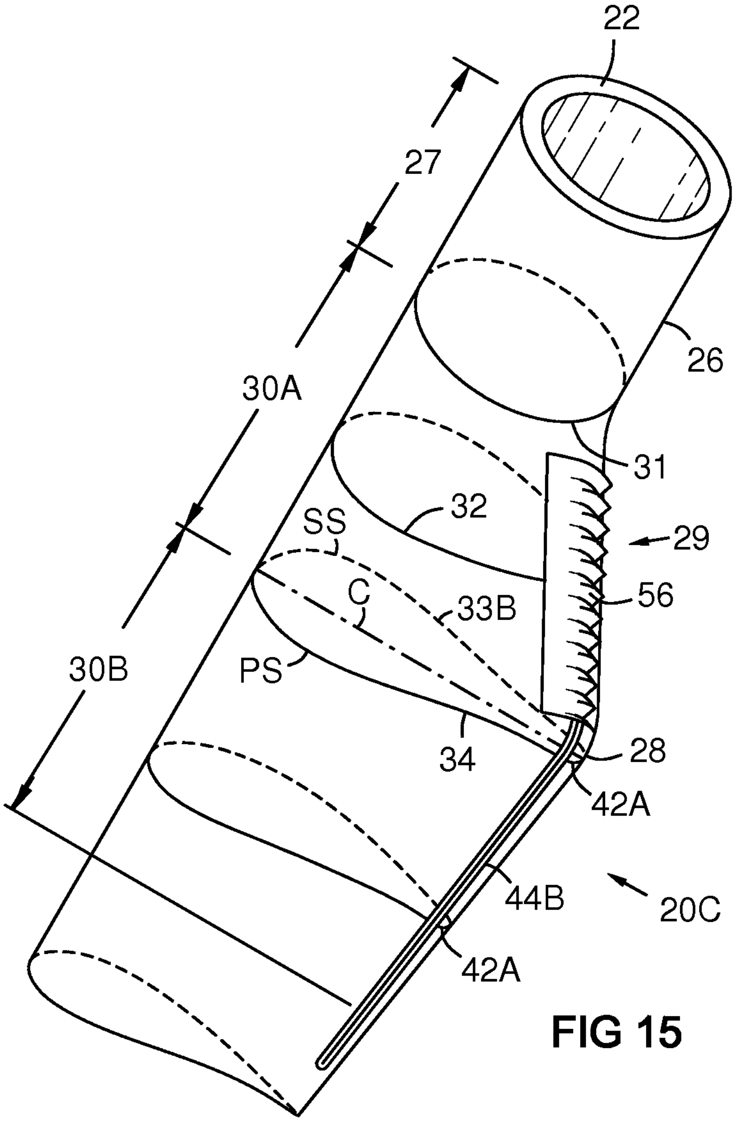


FIG 15

INTERNATIONAL SEARCH REPORT

International application No
PCT/US2015/048233

A. CLASSIFICATION OF SUBJECT MATTER
INV. F03D1/06
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)
F03D

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, 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	US 2012/134836 A1 (CARROLL CHRISTIAN A [US] ET AL) 31 May 2012 (2012-05-31) paragraph [0037]; figures 2,3,5 -----	1,7,13
X	EP 2 514 961 A1 (SIEMENS AG [DE]) 24 October 2012 (2012-10-24) figures 6,7 -----	1,7,13
A	US 2012/051936 A1 (EISENBERG DREW [US]) 1 March 2012 (2012-03-01) -----	1

☐ 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

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"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
12 May 2016	20/05/2016

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	Biloen, David

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/US2015/048233

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