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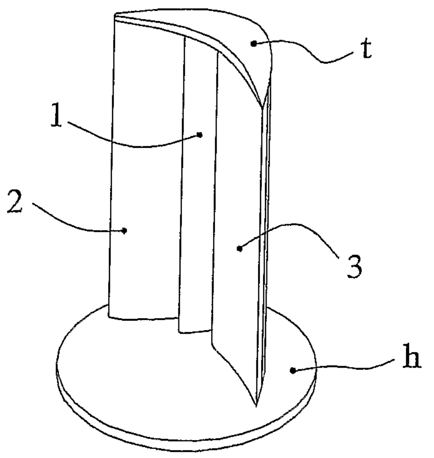
(54) **Title:** HIGH LIFT ROTOR OR STATOR BLADES WITH MULTIPLE ADJACENT AIRFOILS CROSS-SECTION



(57) **Abstract:** High lift rotor or stator blades with multiple adjacent airfoils cross-section, constituted from a main fin 1 and from at least one other secondary fin 2 and/or 3 joined through a root h and a tip t, and in the span between the root and tip is always imaginable a main airfoil P that circumscribes all the fin's airfoils. The peculiarity of this blades consists in the slots between the fins that enables transfering part of the air-flow with high energy, from the lower to the upper surface of the blades, with consequent increases of the boundary layer energy on the upper surface. Adopting the slots is possible to design blades that have both the camber and the surface greater than the actual blades in use, consequently increasing the lift and delaying the onset of the stall flutter.

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High lift rotor or stator blades with multiple adjacent airfoils cross-section.

Description

This invention relates to high performance rotor or stator blades and more particularly for applications in variable pitch fan (adopting the twisted stator row upstream the rotor as well the rotor blades described in the patent application WO02055845 "A Turbine Engine"), turbo-machinery and wind turbine.

The variable pitch systems, especially applied to fan assemblies, introduce problems in the achievable performance and in the stall flutter because of the reduced number of blades. Indeed, the lower the number of blades and: the lower the efficiency; the lower the performance; and the higher the pressure losses. The fact is that reducing the number of blades: both the work and the lift coefficient decrease because of the reduced stream line deflection amongst the airfoils leading and trailing edges; the aerodynamic forces decrease because of the lower rotor blades surface and the lower lift coefficient; the pressure loses increase and the efficiency decrease because of the boundary layer detachment point, on the airfoils upper surface, moves towards the leading edge.

It is therefore the main object of this invention to provide blades which have big surfaces, big camber and boundary layer detachment points closed to the trailing edge; even if applied in stator and rotor rows with both low number of blades and high attach angles.

The blades according to the invention will be referred hereafter with the acronym MAB "Multiple Airfoils Blade"; instead the multiple adjacent airfoils cross-section will be referred hereafter with the acronym MAS "Multiple Airfoils Section".

The objects of this invention will become readily apparent from the following description of the drawing in which:

Fig. 1a and 1b show the main geometric characteristics of the airfoils (a is the trailing edge, u is the leading edge, d is the upper surface, u is the lower surface, c is the chord and m is the middle line) and the attach angles α, respectively, in a traditional concave-convex airfoil and in a MAS concave-convex one;

Fig. 2a and 2b outline the streamlines path and the average speeds v in the boundary layer on the upper surface, respectively, in a traditional airfoil and in a MAS one (note that the main airfoil P, the attach angle and the external conditions are the same in both the airfoils);

Fig. 3a, 3b and 3c define, respectively, the speed triangle upstream an axial compressor stage and the speed triangles downstream the same compressor stage realized with traditional airfoils and with MAS ones;

Fig. 4a, 4b and 4c define, respectively, the speed triangle upstream an axial turbine stage and the speed triangles downstream the same turbine stage realized with traditional airfoils and with MAS ones;

Fig. 5 show few examples of MAS airfoils: 1 is the main fin; 2÷2n′ are the fin located upstream the leading edge; 3÷3n′ is the fin located downstream the trailing edge; S÷Sn′ are the slots; and P is the main airfoils which circumscribes all the fin′s airfoils;

Fig. 6a, 6b and 6c, respectively, show the rotor blade of a variable pitch fan in frontal, lateral and perspective views and the relative cross-sections in which are recognizable the multiple adjacent airfoils fins 1 and 2 as well the main airfoils P;

Fig. 7 sketch out few examples of general MAB plane shapes;

Fig. 8, 9 and 10 show few examples of rotor MAB;

Fig. 11 shows few different design chose of the same tapered rotor MAB: 1 is the main fin; 2 is the secondary fin; t is the tip fin that reduces the free vortex generation and has a structural function while t′ is the tip fin further useful to achieves the blades performance; h is the root fin that has only structural function (It′s the hub in fix pitch or the base-plate in variable pitch) while h′ is the root fin useful also to achieves the blades performance; and a is the projection among the fins needed to strengths the blades, protects the shape of the slots and avoids vortices propagation; it is underlined that it is possible to design any combination among the shape and type of MAB, with several MAS and projections a both for rotor or stator blades;

Fig. 12 shows the example of a twisted stator blade 20, partially constituted from MAS airfoils, lodged inside one Air-lntake 100;

Fig. 13 shows the example of the variable pitch rotor 110 with the MAB 30 shown in Fig. 6;

Fig. 14 shows the example of the rotor 120 of an axial compressor with the MAB 40;

Fig. 15 shows the example of the rotor 130 of a centrifugal pump with the MAB 50.

Referring to Fig. 2, with positive attach angles, the air-flow that encircles the upper surface increases continuously the speed and decreases the pressure from the leading edge towards the airfoil thickest point. Instead, from the thickest point moving towards the trailing edge the air-speed decreases and there is the pressure recovery; but, inside the boundary layer, the particles closer to the airfoil surface endure a greater air-speed deceleration than the expected one because of the energy loses due to the friction. In this latter case, it can be considered that the particles assume an opposite direction to the motion and are generated vortices. Thus, on the upper surface of the airfoil there is the separation of the boundary layer. When the separation point moves towards the leading edge the streamlines don't follow anymore the airfoil deflection (see point D in Fig. 2a) and a lot of vortices becomes generated; it does appear the stall flutter. It's clear that the vortices always dissolve energy and the higher the vortices propagation beyond the trailing edge and the lower are both the aerodynamic and acoustic efficiencies.

The separation point moves towards the leading edge increasing the camber and the attach angles. Moreover, both in stator and rotor row applications, the stall flutter depends from the number of the blades and more particularly depends from the solidity, the ratio between the chords and the mechanical pitch (distance between the airfoils): the separation point moves towards the trailing edge increasing the solidity. Thus, with the traditional technique, it is possible to design airfoil with high camber that work with high values of attach angles only when the solidity has very high values. For example it can be considered the different camber of the propeller airfoils in the actual turbo-fan: the airfoils camber increase closer to the hub.

After this consideration it is simpler to understand the reason that didn't allows to the variable pitch rotor to be developed in turbo-fan and turbo-machinery. Indeed, in these latter applications the benefits concerning the variable pitch technique become sensibly reduced with the reduction of the rotor blades (reduced values of the solidity).

It is therefore the first object of this invention to provide rotor blades to increase both the lift and the efficiency of the propellers, especially with low values of the solidity. In order to achieve this objective it has to be increased the rotor blades camber but moving the boundary layer separation points towards the trailing edges. Therefore it's necessary to increase the energy of the boundary layer on the upper surface of the airfoils. A useful solution is the MAB. Indeed introducing the slots S, shaped between the fins, part of the energy of the lower-surface's boundary layer is carried to the upper-surface's one. Referring to the Fig. 2b, the particles of the boundary layer in the point D are mixed with the higher energy particles that come from the slot S. Thus, in the point C the energy of the boundary layer is bigger than in the traditional airfoil and the separation point is moved towards the trailing edge even with high camber. Furthermore it's possible to increase the lift because of the increased surface. Referring to Fig. 1 and Fig. 2, it's evident that the total surface of a traditional airfoil is lower than the surface of a MAS one which has the same main airfoil P.

It is a still further object of this invention to provide rotor blades to increase the compressors and fans pressure ratio, especially with low values of the solidity. In order to achieve this objective it's necessary to increases the work L that the rotor blades supply to the flow. The following description it has been referred to axial applications, but the same theory and results can be applied to centrifugal ones. From the energetic equations of the fluid, it's obtained a relation called "equation of the work to the differences of kinetic energies" that it's suitable to estimate the pressure rise by the propeller and the axial compressors. The work is expressed in relation to the absolute kinetic energies C, of the relative energies W and of the driving energies U; and the work L is dues to the change of these speeds amongst the sections upstream and downstream the rotor blades. In the compressors, pumps, fans, propellers, and more generally in the operating machine:

$$L=(C_2^2-C_1^2)/2+(W_1^2-W_2^2)/2+(U_2^2-U_1^2)/2$$

In axial machines, it's possible to consider the same driving speed U for both the leading and trailing edges ($U_1 = U_2 = U = Cost.$). Defining y the angles between the absolute speeds C and the driving ones U, and referring to the Carnot theorem, is obtained the "Euler" equation of the work:

$$L=U_2 \cdot C_2 \cdot \cos y_2 - U_1 \cdot C_1 \cdot \cos y_1 = U \cdot (C_2 \cdot \cos y_2 - C_1 \cdot \cos y_1)$$

It's clear that to increase the work it's necessary to increase $C_2 \cdot \cos y_2$ and/or decrease $C_1 \cdot \cos y_1$. In practice it's necessary to increase the deflection of the streamlines among the rotor airfoils. That can be done in one hand increasing the camber of the rotor airfoils, in the other hand increasing the attach angles. Thus the proposed solution is again the MAB. Fig. 3, show a graphical comparison between two similar stages of an axial compressor. The stagger angles, the mechanical pitch and the operating conditions are the same in both the configurations, but not the airfoils. Thus the speed triangle upstream the rotors rows is the same; instead the speed triangles downstream the rotor row are sketched out considering the maximum deflection allowed by the airfoils without incur in the stall flutter. It's evident that $C_2' \cdot \cos y_2'$ is bigger than $C_2 \cdot \cos y_2$ and therefore that increasing the streamline deflection it's increased the work conferred to the gas or fluid.

It is a still further object of this invention to provide stator blades to increase both the rotor efficiency and the rotor pressure ratio, especially with low values of the solidity. In order to achieve this objective it has to be increased the stator blades camber but moving the boundary layer separation points towards the trailing edges. Indeed, increasing the streamline deflections of the stator row without incur in the stall flutter, the rotor stagger angles can be decreased (increasing the rotor efficiency) and the attach angles increase (increasing the rotor pressure ratio). The solution is therefore to adopt stator MAB.

It is a still further object of this invention to provide rotor blades to increase the energy achievable from the turbines, especially with low values of the solidity. In order to achieve this objective it's necessary to increase the work L that the rotor blades capture from the flow. With the same theory illustrated above for the operating machine, it is known that the energy absorbed from the axial turbines is proportional to the following equation:

$$L = U \cdot (C_1 \cdot \cos y_1 - C_2 \cdot \cos y_2)$$

As described for the axial compressor stage, to increase the work it's necessary to increase $C_2 \cdot \cos y_2$ and/or decrease $C_1 \cdot \cos y_1$. In practice it's again necessary to increase the deflection of the streamlines among the rotor airfoils. That can be done in one hand increasing the camber of the rotor airfoils, in the other hand increasing the attach angles. Thus the proposed solution is again the MAB. Fig. 4, show a graphical comparison between two similar stages of an axial turbine. The stagger angles, the mechanical pitch and the operating conditions are the same in both the configurations, but not the airfoils. Thus the speed triangle upstream the rotors rows is the same; instead the speed triangles downstream the rotor row are sketched out considering the maximum deflection allowed by the airfoils without incur in the stall flutter. It's evident that $C_2^{'} \cdot \cos y_2^{'}$ is bigger than $C_2 \cdot \cos y_2$ and therefore that increasing both the gas and fluid streamline deflection it's increased the attainable energy.

Claims

1. High lift rotor or stator blades having multiple adjacent airfoils cross-section, said airfoils being partially or completely placed on themselves; the blades being constituted by a main fin (1) and by at least a second fin (2) placed nearby the leading edge of the main fin (1), and/or at least a third fin (3) placed nearby the trailing edge of the main fin; the secondary fin being located close to the upper and/or lower surface of the main fin (1); said fins (1,2,3) being joined through a root (h) and a tip (t) forming, in the span between them, a main airfoil (p) that circumscribes all the airfoils of the fins; each of said blades having at least one slot (S) that provide to transfer part of the flow, with high energy, from the lower to the upper surface of the blades, with consequent increases of the boundary layer energy on the upper surface.
2. High lift rotor or stator blades according to claim 1, characterised in that the second fins (2) are two or more.

3. High lift rotor or stator blades according to claim 1, characterised in that the third fins (2) are two or more.
4. High lift rotor or stator blades according to claim 1, characterized in that the blades, as well the fins (1,2,3), are twisted and/or untwisted, tapered and/or with a constant chord, with or without a movable part, completely adjustable or fixed.
5. High lift rotor or stator blades according to claim 1, characterized in that each blade on the whole is single, being the fins joined through a root (h) and a tip (t) that reduce the external free vortices; said blades being realized both from several assembled pieces or from a single one.
6. High lift rotor or stator blades according to the claim 1, characterized in that the dimensions of the slots (S) are similar and/or different to the dimensions of the fin's chords.
7. High lift rotor or stator blades according to the claim 1, characterized in that the dimension of the main fin chord is similar and/or different to the dimensions of the secondary fins chords.

8. High lift rotor or stator blades according to the claim 1, characterized in that the airflow and the boundary layer across the slots (S) are of the laminar and/or turbulent types.
9. High lift rotor or stator blades according to claim 1, characterized in that the airfoils of the fins, as well the main airfoil (p), are thick or thin are of the symmetrical, conventional cambered, reflexed, aft-loaded, supercritical type or a combination of the former characteristics.
10. High lift rotor or stator blades according to claim 1, characterized in that the slots (S) are of the convergent, divergent and/or with constant area type, in the axial and radial directions.
11. High lift rotor or stator blades according to claim 1, characterized in that among the fins is placed at least one laminar or curved projection (a) that strengths the blades, protects the shape of the slot and avoids vortices propagation.
12. High lift rotor or stator blades according to claim 11, characterized in that the projection (a) has the plane shape coincident with the main airfoil (P) or a different shape; the shape of said

projection is thus contained in the main airfoil (P) perimeter or not.

13. High lift rotor or stator blades according to claim 1, characterized in that at least one fin is rotatable in respect of the other ones so that to modify the shape of the slot (S).

14. High lift rotor or stator blades according to claim 1, characterized in that at least in one section of the blade the flow is transonic or supersonic; and the upstream fin produces shock waves allowing to the following fins to work with subsonic flow.

15. High lift rotor or stator blades according to claim 1, characterized in that the blades are realized in superconductor material ad they are crossed from high density electrical currents so that to generate high magnetic field.

16. High lift rotor or stator blades according to claim 1, characterized in that a plurality of the bladesw are employed in turbine engine, axial & centrifugal compressors, axial & centrifugal ventilator, propeller, fan, axial & centrifugal pumps, axial & centrifugal turbines in aeronautical, maritime and space fields.

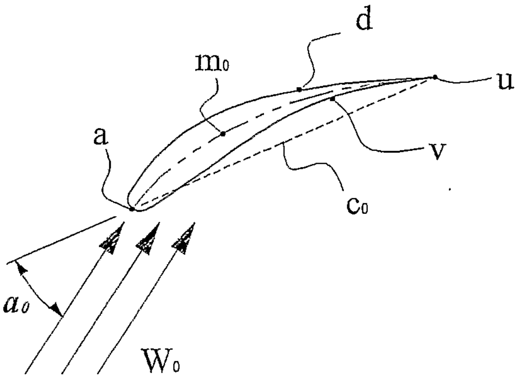


Fig. 1a

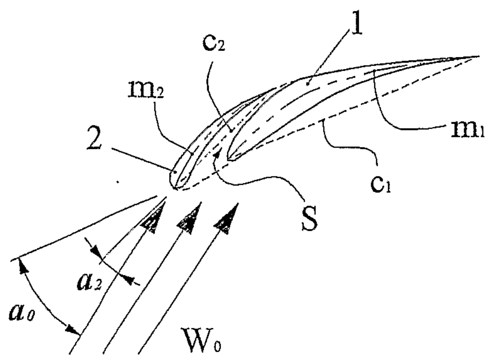


Fig. 1b

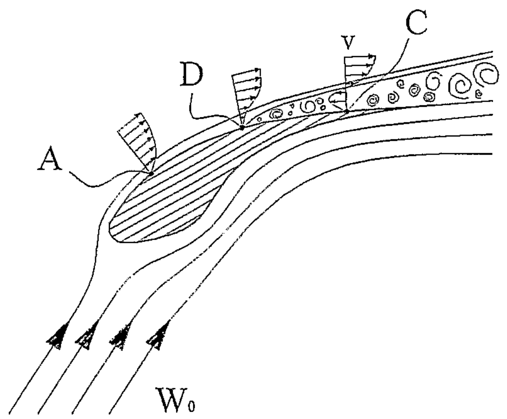


Fig. 2a

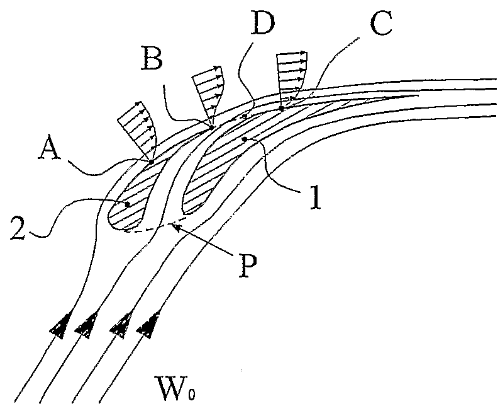


Fig. 2b

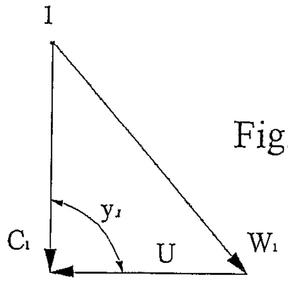
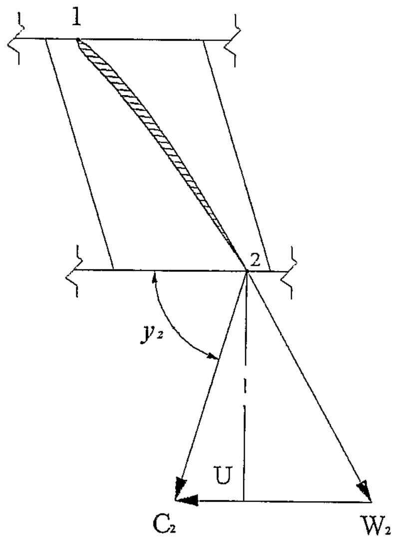


Fig. 3a

Fig. 3b



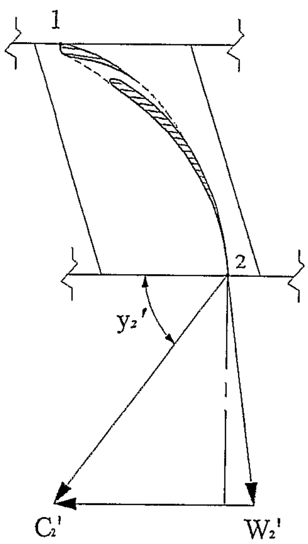


Fig. 3c

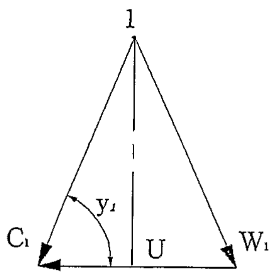
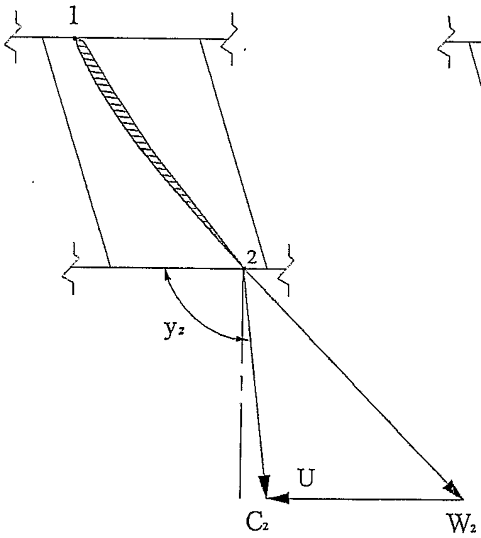


Fig. 4a

Fig. 4b



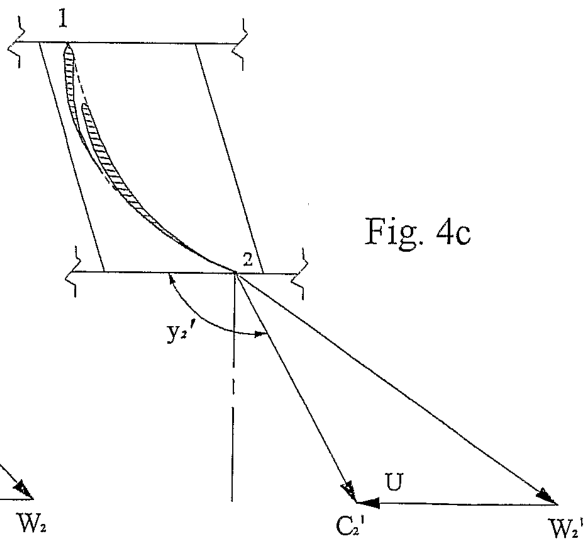


Fig. 4c

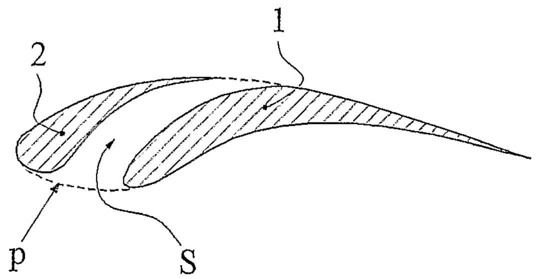


Fig. 5a

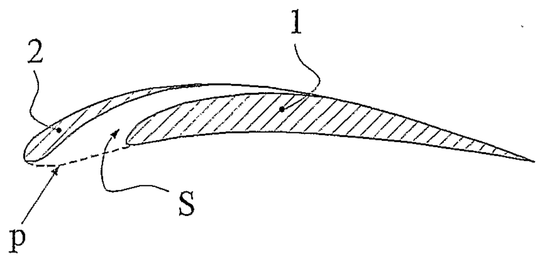


Fig. 5b

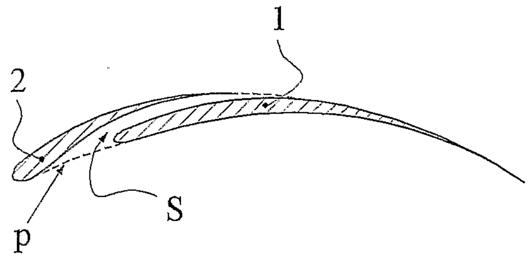


Fig. 5c

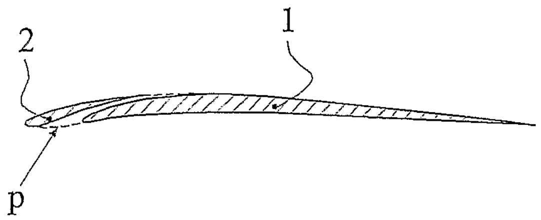


Fig. 5d

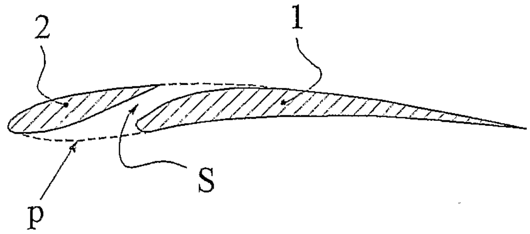


Fig. 5e

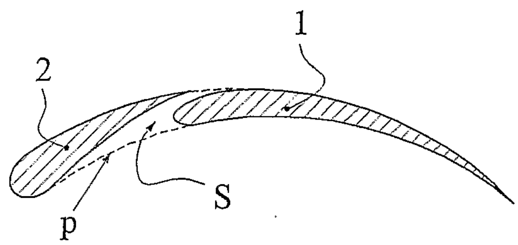


Fig. 5f

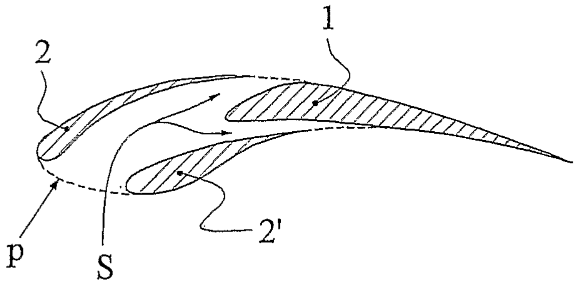


Fig. 5g

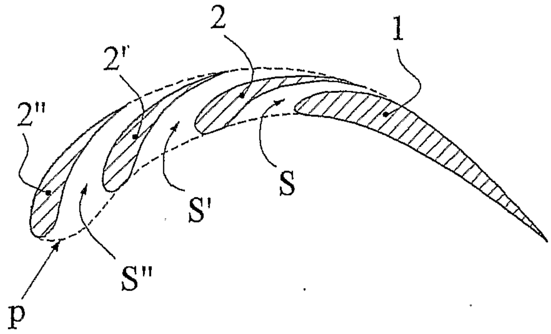


Fig. 5h

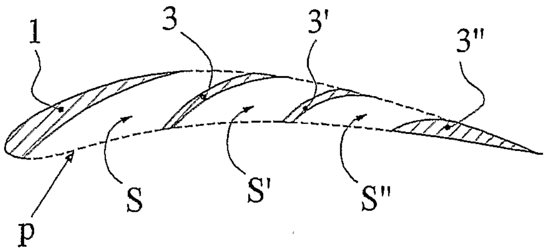


Fig. 5i

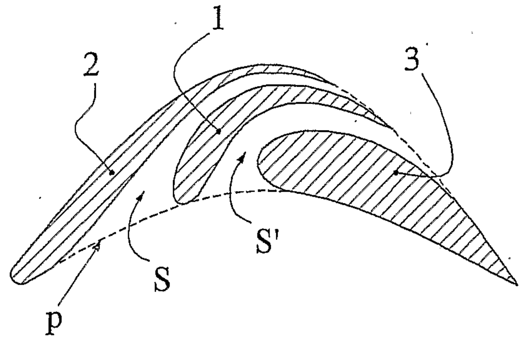


Fig. 5l

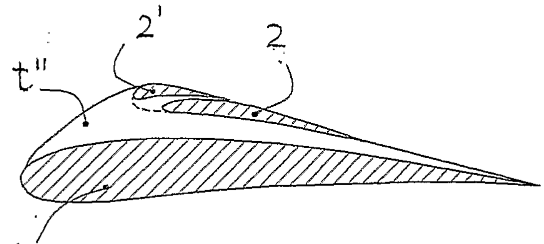


Fig. 5m

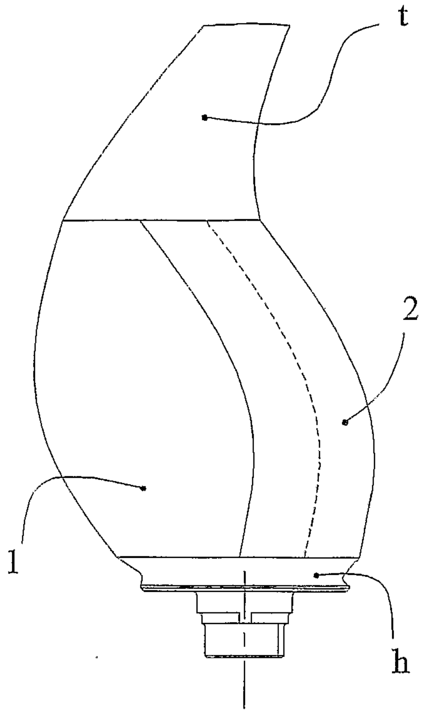


Fig. 6a

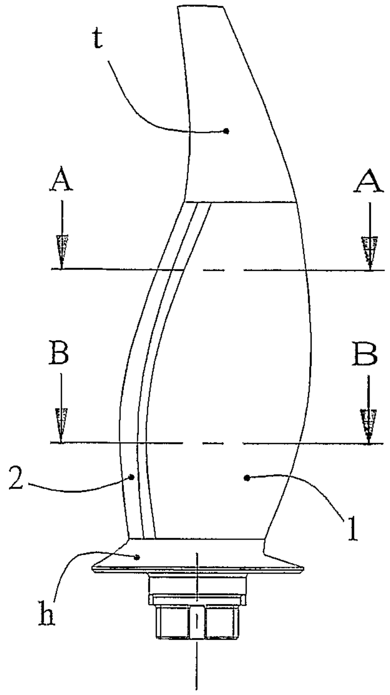


Fig. 6b

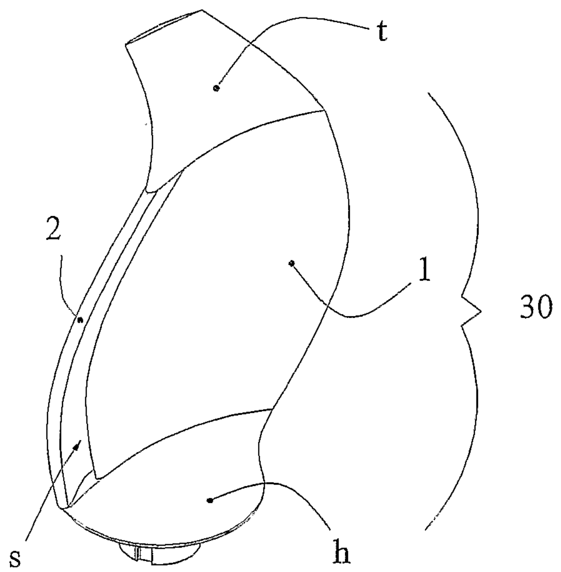
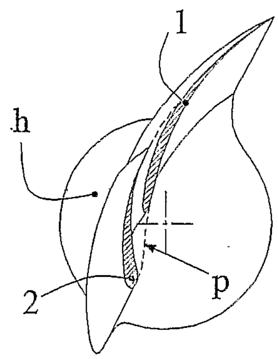


Fig. 6c



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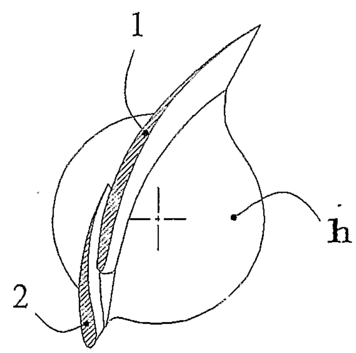

Sez. B-B

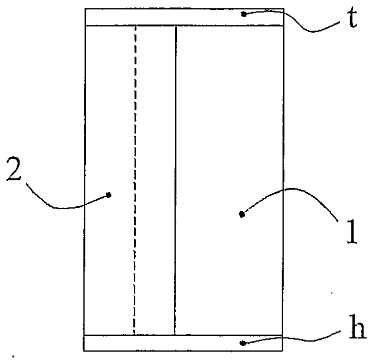

Fig. 7a

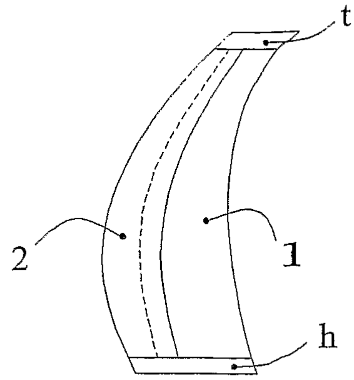

Fig. 7b

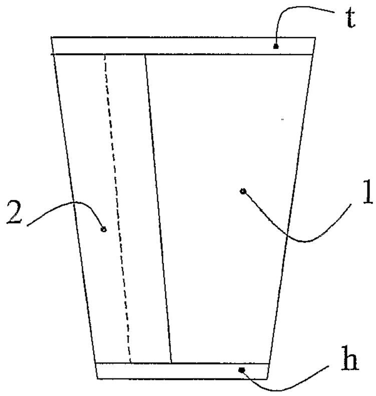

Fig. 7c

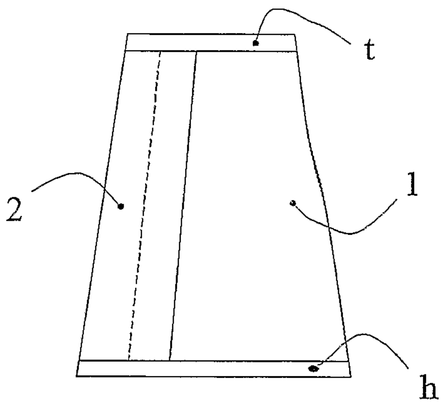

Fig. 7d

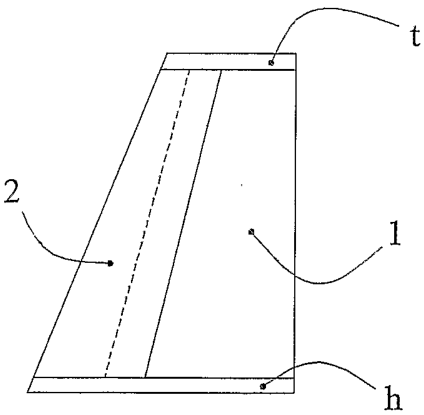

Fig. 7e

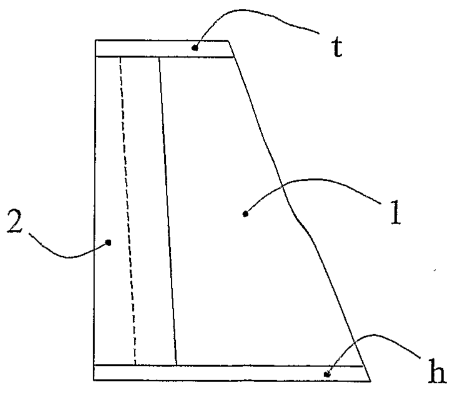

Fig. 7f

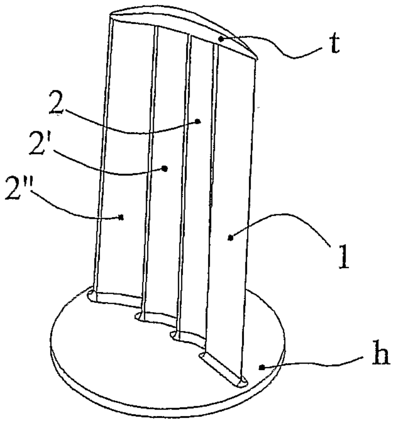

Fig. 8a

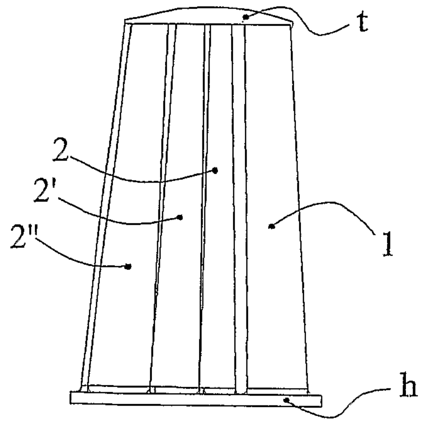

Fig. 8b

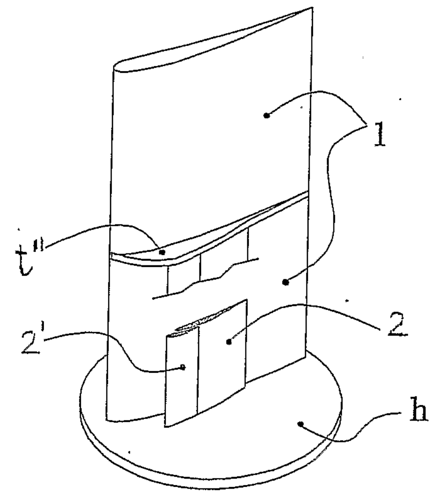

Fig. 9a

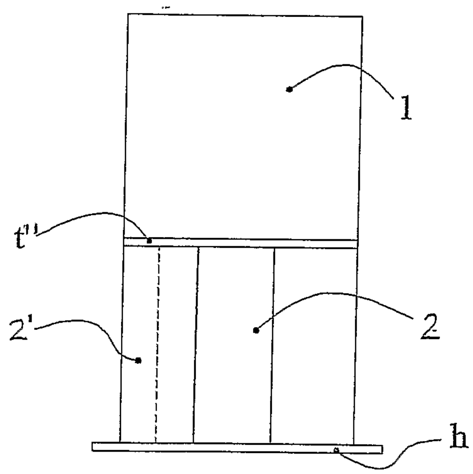

Fig. 9b

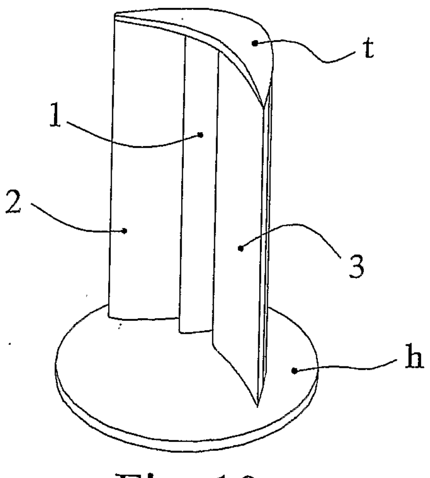

Fig. 10a

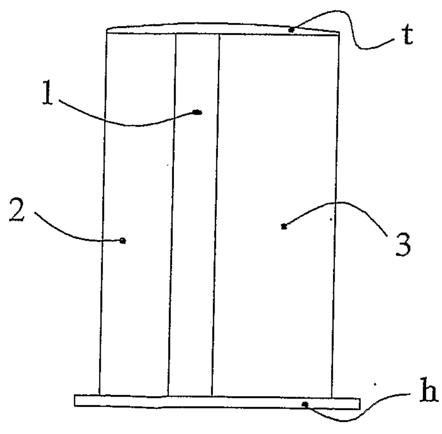

Fig. 10b

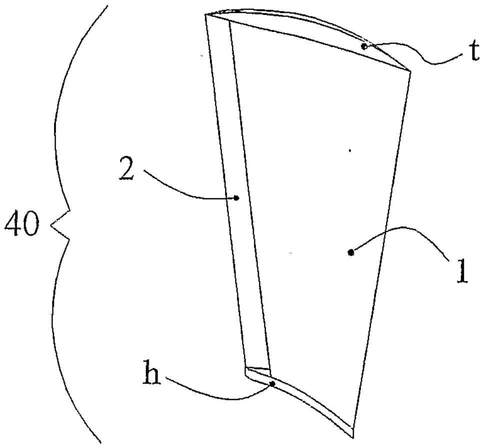

Fig. 11a

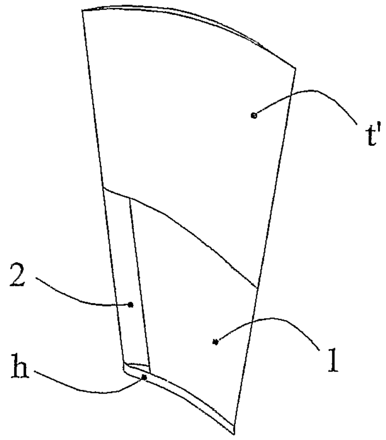

Fig. 11b

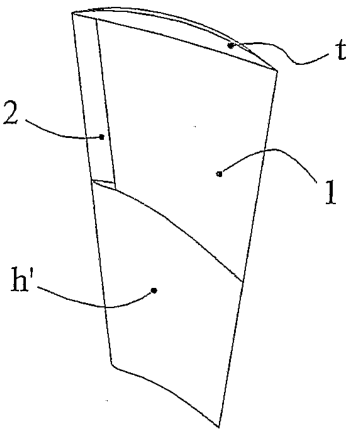

Fig. 11c

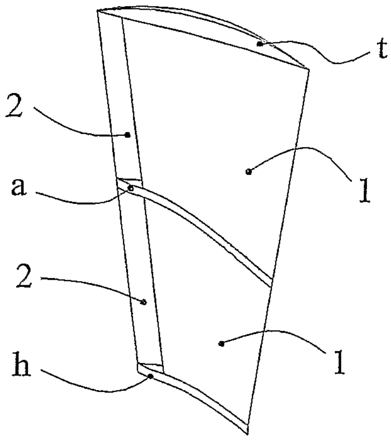

Fig. 11d

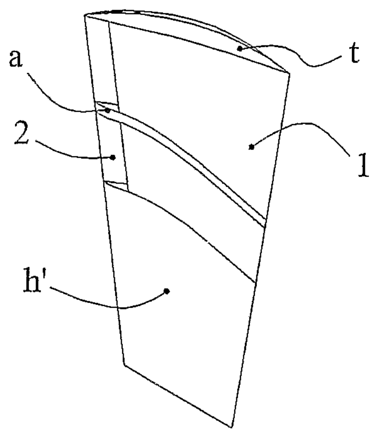

Fig. 11e

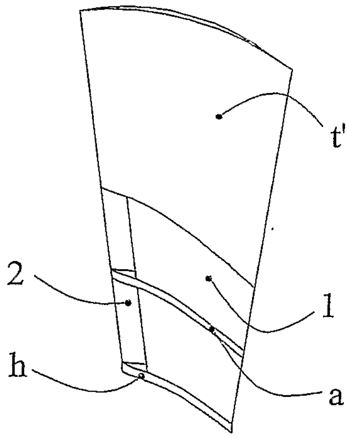

Fig. 11f

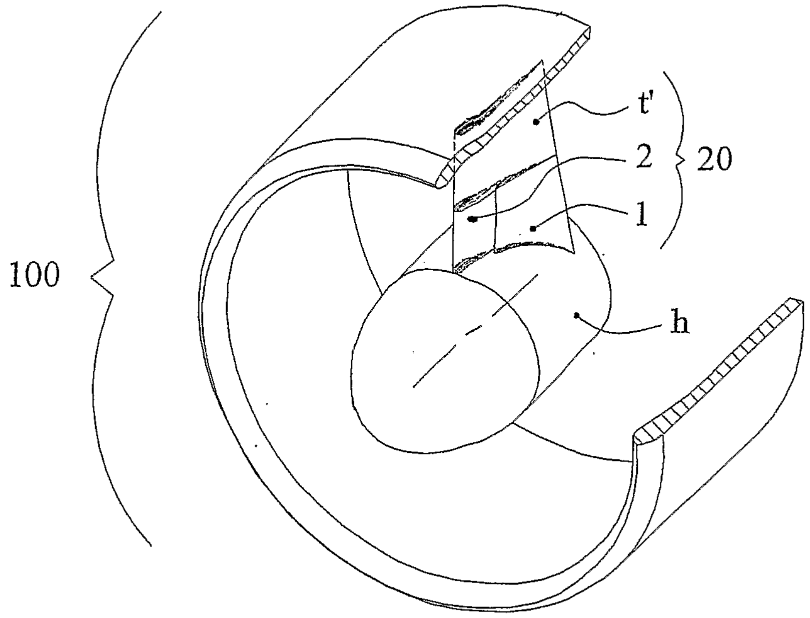

Fig. 12

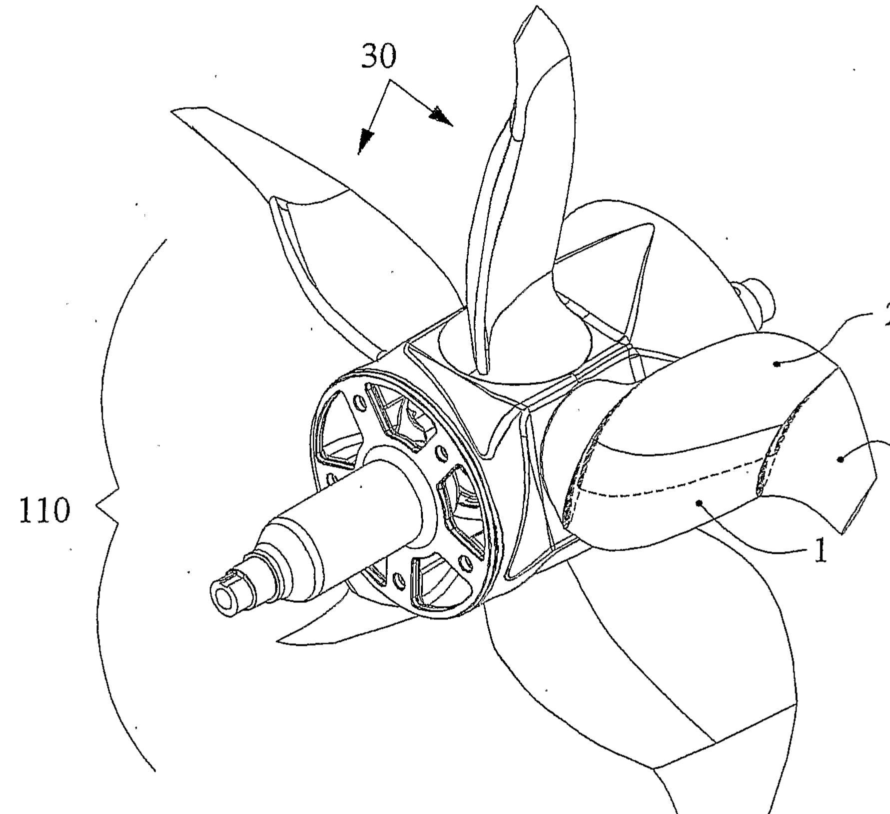

Fig. 13

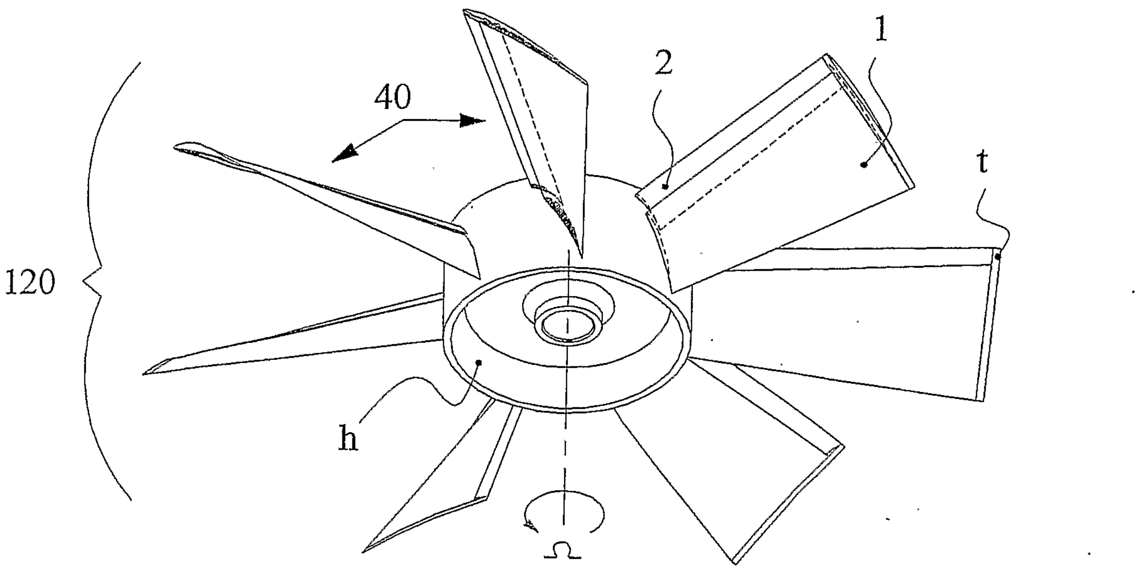

Fig. 14

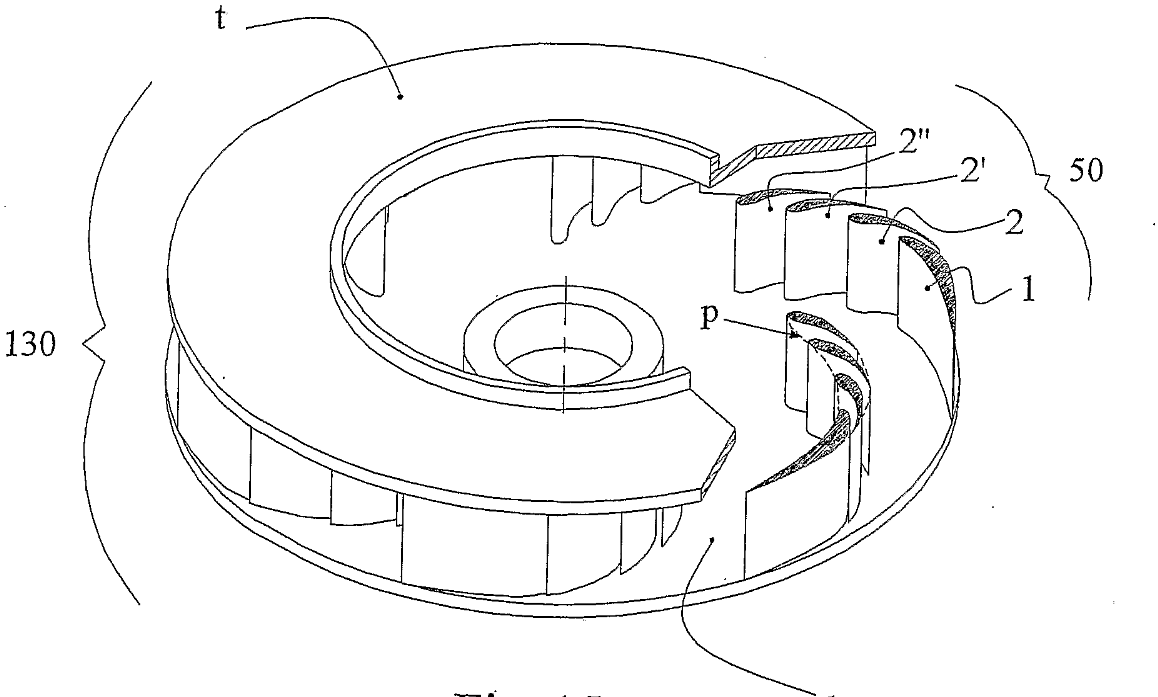

Fig. 15

INTERNATIONAL SEARCH REPORT

International Application No
PCT/EP2004/011546

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F01D5/14

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)
IPC 7 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 practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 2 106 193 A (* ROLLS-ROYCE LIMITED) 7 April 1983 (1983-04-07) abstract; figures 2,4 page 1, line 3 - line 5 page 1, line 35 - line 56 page 1, line 81 - line 106 page 2, line 19 - line 32 -----	1,4-12, 16
X	US 2 135 887 A (FAIREY CHARLES RICHARD) 8 November 1938 (1938-11-08) page 1, column 1, line 1 - line 4; figures page 1, column 1, line 22 - column 2, line 13 ----- -/--	1,2, 4-10,13, 16

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

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
25 January 2005	04/02/2005

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, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	de Rooij, M

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3 692 425 A (JOHN R. ERWIN) 19 September 1972 (1972-09-19) abstract; figures column 1, line 4 - line 7 column 1, line 58 - column 2, line 37 column 3, line 1 - line 21	1,4-12, 14,16
X	DE 390 486 C (DR. RUDOLF WAGNER) 20 February 1924 (1924-02-20) page 1, line 1 - page 2, line 32 page 2, line 109 - page 3, line 27 page 3, line 88 - line 101; figures	1,2, 4-12,16
X	US 2 938 662 A (ECKERT BRUNO ET AL) 31 May 1960 (1960-05-31) page 1, column 1, line 1 - line 6 page 1, column 2, line 23 - page 2, column 1, line 26	1,4-10, 16
X	US 1 553 627 A (NAGLER FORREST) 15 September 1925 (1925-09-15) page 1, line 8 - line 27 page 1, line 93 - page 2, line 15 page 2, line 109 - page 3, line 13 page 3, line 29 - line 52; figures 2-5	1-12,16
X	US 1 724 456 A (CROOK LOUIS H) 13 August 1929 (1929-08-13) the whole document	1-13,16
A	US 2 576 700 A (SCHNEIDER HEINRICH) 27 November 1951 (1951-11-27) column 1, line 1 - line 30; figures	1,2

INTERNATIONAL SEARCH REPORT

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PCT/EP2004/011546

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