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GYATT G W: "DEVELOPMENT AND TESTING OF VORTEX GENERATORS FOR SMALL HORIZONTAL AXIS WIND TURBINES", FINAL REPORT DOE/NASA/0367-1, XX, XX, 1. Juli 1986 (1986-07-01), XP000861589,

FIELD OF THE INVENTION

The present invention relates to a swirl element for swirling a fluid flow and for reducing noise and increasing yield for a rotating aerodynamic profile, and to a method of manufacturing such a swirl element.

TECHNICAL BACKGROUND

Aerodynamic profiles generate increased noise, increased drag and mechanical loads, particularly at high speeds and in the event of static or dynamic stall. There are increasingly strict regulations on noise emissions, particularly for wind turbine rotor blades, which influence the design and ultimately the yield. In addition, environmental influences such as gusts of wind lead to stalling and corresponding dynamic loads and vibrations. This leads to approval problems, restrictions on the areas of application and more massive profile designs.

Vortex elements are often used in rotors for wind turbines, primarily in the radially outer rotor blade areas where the highest flow velocities prevail. Previous vortex elements, so-called vortex generators or vortex generators, are used to form a turbulent boundary layer along the profile surface, which is less susceptible to stall. EP 2 824 320 A1 describes such vortex generators, which are applied to the vacuum side in the front or middle areas of the airfoil.

There are also noise reduction measures for wind turbines, also primarily in the radially outer rotor blade areas. These measures are aimed at the so-called trailing edge vortex, which is created at the profile trailing edge. This is largely responsible for noise emissions and creates a certain resistance or reduces the aerodynamic efficiency of the airfoil. To reduce the end edge vortex, a serrated structure, also known as serration, is sometimes provided on the rear end edge of the profile. For example, DE 10 2014 213 929 A1 describes such a serrated structure. Further prior art is known from Gyatt G W:

"DEVELOPMENT AND TESTING OF VORTEX GENERATORS FOR SMALL HORIZONTAL AXIS WIND TURBINES", Final Report DOE/NASA/0367-1, XX, SS, July 1, 1986.

SUMMARY OF THE INVENTION

Against this background, the present invention is based on the task of providing a new approach for reducing noise, increasing efficiency and reducing the load on aerodynamic profiles.

According to the invention, this task is solved by a turbulence element with the features of claim 1 and/or by a method with the features
of patent claim 12.

Accordingly, it is planned:

- a turbulence element for turbulence of a fluid flow, in particular for a rotating aerodynamic profile or a turbine, comprising: a fastening section designed for fastening to a profile surface;

and a flow-active section connected to the fastening section, which has a guide plate that is twisted around a common axis at least in sections with its entire cross-section.

- A method of manufacturing a turbulence element according to the invention, comprising the steps of Providing a sheet, in particular a thermoplastic fiber composite sheet or a metallic sheet, which is cut to size to form an aerodynamically active section; introducing the sheet into a forming tool, the forming tool being designed as a forming press tool, in particular a hot forming press tool; and forming the sheet by means of the forming press by applying a twist to the sheet by at least 10°, in particular up to 90°, with its entire cross section about a common axis by means of a corresponding shape of the forming press tool, at least in sections.

The idea underlying the present invention is to form a swirl element with a guide plate twisted over the entire cross-section and to fasten it to an aerodynamic profile with a fastening section that is separate from an aerodynamically active section. This makes the swirl element easy to manufacture and extremely flexible to use. In particular, different effects can be achieved with vortices generated in this way on an aerodynamic profile, depending on the dimensions and positioning on the profile surface. In addition to generating turbulent boundary layers in the manner of a vortex generator, the turbulence element according to the invention can also be used to reduce noise in the manner of previous serrations. In particular, according to the invention, in addition to a serrated extension beyond the profile end edge, a vortex that additionally reduces the profile end edge vortex is also generated. Compared to conventional serrations, this additionally reduces the noise emission of an aerodynamic profile and further increases efficiency.

For example, according to the invention, an increase in the lift coefficient and glide time, which ultimately means a reduction in resistance and an increase in yield, of up to 3 % can be achieved compared to conventional serrations. Furthermore, a noise reduction in a range of at least > 1 dB(A) to > 5 dB(A) can be achieved.

With the noise reduction according to the invention, a larger dimensioning or a higher number of systems within the noise regulations is advantageously possible in this way. This achieves a synergy of increased yield and simultaneous noise reduction, while also ensuring simple and cost-effective manufacturability.

The present invention can be used for a wide variety of rotating aerodynamic profiles. In addition to use for rotor blades of rotors on wind turbines, applications for drive propellers or other rotating profiles are also conceivable, for example.

The Reynolds number range for applications according to the invention is correspondingly broad, lying in the range of approximately 1×10^5 to 1×10^7 , in particular 0.5×10^6 to 30×10^6 . Conceivable but not exclusive areas of application are, for example, for rotor blades and propellers in the range of 1 x 10^6 to 10 x 10^6 and for turbines and jet engine housings.

In the context of the present invention, a sheet metal is generally understood to be a flat semi-finished product, whereby the material or its manufacture is not important. In addition to metals such as aluminum, titanium, stainless steel or the like, plastic materials, preferably fiber composite materials, in particular thermoplastic fiber composite materials, are also used in particular.
Question. It may or may not necessarily be a rolled product. It includes, among other things, flat or strip-like semi-finished products that can be formed.

Consequently, a baffle plate is to be understood in particular as a twisted formed flat semi-finished product, which is twisted with its entire cross-section to swirl a flow. However, it also includes 3D formed elements with a correspondingly twisted shape.

In accordance with the invention, the guide plate is designed with its entire cross-section twisted around a common axis, at least in sections. In particular, the entire cross-section of the baffle is thus used to generate the vortex.

Accordingly, the guide plate has a predetermined pitch over its length, which can be constant or of varying degrees due to the torsion over the cross-section. According to the invention, such a gradient can be distributed evenly or to varying degrees over the length. In particular, the pitch can increase over the length of the guide plate, so that in this way an increased acceleration or an increased twist of the vortex to be generated can be achieved.

The rotation can continue over an angular segment, over an entire revolution or over several revolutions. Twists in the range from >10°, preferably from >45°, up to several revolutions, for example up to two full revolutions (720°), are particularly conceivable, although even greater numbers of revolutions are not ruled out.

Local gaps, for example in the form of recesses in the twisted guide plate, or interruptions or endings of the twist, for example with straight sections, can be provided in the twist. Such a twist can therefore also be formed by one or more kinks in the guide plate.

According to the invention, the guide plate is triangular, trapezoidal, partially circular, partially elliptical and/or polygonal. Furthermore, composite shapes are also possible.

The dimensions of the baffle plate, in particular the basic shape of the baffle plate, can vary depending on the application. For example, widths from 0.2 mm to 300 mm, thicknesses in the range from 0.2 mm to 10 mm, preferably 0.25 mm to 5 mm, and lengths from 0.1 times to 20 times the width are conceivable. The thickness is always dimensioned as small as possible in order to generate as little resistance as possible due to any edge that may be created. In particular, the thickness is adapted to the width and length accordingly in order to provide sufficient rigidity for the desired turbulence and sufficient strength for the desired service life (e.g. in the event of hail).

A wide variety of forms and types of attachment to the profile surface are also conceivable for the fastening section. In one embodiment, the fastening section can simply be attached or applied to the profile surface, for example adhesively or by means of an adhesive. A small thickness of the fastening section is advantageous in order to keep the edge created at the edge of the fastening section as small as possible. In particular, a front end edge of the fastening section can also be bevelled, for example with a chamfer, in order to smooth the transition and thus minimize resistance.

In a further embodiment, it is conceivable to integrate the fastening section into the profile surface. For example, a groove or recess corresponding to the thickness of the fastening section can be provided in the profile surface, into which the fastening section can be countersunk.

In one embodiment, the fastening section is formed from the same semi-finished product as the guide plate. In the simplest embodiment, the fastening section therefore has a flat shape that can be attached to the profile surface with a material bond or adhesively. In addition, shapes adapted to a profile surface shape, for example with a kink or two-dimensional or three-dimensional curvature, are conceivable.

Adhesive attachment of the fastening section makes it very easy to retrofit existing aerodynamic profiles, especially on wind turbines. It also enables local reinforcement of an aerodynamic profile, especially in the highly stressed area of profile end edges.

It would also be conceivable to mount the fastening section in a recess or slot in the profile surface, for example directly on the profile end edge. The fastening section is shaped according to the slot geometry.

It is also possible to design the fastening section independently of the aerodynamically active section and to subsequently couple the aerodynamically active section to the fastening section. Various movable or immovable couplings are conceivable for this purpose. For example, the fastening section can be designed as a type of base to which the aerodynamically active section is attached or mounted. An articulated or rotatable mounting of the aerodynamically active section on the fastening section is also conceivable. Furthermore, a simple suspension of the aerodynamically active section, for example on a wire or cable tensioned on the profile surface, would also be conceivable.

In the case of an aerodynamic profile, the fastening section can be arranged or attached on the suction side or upper side of the profile or on the pressure side or lower side of the profile. It is also conceivable that the fastening section extends over both sides of the profile, for example in a V-shaped cross-section over the profile end edge, possibly with a corresponding kink in the area of the profile end edge.

For the purposes of the present invention, the aerodynamic profile or profile surface is also to be understood as attachments attached to the profile and their surfaces and edges, in particular toothed elements, flaps or the like. For example, the attachment section can also be designed for attachment to tooth elements of conventional serrations or for attachment to a surface or an edge of a flap, for example a backflow flap or a Gurnay flap, and attached accordingly in an aerodynamic profile according to the invention.

Swirl elements according to the invention can be provided in sections on the aerodynamic profile. In particular, turbulence elements according to the invention can be provided in combination with other aerodynamic measures, such as vortex generators or serrations, on an aerodynamic profile.

The manufacturing process according to the invention is designed for the simple production of large numbers of swirl elements according to the invention. Forming is carried out by twisting the sheet metal with the entire cross-section around a common axis. Depending on the material of the sheet metal, this forming process can be carried out in a cold or hot state.

In the case of a forming press tool, the shape of the tool with corresponding indentations and/or elevations ensures the desired twist when a normal force is applied. A twisting angle is limited to a maximum of a quarter turn, i.e. approximately 90°, to ensure demoldability. In particular, a plurality of jointly inserted guide plates, i.e. the guide plates of several inserted swirl elements and/or several guide plates of one swirl element, can be formed in parallel in a corresponding pressing tool.

Rotary actuators, in particular rotary solenoids, which are also known as rotary magnets, are preferably magnetic actuators that can perform a rotary movement with a predetermined torque via a predetermined angle of rotation. The angle of rotation is usually less than or equal to half a revolution or 180°. The rotary magnet is preferably designed to match the shape and material of the sheet metal in terms of its torque. In particular, a large number of parallel rotary magnets can be used to form a large number of jointly inserted guide plates in parallel.

Other manufacturing methods for producing the swirl element are also conceivable, for example 3D molding processes such as 3D printing or 3D milling.

Advantageous embodiments and further developments are shown in the further sub-claims and in the description with reference to the figures in the drawing.

According to one embodiment, the guide plate is twisted in on itself so that the axis runs in the guide plate. In particular, this involves a torsion of the guide plate along the axis. In particular, the axis runs in the longitudinal expansion direction of the guide plate. In this way, the guide plate is automatically stiffened by the deformation.

According to the invention, the guide plate is twisted about the axis by at least 10°, in particular by at least an eighth of a turn or approximately 45°, preferably by at least a quarter of a turn or approximately 90°. Advantageously, a sufficient swirl of a vortex can thus be generated, which is sufficient to generate a turbulent boundary layer and/or to reduce the end edge vortex. In addition, such twists can be easily produced in large quantities using processes suitable for mass production, such as press molds.

According to one embodiment, the baffle plate is asymmetrical, in particular asymmetrical in a planar projection, for oblique flow. Accordingly, a sheet metal blank is already asymmetrical before forming. An asymmetry remains after twisting. This means that, particularly in wind turbines, the guide plate is able to cope with the actual inclined flow conditions of the rotor blade caused by the rotation. Alternatively or additionally, the sheet metal blank can have different sizes and/or asymmetries of guide plates, or different sheet metal blanks can have different sizes and/or asymmetries of guide plates.

According to the invention, the guide plate is helically or helically twisted. In particular, an axis located in the center of the guide plate can be formed with a reinforcing element, for example a central round profile or tube section, around which the plate is twisted. This provides a particularly rigid shape. In particular, this also enables multi-start screw shapes or a multiple helix shape of the aerodynamically active section. Such designs are suitable, for example, for aerodynamically active sections mounted in rotation on the fastening section, as a significantly higher pitch and possibly also a higher number of pitch turns is advantageous here due to the inherent rotation.

According to one embodiment, an alignment section is provided between the fastening section and the aerodynamically active section of the swirl element for aligning the axis of the aerodynamically active section differently from the fastening section. The alignment of the axis of the deflector plate is therefore advantageously independent of the alignment of the fastening section, which is determined by the profile surface. This means that the guide plate can be advantageously aligned parallel to the profile surface or at an angle to the profile. In this way, depending on the position and alignment, the guide plate can be aligned with an aerodynamic profile for additional lift generation and/or increased noise reduction. In particular, the alignment of the guide plate can be individually adapted to the local conditions both axially and radially on an aerodynamic profile. The alignment section can, for example, describe a kink and/or a step and/or a curve shape. It can align the aerodynamically active section to a suction side or a pressure side. Alternatively or additionally, a lateral or radial alignment component is possible.

According to one embodiment, the fastening section is formed in one piece with the aerodynamically active section and/or the alignment section. In particular, it is a one-piece sheet or a one-piece strip. Accordingly, the swirl element is made from a common semi-finished product, which is formed into a guide plate in the area of the aerodynamically active section and is left in a shape suitable for fastening or is formed in the area of the fastening section, for example adapted to the profile surface. An alignment section can also be formed in one piece with it, for example as a kink and/or step and/or curved shape of the semi-finished product.

According to one embodiment, the fastening section and the aerodynamically active section are designed with two different parts that are coupled together. In particular, this can be a form-fit coupling, for example by means of a snap-in connection. It would also be conceivable to suspend aerodynamically active sections, for example on a bolt, wire, cable or the like of the fastening section. The fastening section can have a wide variety of shapes. For example, a flat attachment on the profile surface is conceivable. However, attachment to an edge of the profile surface or in a recess in the profile surface is also conceivable.

According to the invention, a plurality of flow-active sections connected to the fastening section is provided. In particular, these are arranged on the fastening section with at least substantially the same alignment of the axes. Advantageously, in this way a plurality of flow-active sections can be produced in a common step on the one hand and mounted in a common step on the other. The plurality can be at least two and is not limited upwards. In particular, production and/or flow-related deviations in alignment are possible. Preferably, the flow-active sections are arranged at regular intervals from one another. However, local concentrations or increasing densities of the flow-active sections over the course are also conceivable, for example. In practice, the width of the fastening section will be limited by a production facility. For example, it would be conceivable to provide any maximum width of a fastening section with a density of up to 1000 flow-active sections per one meter width of the fastening section. In particular, in the case of a rotor blade for the rotor of a wind turbine, densities in the range of 5 to 50 aerodynamically active sections per one meter width of the fastening section can be provided.

According to the invention, neighboring flow-active sections are each alternately twisted in different directions of rotation to generate counter-rotating vortices. In this way, velocity vectors meeting in overlapping areas of the vortices are always in the same direction. This is particularly advantageous with high densities or small distances between the aerodynamically active sections. This reduces the friction between the vortices, resulting in less drag overall. In this way, the same effect of the turbulence elements can be achieved with reduced resistance.

According to an unclaimed embodiment of an aerodynamic profile, the flow-active section is arranged in the region of a profile end edge of the profile surface, wherein the flow-active section is provided for generating a vortex reducing the end edge vortex. In particular, the flow-active section is arranged projecting beyond the profile end edge at which an end edge vortex is generated. In this way, the reducing effect on the end edge vortex is maximized. Compared to conventional serrations, an additional effect is thus achieved, which contributes to noise reduction and increased efficiency and, if necessary, to static and/or dynamic load reduction.

According to a further unclaimed embodiment of the aerodynamic profile, the flow-active section is arranged on the profile surface and is intended to generate a vortex that prevents a flow separation from the profile surface. In particular, this creates a turbulent boundary layer. In this way, the turbulence element according to the invention is provided instead of conventional vortex generators.

According to one embodiment of the unclaimed aerodynamic profile, a plurality of swirl elements is provided. Alternatively or additionally, at least one, i.e. one or more, swirl elements comprising a plurality of aerodynamically active sections may be provided. Neighboring aerodynamically active sections are each alternately twisted in different directions of rotation to generate opposing vortices. In mutual areas of influence of neighboring vortices, their velocity vectors are thus in the same direction in the circumferential direction. This ensures that the vortices exist next to each other with significantly less friction than with co-rotating vortices. This reduces the resistance generated by the swirl elements, particularly in areas with small angles of attack (AoA), such as in the outer area of rotor blades.

The above embodiments and further developments can be combined with each other as desired, if appropriate. In particular, all embodiments of the turbulence element can be transferred to the aerodynamic profile and the method for producing a turbulence element, and vice versa if appropriate.

CONTENT OF THE DRAWING

The present invention is explained in more detail below with reference to the embodiments shown in the schematic figures in the drawing. They show:

Fig. 1 a perspective view of a turbulence element;

Fig. 2 a side view of the turbulence element as shown in Fig. 1;

Fig. 3 a schematic top view of a turbulence element with a large number of aerodynamically active sections;

Fig. 4 a schematic top view of a turbulence element according to a further embodiment;

Fig. 5 a schematic sectional view of an aerodynamic profile;

Fig. 6 a schematic sectional view of an aerodynamic profile according to a further embodiment;

Fig. 7 a schematic sectional view of an aerodynamic profile according to a still further embodiment;

Fig. 8 a schematic sectional view of an aerodynamic profile according to a further embodiment;

Fig. 9 a schematic sectional view of an aerodynamic profile according to a further embodiment;

Fig. 10 a detailed perspective view of a baffle plate according to one embodiment;

Fig. 11 a rear view of the guide plate according to Fig. 10;

Fig. 12 a perspective view of the area of a profile end edge with swirl element;

Fig. 13	a perspective view of an aerodynamic profile with a profile end edge according to Fig. 12;
Fig. 14	a rear view of the aerodynamic profile as shown in Fig. 13;
Fig. 15	a perspective view of an aerodynamic profile according to a further embodiment;
Fig. 16	a top view of the aerodynamic profile as shown in Fig. 15;
Fig. 17	a rear view of the aerodynamic profile as shown in Figs. 15 and 16;
Fig. 18	a perspective view of a baffle plate according to a further embodiment;
Fig. 19	a top view of the guide plate according to Fig. 18;
Fig. 20	a rear view of the guide plate as shown in Figs. 18 and 19;
Fig. 21	a schematic top view of turbulence elements according to a further embodiment;
Fig. 22	a schematic side view of a section of an aerodynamic profile with turbulence elements as shown in Fig. 21;
Fig. 23	a schematic top view of a turbulence element according to a further embodiment;
Fig. 24	a front view of an aerodynamically active section with several baffles;
Fig. 25	a schematic side view of the aerodynamically active section as shown in Fig. 24;
Fig. 26	a side view of a turbulence element according to a further embodiment;

Fig. 27	a side view of a turbulence element according to a still further embodiment;
Fig. 28	a perspective view of a turbulence element according to a further embodiment;
Fig. 29	a perspective view of a turbulence element according to a still further embodiment;
Fig. 30	a perspective view of a turbulence element according to a further embodiment;
Fig. 31	a rear view of the turbulence element as shown in Fig. 30;
Fig. 32	a schematic perspective view of a section of an aerodynamic profile according to a further embodiment;
Fig. 33	a plan view of the aerodynamic profile as shown in Fig. 32;
Fig. 34	a schematic side view of an aerodynamic profile according to a further embodiment;
Fig. 35	a schematic side view of an aerodynamic profile according to yet another embodiment;
Fig. 36	A front view of a twisted guide plate;
Fig. 37	a front view of a guide plate twisted in the opposite direction;
Fig. 38	a schematic representation of guide plates arranged next to each other and twisted in opposite directions;

Fig. 39	A schematic representation of the flow conditions on an aerodynamic profile;
Fig. 40	a schematic representation of the flow conditions on an aerodynamic profile according to a further embodiment;
Fig. 41	A top view of a rotor blade according to one embodiment;
Fig. 42	a detailed view of the edge of the rotor blade as shown in Fig. 41;
Fig. 43	A schematic representation of a wind turbine with a rotor that has an aerodynamic profile according to the invention;
Fig. 44	A schematic representation of a turbine housing which has an aerodynamic profile according to the invention;
Fig. 45	a schematic representation of a separate fastening section and aerodynamically active section;
Fig. 46	a schematic representation of a turbulence element with the parts shown in Fig. 45;
Fig. 47	A schematic diagram of a wind tunnel;
Fig. 48	a side view of the measurement setup of a noise measurement in the measurement volume of the wind tunnel according to Fig. 47;
Fig. 49	a diagram of a measurement result with the measurement setup according to Fig. 48;
Fig. 50	a further diagram of a measurement result with the measurement setup shown in Fig. 48;

Fig. 51 a top view of a standard trapezoidal ration;

Fig. 52 a rotated top view of a standard trapezoidal ration;

Fig. 53 A perspective view from the front and top of a trapezoidal serration rotated from 45 to 150 degrees;

Fig. 54 a top view of a serration trapezoidal and twisted from 45 to 180 degrees;

Fig. 55 a front view of a serration trapezoidal and rotated from 45 to 180 degrees;

Fig. 56 A perspective view of a serration;

Fig. 57 a numerical dynamic stall simulation with the DLR-TAU code;

Fig. 58 a schematic representation of counter-rotating vortices at the trailing edge of a rotor blade due to counter-rotating serrations;

Fig. 59 a lift coefficient diagram;

Fig. 60 a resistance coefficient diagram;

Fig. 61 a torque coefficient diagram;

Fig. 62 a sliding number diagram;

Fig. 63 a lift coefficient diagram of a further embodiment;

Fig. 64 a resistance coefficient diagram of a further embodiment;

Fig. 65 a torque coefficient diagram of a further embodiment;

Fig. 66 a sliding number diagram of a further embodiment;

Fig. 67 A forming tool for producing a swirl element;

Fig. 68A a sheet before forming; and

Fig. 68B a swirl element with twisted guide plate.

The accompanying figures of the drawing are intended to provide a further understanding of the embodiments of the invention. They illustrate embodiments and, in connection with the description, serve to explain principles and concepts of the invention. Other embodiments and many of the advantages mentioned will become apparent with reference to the drawings. The elements of the drawings are not necessarily shown to scale with respect to each other.

In the figures in the drawing, identical, functionally identical and identically acting elements, features and components are each provided with the same reference symbols, unless otherwise specified.

DESCRIPTION OF DESIGN EXAMPLES

Fig. 1 shows a perspective view of a turbulence element 1.

The swirl element 1 is designed to swirl a fluid flow and is intended for an aerodynamic profile. It has a fastening section 2, shown here only in sections, which is designed for fastening to a profile surface. A flow-active section 3, which has a guide plate 4, is connected to the fastening section 2.

The entire cross-section of the guide plate is twisted around a common axis 5. This enables a flow running along the guide plate to be twisted and thus generate a vortex.

In the embodiment shown, the guide plate 4 is twisted in on itself so that the axis 5 runs in the guide plate 4. This is a torsion of the guide plate 4.

In this example, the guide plate 4 is rotated by a quarter turn, i.e. approximately 90°, around the axis 5. Advantageously, the swirl element 1 therefore has no undercut and can thus be easily produced in large quantities, for example using the compression molding process.

A method for manufacturing such a swirl element 1 includes, for example, the steps of providing a sheet metal, in particular a thermoplastic fiber composite sheet or a metallic sheet metal, which is cut to size to form the aerodynamically active section 3, placing the sheet metal in a forming press tool, in particular in the case of a thermoplastic material, a hot forming press tool, and forming the sheet metal by means of the forming press by applying the twisting of the sheet metal by approximately 90° with the entire cross-section around the common axis 5, which is realized by a corresponding shape of the tool.

Of course, other forming manufacturing processes for forming the blank would also be conceivable. Furthermore, generative manufacturing processes, in particular 3D printing, or machining manufacturing processes, in particular 3D milling, as well as injection molding for the production of the contour of the guide plate would also be conceivable.

Fig. 2 shows a side view of the swirl element 1 according to Fig. 1.

This view shows that the aerodynamically active section 3 is aligned differently with its axis 5 compared to the fastening section 2. For this purpose, the swirl element 1 has an alignment section 6, in which, for example, a bend 9 at the transition between the fastening section 2 and the guide plate 4 is provided to align the aerodynamically active section 3 in the embodiment shown. In this way, the aerodynamically active section 3 or its axis 5 can be aligned independently of the contour of an aerodynamic profile on which the fastening section 2 can be fastened.

In this embodiment, the fastening section 2 is formed in one piece with the aerodynamically active section 3 and the alignment section 6. This is a one-piece strip formed from a common flat semi-finished product, for example a metal sheet or a thermoplastic fiber composite sheet.

A raw material for the sheet can be provided, for example, as sheet material wound onto rolls.

Fig. 3 shows a schematic top view of a swirl element 1 with a plurality of aerodynamically active sections 3.

The plurality of flow-active sections 3 is provided connected to a common fastening section 2. In this embodiment example, the flow-active sections 3 are arranged directly adjacent to one another on the fastening section 2. An alignment of the respective axes 5 of the flow-active sections 3 is essentially the same, i.e. only with slight angular deviations, for example in the range of less than 20° to the parallel.

The individual aerodynamically active sections 3 are each formed here with a trapezoidal basic shape. For example, triangular recesses are cut out of the left-hand side of a sheet that is flat in its basic shape. The guide plates 4 of the aerodynamically active sections 3 are then twisted around their respective axis 5 using a forming process.

In the embodiment shown, the guide plates 4 are rotated around the respective axis 5 by approximately one eighth of a turn, i.e. by approximately 45°. Neighboring flow-active sections 3 are alternately twisted in different directions of rotation. In this way, the swirl element 1 can be used to generate a large number of vortices in opposite directions.

Fig. 4 shows a schematic top view of a turbulence element 1 according to a further embodiment.

In this embodiment, a large number of aerodynamically active sections 3 are also provided, which are connected to a common fastening section 2. In contrast to Fig. 3, however, the aerodynamically active sections 3 with their guide plate 4 are arranged at regular intervals from one another. The spacing here is, for example, the width of a guide plate 4.

A further difference in this embodiment compared to Fig. 3 is that the guide plates 4 are on the one hand in the same direction and on the other hand are each twisted more around the axis 5. As an example, this is about half a twist in each case, i.e. a twist of about 180°.

Such a twisting can be realized with a method for producing a swirl element 1, which comprises the steps of providing a sheet, in particular a thermoplastic fiber composite sheet or a metallic sheet, which is cut to size to form the aerodynamically active sections 3; inserting the sheet metal into a tool, the tool being designed as a receptacle connected to an axis of rotation of a rotary actuator, in particular a rotary magnet; and forming the sheet metal by means of the rotary actuator, in particular a rotary magnet, by applying a twist of up to 180° to the sheet metal, at least in sections, with its entire cross-section about a common axis 5 by rotating the rotary magnet.

In particular, a number of rotary magnets corresponding to the number of sections to be rotated can be provided. Accordingly, all aerodynamically active sections can be rotated simultaneously so that comparatively high cycle rates and therefore short production times are possible.

Depending on the material, the sheet can be heated before twisting, at least in the area of the sections to be twisted, for example using a contact heater or hot air. In this way, hot forming is also possible using the rotary magnets.

In further embodiments, an industrial robot can also be used as an alternative or in addition to rotary magnets for rotation. Accordingly, the holder would be coupled to an axis of rotation of an industrial robot and the twisting would be performed by rotating the axis of rotation. In this case, sequential twisting of the sections to be twisted one after the other with the industrial robot would be conceivable.

Fig. 5 shows a schematic sectional view of an aerodynamic profile 10.

The aerodynamic profile 10 is exemplified here as a rotor blade 17 and is only shown in the area of its profile end edge 13.

The aerodynamic profile 10 has a profile surface 11 extending on the upper side and on the lower side as well as over the profile end edge 13. In the embodiment shown, the underside of the aerodynamic profile is a pressure side and the upper side is a vacuum side.

A swirl element 1 is attached to the profile surface 11. In the embodiment shown, the attachment section 2 is attached to the underside or pressure side in the area of the profile end edge 13. The flow-active section 3 is aligned to swirl a flow 12 running along the profile surface 11, which is schematically symbolized here with arrows. In the embodiment shown, the flow-active section 3 protrudes beyond the profile end edge 13. The presence of the aerodynamically active section 3 in the end edge area alone already reduces the end edge vortex, similar to conventional serrations. However, the twisting of the aerodynamically active section 3 is also intended to generate a vortex that reduces the trailing edge vortex. In this way, an end edge vortex generated in the area of the end edge 13 is additionally reduced.

Furthermore, the aerodynamically active section 3 is angled downwards at an angle a to the fastening section 2 and consequently to the profile surface 11 by means of the alignment section 6, which in this example has a bend 9. In this way, in addition to generating a vortex and influencing the end edge vortex, a kind of local extension of the profile is achieved, which generates additional lift.

Fig. 6 shows a schematic sectional view of an aerodynamic profile 10 according to a further embodiment.

This embodiment differs from Fig. 5 in that the alignment section 6 is formed with an elongated curvature that extends into the aerodynamically active section instead of a kink.

Fig. 7 shows a schematic sectional view of an aerodynamic profile 10 according to a still further embodiment.

This embodiment differs from Fig. 5 in that the attachment section 2 is attached to the upper side of the profile, i.e. to the negative pressure side of the rotor blade 17. In addition, the aerodynamically active section 3 in this embodiment essentially continues the contour of the upper side of the profile 11 beyond the profile end edge 13. In this way, a comparable position of the aerodynamically active section 3 is achieved compared to Fig. 5. The alignment section 6 is therefore essentially straight in this embodiment.

Fig. 8 shows a schematic sectional view of an aerodynamic profile 10 according to a further embodiment.

This embodiment differs from Fig. 7 in the shape of the front edge 18 of the fastening section 2, which is provided with a chamfer. In this way, the transition is smoothed and any vortex formation at the edge 18 is avoided, which reduces the air resistance.

Fig. 9 shows a schematic sectional view of an aerodynamic profile according to a further embodiment.

This embodiment is also based on the embodiment shown in Fig. 7, whereby here the aerodynamically active section 3 is angled upwards. The alignment section 6 thus includes an upward bend. In this way, the aerodynamically active section 3 is more strongly aligned with the trailing edge vortex compared to Fig. 7. This results in a greater reduction in noise.

Fig. 10 shows a detailed perspective view of a guide plate 4 according to one embodiment.

The guide plate 4 is formed with a shaped flat semi-finished product or sheet metal, which is continuously twisted over its length about a central axis 5 by a total of a quarter of a turn.

In its basic form, the sheet is designed as a blank, with a length of 1 and a width of b.

In the embodiment shown, the length 1 is significantly greater than the width b. The guide plate 4 has two short edges 19, 20, which are straight. Furthermore, two long edges 21, 22 are provided, which are formed with a curve. In particular, the curve is provided with a continuous curvature, which creates a bulbous contour of the basic shape of the metal sheet. The front short edge 19 is wider than the rear short side 20, so that a widest point or a belly is closer to the front short edge 19.

To produce the baffle plate 4, the sheet metal can either be pressed in its basic form into the corresponding shape or twisted using a rotary actuator. In particular, the manufacturing process can be adapted to the material of the sheet metal. In addition to metals such as aluminum, titanium, stainless steel or the like, plastic materials, preferably fiber composite materials, in particular thermoplastic fiber composite materials, can also be used as a material for the guide plate 4. Such fiber composite materials are particularly advantageous for wind turbines due to the very similar coefficients of thermal expansion compared to the materials normally used for the rotor blades. In this way, the fastening surface of the fastening section, particularly in the case of adhesive fastening, is exposed to less stress and therefore remains durable. Preferably, UV- and weather-resistant plastics are used to ensure a service life of at least 5, in particular at least 10, preferably at least 20 years.

The guide plate 4 is shown here as an aerodynamically active section 3 for a swirl element 1 and is shown independently of the fastening section 2. To produce a turbulence element 1, the guide plate 4 can be connected to a fastening section, in particular by a fastening means, by form fit and/or by material connection, for example by gluing, screwing and/or riveting.

Fig. 11 shows a rear view of the guide plate 4 according to Fig. 10.

In addition to the 90° rotation, a lateral offset of the narrower rear short side shown in the foreground to the wider front short side can also be seen here. A flat semi-finished product forming the guide plate 4 is already cut slightly asymmetrically in a flat projection to produce the guide plate 4.

Fig. 12 shows a perspective view of the area of a profile end edge 13 with a swirl element 1.

The swirl element 1 is formed with a common fastening section 2 and a plurality of aerodynamically active sections 3. The design is essentially as described in relation to Fig. 1, whereby the fastening section 2 is continued in its width and further parallel aerodynamically active sections 3 are provided at regular intervals.

The aerodynamically active sections 3 are each formed here with an exemplary section cut to a rectangular basic shape, which is formed as a guide plate 4 with a twist of approximately 90° and is formed in one piece with the common fastening section 2.

The fastening section 2 is attached flat to the profile surface 11 adjacent to the profile end edge 13. For example, the fastening section 2 is attached to the profile surface 11 with a material bond or adhesively. In this way, such turbulence elements 1 are easy to install and, in particular, easy to retrofit to existing aerodynamic profiles, for example of wind turbines.

Fig. 13 shows a perspective view of an aerodynamic profile 10 with a profile end edge 13 as shown in Fig. 12.

The width of the aerodynamic profile 10 is only shown here in sections and can be extended to any width. In particular, only part of the width of the aerodynamic profile 10 can be provided with the turbulence element 1. For example, the radially outer half of a rotor blade of a wind turbine can be provided with one or more turbulence elements 1.

Fig. 14 shows a rear view of the aerodynamic profile according to Fig. 13.

This view clearly shows a torsion angle ϕ of the guide plates 4 of the aerodynamically active areas of 90° as well as their regular spacing with a distance d. The distances d are calculated in such a way that a constant number of aerodynamically active areas 3 are evenly distributed per meter of profile width.

Fig. 15 shows a perspective view of an aerodynamic profile 10 according to a further embodiment.

Fig. 16 shows a top view of the aerodynamic profile 10 as shown in Fig. 15.

Fig. 17 shows a rear view of the aerodynamic profile 10 as shown in Figs. 15 and 16.

According to this embodiment, the aerodynamic profile 10 is provided with a predetermined width B, here purely by way of example of 1 m, and a predetermined number of aerodynamically active sections 3-1, 3-2, ..., 3-n, here purely by way of example 20 pieces. Accordingly, a density of aerodynamically active areas is n/B, here exemplarily 20 pieces per meter.

In further embodiments, the density can be in the range of 1 to 1000 per 1 m, depending on the area of application. For example, such a range for wind turbines is preferably 5 to 50 pieces per 1 m.

Fig. 18 shows a perspective view of a guide plate 4 according to a further embodiment.

Fig. 19 shows a top view of the guide plate 4 according to Fig. 18.

Fig. 20 shows a rear view of the guide plate 4 according to Figs. 18 and 19.

The guide plate 4 is also formed with a shaped flat semi-finished product or sheet metal, which is continuously twisted around a central axis 5 along its length. The twist here is half a turn or a twist angle ϕ 180°.

In its basic form, the sheet is provided as a parallelogram-shaped, here exemplarily as a rectangular, blank, with a length 1 and a width b. In the embodiment shown, the length 1 is many times greater than the width b. The guide plate 4 has two short edges 19, 20, which are straight. Furthermore, two long edges 21, 22 are provided, which are also straight.

To produce the baffle plate 4, the sheet metal can be twisted in its basic shape using a rotary actuator. In particular, the manufacturing process can be adapted to the material of the sheet metal. In addition to metals such as aluminum, titanium, stainless steel or the like, plastic materials, preferably fiber composite materials, in particular thermoplastic fiber composite materials, can also be considered as a material for the guide plate 4, as already described with reference to Fig. 10.

The guide plate 4 is also shown here as an aerodynamically active section of a swirl element 1 and is shown independently of a fastening section 2. To produce a swirl element 1, the guide plate 4 can therefore also be connected to a fastening section 2.

Fig. 21 shows a schematic top view of turbulence elements 1 according to a further embodiment.

Schematically shown here are two swirl elements 1 arranged next to each other.

As explained in relation to the embodiment shown in Fig. 10, the swirl elements 1 are formed with a bulbous, flat semi-finished product, which has two short straight edges 19, 20 and two long curved edges 21, 22. In contrast to Fig. 10, however, a rotation about the axis 5 by half a turn is provided here.

Furthermore, in this embodiment, the fastening section 2 is provided directly in the guide plate 4 of the aerodynamically active section 3. For this purpose, the guide plate 4 has a recess 23, which can be attached to an edge of an aerodynamic profile, indicated schematically here, and is provided for a form-fit and/or material-fit connection with the profile.

Fig. 22 shows a schematic side view of a section of an aerodynamic profile 10 with turbulence elements 1 as shown in Fig. 21.

The swirl elements 1 are attached with their recess 23 to the aerodynamic profile 10 at the profile end edge and thus connected with a material bond, for example by means of an adhesive or welded connection. The recess 23 is adapted to the shape of the profile end edge 13 for this purpose.

Fig. 23 shows a schematic top view of a turbulence element 1 according to a further embodiment.

The swirl element 1 according to this embodiment differs from the embodiment according to Fig. 21 by a central reinforcement 24 of the swirl element 1 running along the axis 5. In particular, this can be a solid material thickening or a tubular reinforcement. The twisting of the guide plate 4 thus runs around the reinforcement 24.

Fig. 24 shows a front view of an aerodynamically active section 3 of a swirl element 1 with several baffles 4.

Fig. 25 shows a schematic side view of the aerodynamically active section 3 as shown in Fig. 24.

Several baffles 4, for example three baffles 4, are provided on an aerodynamically active section 3. Each of the baffles 4 runs helically twisted around a common central axis 5.

In the embodiment shown, the guide plates 5 are directly connected to each other in a joint in the center of the aerodynamically active section 3, i.e. in the area of the axis 5. In further embodiments, it would also be conceivable here, as described with reference to Fig. 23, to provide a central reinforcement 24 around which the guide plates 4 are twisted.

For example, such a component can be manufactured using an extrusion process. The twist can be applied by means of torsion during or after extrusion. Of course, generative manufacturing processes such as 3D printing, 3D machining processes such as 3D milling or injection molding are also possible manufacturing processes.

Such an aerodynamically active section 3 can, in particular, be designed as a rotating aerodynamically active section and be attached to a fastening section 2, which in this case can, for example, be of a base-like design, so that it can rotate about the axis 5.

Fig. 26 shows a side view of a turbulence element 1 according to a further embodiment.

In this embodiment, the connecting element 1 has a fastening section 2, which has two V-shaped legs 25. In the area of a joint area 26 connecting the two legs 25, the guide plate 4 is connected to the fastening section 2 at the wider short edge 19.

In addition, the swirl element 1 has an aerodynamically active section 3 directly adjacent to the impact area 26, which is formed with a guide plate 4 as shown in Fig.

10. In further embodiments, an aerodynamically active section 3 according to a further embodiment example would also be conceivable.

Fig. 27 shows a side view of a turbulence element 1 according to a still further embodiment.

From the view shown, a plate-like shape of the legs 25 can be seen, which are intended for adhesive attachment to a profile surface. Adjacent to the legs 25, two adjacent aerodynamically active sections 3A, 3B are provided in the joint area 26. These are aligned with their axes 5 parallel, but with a twist in the opposite direction. In this way, friction between neighboring vortices is reduced, as they have almost the same velocity vectors in their areas of influence. This is explained in more detail with reference to Fig. 38.

Fig. 28 shows a perspective view of a turbulence element 1 according to a further embodiment.

This embodiment is based on the embodiment shown in Fig. 27 and has a large number of adjacent aerodynamically active sections 3A, 3B arranged in opposite directions.

Fig. 29 shows a perspective view of a turbulence element 1 according to a still further embodiment.

In this embodiment, the arrangements of aerodynamically active sections 3, 3A, 3B are provided locally differently. Over part of the width of the swirl element 1, the aerodynamically active sections are spaced apart, approximately by the width of a baffle 4 as described with reference to Fig. 14, and are aligned with their baffles 4 parallel to each other. The guide plates 4 are each twisted in the same direction.

In a second section, which is provided here purely for illustrative purposes on the right-hand side of the swirl element 1 in the illustration, the arrangement changes to an arrangement of adjacent aerodynamically active sections 3A, 3B positioned directly next to each other, the guide plates 4A, 4B of which each have an opposing twist. Only one pair of such adjacent aerodynamically active sections 3A, 3B twisted in opposite directions is shown here. Of course, the section of oppositely twisted aerodynamically active sections 3A, 3B can be continued in any length or with a plurality of such pairs.

Fig. 30 shows a perspective view of a turbulence element 1 according to a further embodiment.

This embodiment differs from the embodiment shown in Fig. 28 in the basic shapes of the guide plates 4, which here have a trapezoidal shape.

As described in relation to Fig. 28, there are a large number of adjacent aerodynamically active sections 3A, 3B, which have guide plates 4 twisted in opposite directions to each other. A twist angle ϕ is also provided here at 90° or as a quarter turn.

In contrast to Fig. 28, the aerodynamically active sections 3A, 3B are additionally angled here starting from the joint area 26, which here also forms an alignment section 6. In this way, an arrangement with the effects described with reference to Figures 5 and 9 can be achieved.

As an example, eight pairs 3A, 3B, i.e. a density of 16 aerodynamically active sections per 1 m, are provided over a length of one meter.

Fig. 31 shows a rear view of the swirl element 1 according to a further embodiment.

In this embodiment, an increased number of aerodynamically active sections 3A, 3B twisted in opposite directions is provided compared to Figs. 28 and 30, which are correspondingly smaller in size. Thus, a higher density of aerodynamically active sections 3A, 3B is provided here, for example 36 per 1 m.

Fig. 32 shows a schematic perspective view of a section of an aerodynamic profile 10 according to a further embodiment.

In this embodiment, the aerodynamic profile 10 has a conventional serrated structure 28, i.e. serrated extensions or serrations, on the profile end edge 13. A swirl element 1 is now attached to these extensions.

In the embodiment shown, the swirl element 1 is essentially designed as shown in Fig. 21 and is attached to the end edge of an extension 28 and, for example, connected to it with a material bond.

Fig. 33 shows a plan view of the aerodynamic profile according to Fig. 32.

This view shows an oblique alignment of the aerodynamically active section 3 or its axis 5, which is at an angle to the profile end edge 13. The guide plate 4 is asymmetrical to the inclined flow.

Preferably, a flat semi-finished product forming the guide plate 4 is already cut asymmetrically in a flat projection to produce the guide plate 4.

The reason for this is that the flow direction of rotating airfoils is practically diagonal to the airfoil chord. The inclined guide plate 4 or the inclined alignment of the aerodynamically active section 3 corresponds to this inclined alignment of the flow to avoid flow resistance.

Due to the comparatively long deflection over the extension 28, this effect is stronger here than with aerodynamically active sections attached directly to the profile surface 11. Of course, this concept of inclined flow or inclined alignment of the aerodynamically active section 3, in particular the inclined design of the guide plate 4, can also be transferred to swirl elements 1 attached directly to an aerodynamic profile 10 in order to reduce drag.

Fig. 34 shows a schematic side view of an aerodynamic profile according to a further embodiment.

In this embodiment, a swirl element 1 is attached to the profile surface 11 approximately in the middle of the profile cross-section. The flow-active section 3 is thus arranged parallel to the profile surface 11 and is intended to generate a vortex 16 that prevents a flow separation from the profile surface 11. In this embodiment, the turbulence elements thus serve primarily to generate a turbulent boundary layer of the flow 12, which serves to prevent stall.

The fastening section 2 is designed here as part of a stepped plate, on which there is also a step provided as an alignment section 6. The aerodynamically active sections 3 are formed in the manner described with reference to Fig. 21 and are attached to a rear edge of the stepped plate with a material bond.

In the illustrated embodiment, only 2 aerodynamically active sections 2 are shown purely schematically. Of course, such a series of aerodynamically active sections as well as the stepped plate with fastening and alignment section can be continued in any width, in particular with a large number of such aerodynamically active sections 3. This means that they can be quickly and easily attached to an aerodynamic profile 10 as a coherent swirl element 1 or mounted in production or retrofitted.

Shown here by way of example are guide plates 4 of the aerodynamically active sections 3 that are spaced apart from one another and twisted in the same direction. In further embodiments, however, guide plates of adjacent aerodynamically active sections 3A, 3B that are twisted in opposite directions can also be used in the same way, particularly if the aerodynamically active sections are arranged more closely together.

Fig. 35 shows a schematic side view of an aerodynamic profile 10 according to a still further embodiment.

This embodiment differs from Fig. 34 in that each aerodynamically active section 3 has an individual attachment section 2 and alignment section 6. This allows a high degree of flexibility in terms of attachment and alignment. Of course, different directions of rotation are also possible here, i.e. in the same direction and in opposite directions.

Fig. 36 shows a front view of a twisted guide plate 4A.

The guide plate 4A is twisted counterclockwise by a quarter of a turn in the plane of the drawing.

Fig. 37 shows a front view of a guide plate 4B twisted in the opposite direction.

The guide plate 4B is twisted clockwise by a quarter turn in the plane of the drawing.

Fig. 38 shows a schematic representation of guide plates 4A, 4B arranged next to each other and twisted in opposite directions.

The twisting of the guide vanes 4A, 4B leads to turbulence in the air flowing over the guide vanes 4A, 4B. The resulting vortices 15A, 15B have an opposite swirl corresponding to the reciprocal rotation of the guide plates 4A, 4B. However, in a region of influence of the vortices 15A, 15B, which is located here in the middle of the schematic representation between the baffles 4A, 4B, the vortices 15A, 15B have circumferential velocity vectors 27 in the same direction, so that the vortices 15A, 15B do not brake each other here but are essentially in the same direction relative to each other in the region of influence. In this way, significantly less aerodynamic resistance is generated than with vortices in the same direction, which would be in opposite directions in an area of influence.

In one embodiment, a plurality of such swirl elements 1 or a swirl element 1 having a plurality of such aerodynamically active areas 3 can be provided. Neighboring aerodynamically active areas 3A, 3B are each alternately twisted in different directions of rotation to generate opposing vortices 15A, 15B, so that their velocity vectors 27 in the circumferential direction are in the same direction in mutual areas of influence of neighboring vortices 15A, 15B.

Fig. 39 shows a schematic representation of the flow conditions on an aerodynamic profile 10.

The flow 12 running over the profile surface 11 separates in the area of the trailing edge 13, whereby the flows on the pressure side and the vacuum side of the profile meet behind the trailing edge 13, creating a trailing edge vortex 14. This end edge vortex is larger at large angles of attack, e.g. due to gusts of wind, than at smaller angles of attack.

A swirl element 1 with aerodynamically active sections 3A, 3B twisted in opposite directions is provided in the area of the profile end edge 13. These generate counter-rotating vortices 15 that reduce the end edge vortex.

Reducing the end edge vortex 14 reduces the aerodynamic resistance and noise emission of the aerodynamic profile 10.

Fig. 40 shows a schematic representation of the flow conditions on an aerodynamic profile 10 according to a further embodiment.

The aerodynamic profile 10 is designed here as explained in more detail with reference to Fig. 22 and has swirl elements 1 with aerodynamically active sections 3 that are twisted in the same direction, but are spaced apart.

An end edge vortex 14 is also present, but is not shown for the sake of clarity. In the area of the profile end edge 13, the aerodynamically active sections 3 of the swirl elements 1, which are twisted in the same direction, generate vortices 15 that reduce the end edge vortex 14.

Due to the spacing of the aerodynamically active sections 3, the areas of influence of the vortices 15 are only minimal or negligible.

Here too, the reduction in the end edge vortex 14 achieved by the aerodynamically active sections 3 reduces the aerodynamic resistance and noise emission of the aerodynamic profile 10.

Fig. 41 shows a top view of a rotor blade 17 according to one embodiment.

Fig. 42 shows a detailed view of the edge of the rotor blade 17 as shown in Fig. 41.

The rotor blade is an example of a rotor blade of a wind turbine. This has conventional serrated structures 28, so-called serrations, on the rear profile end edge on the radially outer half. Additional turbulence elements 1 according to the invention are provided on a radially outer edge of the rotor blade. This is therefore a combined arrangement of conventional serrations and turbulence elements 1 according to the invention.

Instead of conventional serrations, in further embodiments, swirl elements 1 that can be attached flat with the fastening section 2 to the profile surface 11 in the area of the profile end edge can also be provided in accordance with the invention, for example in accordance with one of the embodiments shown in Figs. 3, 4, 12, 15, 28, 29 or 30.

Furthermore, alternatively or additionally, turbulence elements 1 according to the invention can also be provided in central regions of the profile surface, for example in the region of the axis of rotation 29, in particular in the manner described with reference to Figs. 34 and 35, in order to generate turbulent boundary flows on the profile surface 11.

Fig. 43 shows a schematic representation of a wind turbine 30 with a rotor 31 that has rotor blades with an aerodynamic profile 10.

The rotor blades 17 are mounted on a hub 32, which is mounted in a nacelle 34. The nacelle 34 is arranged on a tower 35 and contains a blade adjustment, a gearbox, a brake and a generator. The tower 35 is designed to track the wind direction and can be rotated around the tower axis accordingly.

Said aerodynamic profiles 10 are provided in the outer radial half of the rotor blades in particular, as this is where the highest absolute speeds are reached and therefore the most noise and frictional resistance are generated. In addition, these areas and in particular the inner area of the rotor blade are also susceptible to stalling. All these problems can be countered with turbulence elements 1 according to the invention.

Fig. 44 shows a schematic representation of an unclaimed turbine housing 36, which has an aerodynamic profile 10.

A turbine not described in detail here is arranged in the turbine housing 36, as is known to the person skilled in the art. Together, the turbine housing and the turbine form an engine for an aircraft or spacecraft, for which strict noise regulations also apply.

The turbine accelerates a fluid flow shown here schematically with arrows. The turbine housing 36 has an aerodynamic profile 10 on its outlet side, which allows the emerging fluid flow to emerge as quietly as possible and with low resistance. Turbulence elements according to the invention bring about a reduction in friction and/or noise, in particular in the region of the end edges of the aerodynamic profile 10 of the turbine housing.

In further embodiments, other areas of application of turbulence elements according to the invention are conceivable, in particular for other rotating profiles. For example, these can also be used in propellers or other, in particular rotating, objects with fluid flows.

Fig. 45 shows a schematic representation of separate fastening and aerodynamically active sections.

The fastening section 2 and the aerodynamically active section 3 are formed here with two different parts 7, 8. The two parts 7, 8 can be positively coupled to each other. For this purpose, a latching extension 37 is provided on the aerodynamically active section 3, which can be inserted into a latching recess 38 of the fastening section and can thus be positively connected to it.

The latching extension 37 has a recess 39 that can be brought into engagement with latching elements of the latching recess 38.

The fastening section 2 here is an example of a V-shaped fastening section, whereby the latching recess 38 is provided in the joint area of the V-shape. In this way, a cavity can be provided on the inside of the joint area 26, in which the latching projection 37 can be accommodated.

Fig. 46 shows a schematic representation of a turbulence element 1 with the parts 7, 8 according to Fig. 45.

The fastening section 2 representing the first part 7 is formed here with a predetermined width B, along which a plurality of latching recesses 38 arranged next to one another are arranged in the joint area 26. The aerodynamically active sections 3, representing the second part 8, are inserted into the latching recesses 38 with their latching projections 37 in accordance with the direction of the arrow shown and latched therein. This provides a positive connection between the parts 7 and 8.

Fig. 47 shows a schematic diagram of a wind tunnel 40.

The wind tunnel has a fan 41, a rectifier 42, a nozzle 43 and a measuring volume 44 connected to the nozzle 43.

Fig. 48 shows a side view of the measurement setup of a noise measurement in the measurement volume 44 of the wind tunnel 40.

The measuring volume 44 has a measuring area delimited by Plexiglas, which is marked here with a dashed line. As an example, the measuring area has a cross-sectional area of approx. 1000 mm x 800 mm.

An aerodynamic profile 10 and a noise sensor 45 arranged downstream in the direction of flow are arranged in the measuring volume 44.

A series of tests on noise reduction using swirl elements 1 was carried out with such a test arrangement. For this purpose, noise measurements were carried out with four different configurations of an aerodynamic profile 10 as well as a measurement in an empty duct. The aerodynamic profile 10 to be tested was positioned upright in the measurement duct with a slight angle of attack of 4 degrees.

The following configurations of a rotor blade (modification of the trailing edge of the rotor blade) were to be investigated from an acoustic point of view:

a) Rotor blade without serrations (NACA profile with tripping band (Trip))
b) Rotor blade according to a) with standard serrations (serrated structure with trip)
c) Rotor blade according to a) with modified serrations (swirl elements 1 with width/length ratio of b/1 = 10% and 45 degree twist in opposite direction and with trip)
d) Rotor blade with modified serrations (swirl elements 1 with width/length ratio of b/1 = 20% and 90 degree twist and spacing in the same direction and with trip)
e) Comparison measurement in empty duct

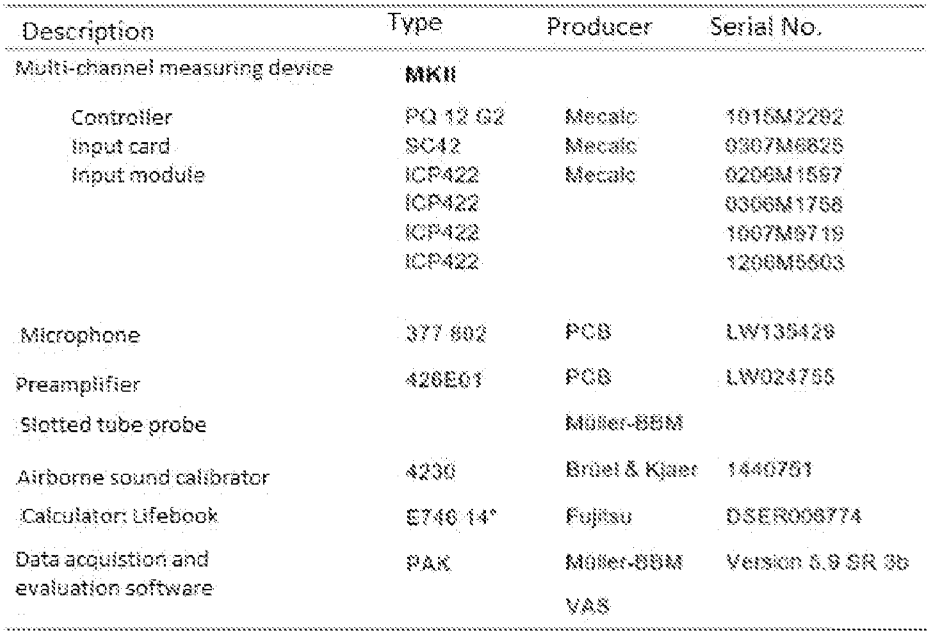
Sound measurements were carried out in the flow using a slotted tube probe as a noise sensor 45 to determine the noise contributions caused by the respective rotor blade in the flow.

Turbulence and the associated fluctuations in pressure and flow velocity are usually present in the free flow. In addition to the pressure fluctuations caused by sound waves, these are also detected by the microphone (slotted tube probe). By using the slotted tube probe, the influence of the turbulence present in the free flow on the microphone is reduced, thus minimizing falsification of the sound measurements in flows.

The microphone in the slotted tube probe was positioned in the middle of the duct at a distance of approx. 50 cm behind the clamped rotor blade at a height of approx. 25 cm. The slotted tube probe was aligned in the direction of the rotor blade and thus in the direction of flow.

The sound measurements were carried out at a flow velocity of 50 m/s in the duct.

The measuring devices used are listed in the following table.



Description	Type	Producer	Serial No.
Multi-channel measuring device	**MKII**		
Controller	PQ 12 G2	Mecalc	1015M2282
Input card	SC42	Mecalc	0307M6825
Input module	ICP422	Mecalc	0206M1587
	ICP422		0306M1758
	ICP422		1007M8719
	ICP422		1208M5503
Microphone	377 B02	PCB	LW135428
Preamplifier	426E01	PCB	LW024755
Slotted tube probe		Müller-BBM	
Airborne sound calibrator	4230	Brüel & Kjaer	1440781
Calculator: Lifebook	E746 14"	Fujitsu	DSER008774
Data acquistion and evaluation software	PAK	Müller-BBM VAS	Version 5.9 SR 3b

The calibration of the measuring devices was checked before and after the measurements using a calibrator. No deviations were found. The devices are also monitored and checked at regular intervals as part of a quality assurance system.

Fig. 49 shows a diagram of a measurement result with the measurement setup shown in Fig. 48.

Fig. 50 shows another diagram of a measurement result with the measurement setup shown in Fig. 48.

Three measurements on configurations of the rotor blades are shown as A-weighted sound pressure level in dB(A) re 20 μΠα in one-third octave bandwidth for each graph.

The increased sound pressure level in the third-octave frequency band with a center frequency of 630 Hz, which is present in all measurement results, is due to acoustic interference from the measurement setup.

Fig. 49 shows a comparison of the measurement results in configurations a), b) and e) at a flow velocity of 50 m/s. The representation is plotted in one-third octave bandwidth from 31.5 Hz to 10 kHz on the X-axis and the sound pressure level from 50 to 90 dB on the Y-axis.

A comparison of the measurement results shows that measurement e) in the empty channel produces the lowest sound pressure levels at the microphone in almost all frequency bands. The measured sound pressure levels of the configurations a) without serrations (NACA profile) and b) of the standard serrations are approx. 4 dB(A) above the measurement results e) in the empty channel.

Fig. 50 shows a comparison of the measurement results in the configurations c) of the rotor blade with swirl elements (45 degrees twisted in the opposite direction, b/1 = 10 %) and d) of the rotor blade with swirl elements (90 degrees twisted in the same direction, b/1 = 20 % with spacing/gap in the toothing) as well as measurement e) in the empty channel. This is a representation in one-third octave bandwidth from 31.5 Hz to 10 kHz.

Summary of the noise measurement results:

	Total Sound pressure level in dB(A)
a) Rotor blade without serrations97	.0
b) Rotor blade with standard serrations96	.9
c) Rotor blade with swirl elements (10%, 45°)	96.5
d) Rotor blade with swirl elements (20%, 90°)	96.2
e) Comparative measurement in an empty wind tunnel92	.8

Fig. 51 shows a top view of a standard trapezoidal ration.

Fig. 52 shows a rotated top view of a standard trapezoidal ration.

At high speeds and/or static and dynamic stall, there is an increase in noise/noise and drag and loads on the airfoils of aircraft wings with fluid flows, in particular the rotor blades of wind turbines. Influences such as gusts of wind and the YAW effect lead to dynamic loads and vibrations that push the large systems to their load limits. Such standard rations have been used to date to reduce noise and resistance.

Fig. 53 shows a perspective view from the front and top of a serration trapezoidal and rotated from 45 to 180 degrees.

Fig. 54 shows a top view of a serration trapezoidal and rotated from 45 to 180 degrees.

Fig. 55 shows a front view of a serration trapezoidal and rotated from 45 to 180 degrees.

Fig. 56 shows a perspective view of a serration.

Structure of the serrations and / or turbulators:

This new serration technology is based on the fact that it has a triangular or trapezoidal or rectangular or curved toothing according to the St.d. T. (Fig. 1 - 2), which is twisted helically (e.g. by 10°, 20°, preferably 45°, particularly preferably 90°, particularly preferably 180° to approx. 360°) (Fig. 53 - 54).

Furthermore, the serration / turbulator can also and/or additionally be curved and/or bent once or several times (see Fig. 55 and 56).

The trapezoidal serrations tested in the wind tunnel have a length that is 4 times their width and are trapezoidal or triangular in shape.

The serrations and / or turbulators consist of a base area (base element) for fastening and one or more helically twisted elements and a transition area connecting these two elements, which can be curved and / or kinked.

The individual serration and / or turbulator can advantageously consist of a single piece of material or can also be assembled from several elements, e.g. by gluing, screwing or riveting.

The helix shape can also provide different pitches within a toothing, e.g. to increase the swirl of the flow and thus the effects.

This vortex element can also be used as a replacement for vortex generators that are mounted individually or with several elements on a base plate. They can also be installed in the area of existing serrations from any manufacturer.
be attached.

The swirl element/serration according to the invention can also start at the profile end edge at an angle of 0 to 90 degrees and then continue helically behind the end edge. This can, for example, also be produced from several parts, e.g. by welding, soldering, plugging, etc.

These serrations can also be attached to the profile end edge in this arrangement (on the top and bottom) and also form a small base area which serves to secure them.

Fig. 57 shows a numerical dynamic stall simulation with the DLR-TAU code.

Fig. 58 shows a schematic representation of counter-rotating vortices at the trailing edge of a rotor blade due to counter-rotating serrations.

Fig. 58 shows the swirl in the same direction (in opposite adjacent directions of rotation) at the end edge.

Fig. 59 shows a lift coefficient diagram of trapezoidal 10% (b/h=10%) serrations fitted at the bottom and max. (20%) serrations fitted at the top.

It can be seen that the 20% serrations fitted at the top (suction side) generate a significantly higher lift than the normal profile (trimmed). The 10% serrations fitted at the bottom (pressure side) generate a slightly lower lift.

Fig. 60 shows a drag coefficient diagram of a NACA 64-618 profile of trapezoidal 10 % serrations mounted at the bottom and max. (20 %) serrations mounted at the top.

Fig. 61 shows torque coefficient diagram of a NACA 64-618 profile of trapezoidal 10% (b/h=10%) serrations mounted at the bottom and max. (20%) serrations mounted at the top.

Fig. 62 shows a sliding number diagram of a NACA 64-618 profile of trapezoidal 10% (b/h=10%) serrations attached at the bottom and max. (20%) serrations attached at the top.

There is a significant increase in lift over the entire angle of attack range, especially with vortices rotating in the same direction (left and right-hand vortices directly next to each other generate surprisingly less drag than vortices rotating in opposite directions).

Test setup and evaluation methodology:

The prepared profiles are measured in the wind tunnel. The wind tunnel has a closed measuring section with a cross-section of $h \times b = 0.8 \times 1m$. Flow velocities of up to 50 m/s can be achieved with a turbulence intensity of $T_i = \sigma_u/\bar{u} \lesssim 0.3\%$. The flow velocity in the wind tunnel is determined by the dynamic pressure $p_d = \rho u^2 = p_{gesamt} - p_s$, where p_total is the total pressure, p_s is the static pressure and ρ is the air density. Both pressures are averaged at eight points each in the antechamber and nozzle of the wind tunnel, and the dynamic pressure is measured using a differential pressure cell. The flow velocity is therefore calculated as follows

$$u = \sqrt{(2p_d/\rho)},$$

with the air density ρ. This is determined taking into account the ambient air pressure measured downstream of the measuring section, the temperature and the relative humidity in order to compensate for the effects of weather or temperature changes on the measurement results.

For aerodynamic measurement of the wing profiles, these are attached vertically to two axes in the closed measuring section.

Turntables are embedded in the base and top plates, which are flush with the profile ends and mechanically decoupled from the wind tunnel walls. The airfoil can thus be rotated around its pitch axis. Multi-component load cells are integrated in the axes outside the measuring section, which allow the forces occurring in three spatial directions and the pitch moment to be measured. In addition, the set pitch angle is recorded with a rotary encoder.

The dimensionless lift, drag and moment coefficients C_L, C_D and C_M of the wing profiles to be measured are calculated from the measured lift and drag forces F_L and F_D as well as the pitch moment M according to

$$C\_L = (2F\_L)/(\rho \cdot c \cdot S \cdot u^{\wedge}2 \quad),$$
$$C\_D = (2F\_D)/(\rho \cdot c \cdot S \cdot u^{\wedge}2 \quad) \text{ and}$$
$$C\_M = 2M/(\rho \cdot c^{\wedge}2 \cdot S \cdot u^{\wedge}2 \quad)$$

with the air density ρ, the chord length c, the profile length S and the mean flow velocity u.

In the aerodynamic measurement of wing profiles, wind tunnel corrections are usually applied, which are not used in this evaluation. For airfoils equipped with flow-influencing elements, there is currently no established method.

The serrations to be tested are attached to their base element with removable double-sided adhesive tape on the rotor blade element.

The rotor blade elements are fitted with a 0.1 mm thick triping band to simulate a slightly turbulent flow (used for all measurements).

In the diagrams, the following diagram values are shown in the Y-axis; the pitch angle = angle of attack is shown in the X-axis:

Coefficient of buoyancy C_L
Resistance coefficient C_D
Moment coefficient C_M
Glide ratio = C_L/C_D

The two profiles NACA 64618 and DU-W250 (outer profiles of a rotor blade) are tested in the wind tunnel with different variations of serrations.

The following abbreviations are used:
NACA clean trip= NACA 64618 profile without serration with tripping band
Trapezoid = Trapezoidal serrations
45 or 90 degrees = torsion angle per serration length
10 % or 20 % = serration length in % of the profile length
Cut = There is a gap the width of a serration tooth between each serration tooth (cut serration teeth)
Gs = Neighboring serration teeth are twisted in opposite directions

Results:

Fig. 59 - 62

The glide ratio of the serration 20% 90 degree cut trapezoid is significantly higher than the NACA 64618 profile trimmed without serration. This shows a very clear increase in performance.

The glide ratio of the serration 10 % 45 degree gs trapezoid is slightly less than the NACA 64618 profile trimmed without serration. This shows a significant increase in performance.

Fig. 63 - 66

The glide ratio of the serration 10 % 45 degree gs trapezoid mounted at the bottom is significantly higher than the NACA 64618 profile trimmed without serration. This shows a very clear increase in performance.

The glide ratio of the serration 20 % 90 degree gs trapezoid mounted at the top is higher than the NACA 64618 profile trimmed without serration. This shows a significant increase in performance. There is also a wider range of glide ratio increase towards higher angles of attack.

Effect:

The reverse flow flaps and/or serrations and/or turbulators increase the lift of the rotor blade and thus also the yield of a wind turbine in the range of 1 - 10 %, preferably 2 - 8 %, particularly preferably 3 - 5 %.

Stall-controlled wind turbines have greater effects than pitch-controlled wind turbines.

Noise reduction is achieved by generating many smaller rotational vortices (compared to the trailing edge vortex of the rotor blade = rearmost vortex in Fig. 58) in the direction of the adjacent flow. These many small vortices can be generated in the same or opposite direction to the direction of rotation (Fig. 58).

These many small vortices create a smaller end-edge vortex area and therefore less drag and more lift and less noise/noise due to the turbulent flow.

The size of the vortex generators is in the range of a few mm to several cm.

These vortex generators can also be installed/arranged specifically at the end of a larger serration.

These can also be retrofitted to the rotor blade or existing serrations.

This achieves a noise reduction of > 2 dB(A), especially > 3 dB(A) and particularly preferably > 5 dB(A).

Furthermore, the reverse flow flaps and / or the serrations and / or the turbulators achieve a load reduction of the wind turbine. This is achieved at a level of > 5%, especially > 10% and particularly preferably > 15% load reduction.

Manufacture:

The materials for the backflow flaps and/or serration and/or turbulator technology are preferably made of thermoplastic fiber-reinforced plastic such as PC or PMMA with high environmental / UV resistance and durability (including appropriate additives for UV and weather protection).

Production can be carried out by means of thermo-pressing molds and/or by twisting the toothing (e.g. heated thermoplastic FRP) using rotary motion actuators such as rotary magnets or stepper motors.

This can also be done simultaneously with many individual teeth of the toothing at the same time or one after the other. This enables short production times.

The buckling and/or curved deformation of the backflow flaps or serrations or turbulators can be achieved by means of heat forming with and without shaping, e.g. bending. In particular, these can undergo multiple deformations in 2D and 3D contour deformation.

Production using 3D printing is also possible.

The elements can also be made of various materials, such as fiber-reinforced plastic materials (FRP), metals or other plastics (in particular with high UV and weather resistance of at least 5 years, preferably at least 10 years, particularly at least 20 years).

Application: for blades, propellers, rotor blades, turbines, housings and other objects with fluid flows.

Fig. 67 shows a forming tool 47 for manufacturing a swirl element 1.

The forming tool 47 is designed as a holder 48 connected to a rotation axis 49 of a rotation magnet 50. The holder is designed for inserting a sheet to be twisted, in particular a sheet or strip of sheet cut to form an aerodynamically active section 3.

Fig. 68A shows a sheet 46 before forming.

This is a sheet metal 46 tailored to form an aerodynamically active section 3, for example a thermoplastic fiber composite sheet or a metallic sheet.

To produce a swirl element 1 from the sheet 46, this is placed in the holder of the forming tool 47. The sheet is then formed by means of the rotary magnet 50 by applying, at least in sections, a twist to the sheet 46 by at least 10°, in particular up to 180°, with its entire cross-section about a common axis 5, which is achieved by turning the axis of rotation 49 of the rotary magnet 50. A twisted guide plate 4 is thus created.

Depending on the material, for example in the case of a thermoplastic material, the sheet 46 can be heated before and/or during twisting.

Fig. 68B a swirl element 1 with twisted guide plate 4.

The swirl element 1 is manufactured in this way and has an aerodynamically active section with a guide plate 4 with a torsion angle of 90°, for example. Of course, other torsion angles of the air baffle 4 are also possible, in particular up to 180°, as shown in Figs. 18 to 20, for example.

Of course, a plurality of parallel guide plates can be twisted in the same way with several parallel forming tools 47, in particular both in an arrangement with the same direction of rotation, for example as shown in Figure 12, or with the opposite direction of rotation, for example as shown in Figures 27, 28 or 30. Furthermore, different arrangements and twists can be produced in sections, for example as shown in Figure 29.

Although the present invention has been fully described above with reference to preferred embodiments, it is not limited thereto, but can be modified in a variety of ways.

Further unclaimed embodiments:

Device for aerodynamically improving a wing/rotor blade, this wing/rotor blade having 3D elements which are at least partially twisted and have at least one twist angle of > 0 °, preferably > 10 °, particularly preferably > 30 °.

Device for aerodynamically improving a wing/rotor blade, this wing/rotor blade having elements which are at least partially twisted and have at least a twist angle of > 10 °, preferably up to 720 °, thereby greatly reducing the turbulence of the trailing edge vortex, which contributes at least to a noise reduction of at least > 3 dB(A), preferably to a very significant noise and/or load reduction and/or an increase in yield.

List of reference symbols

1	Swirl element
2	Fixing section
3	flow active section
3A, 3B	active flow sections
4	guide plate
4A, 4B	baffle plate
5	axis
6	alignment section
7	first part
8	second part
9	kink
10	aerodynamic profile
11	profile surface
12	flow
13	profile end edge
14	end edge swivel
15	vortex
16	vortex
17	rotor blade
18	front edge
19	front short edge
20	back short edge
21	long edge
22	long edge
23	eecess
24	amplification
25	legs
26	joint area
27	circumferential speed vector
28	jagged structures

29	axis of rotation
30	wind turbine
31	rotor
32	hub
33	rotor blade
34	gondola
35	tower
36	turbine housing
37	rast extension
38	rest recess
39	recess
40	wind tunnel
41	fan
42	rectifier
43	nozzle
44	measured volume
45	noise sensor
46	sheet metal
47	shaping tool
48	recording
49	rotation axis
50	rotating solenoid

HVIRVELELEMENT SAMT FREMGANGSMÅDE TIL FREMSTILLING AF ET HVIRVELELEMENT

Patentkrav

1. Hvirvelelement (1) til hvirveldannelse i en fluidstrøm og til støjreduktion og forøgelse af ydelsen for en roterende aerodynamisk profil (10) med:

et fastgørelsesafsnit (2), der er udformet til fastgørelse på en profiloverflade (11) på det roterende aerodynamiske profil (10); og

flere med fastgørelsesafsnittet (2) forbundne strømningsaktive afsnit (3, 3A, 3B), idet de strømningsaktive afsnit (3, 3A, 3B) kan anbringes i området ved en profilendekant (13) på profiloverfladen (11) og hver især har en styreplade (4), idet styrepladerne (4) hver især i det mindste i afsnit er vredet med hele deres tværsnit om en fælles akse (5), og

tilstødende styreplader (4), som hver især skiftevis er vredet helix- eller skrueformigt i forskellige omdrejningsretninger, idet styrepladerne (4) hver især er vredet mindst 10°, især mindst en ottendedel omdrejning, fortrinsvis mindst en fjerdedel omdrejning, om aksen (5), og

idet styrepladerne (4) er trekantformige, trapezformige, delcirkelformige, delellipseformige og/eller mangekantformige.

2. Hvirvelelement (1) ifølge krav 1, **kendetegnet ved, at** styrepladerne (4) har længder fra 0,1 gang til 20 gange bredden.

3. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** styrepladerne (4) har bredder fra 0,2 mm til 300 mm og/eller tykkelser i områder fra 0,2 mm til 10 mm, fortrinsvis 0,25 mm til 5 mm.

4. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** styrepladerne (4) hver især er vredet i sig selv i det mindste i afsnit, således at aksen (5) forløber i den pågældende styreplade (4).

5. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** styrepladerne (4) hver især er udformet asymmetrisk til skrå tilstrømning, især asymmetrisk i en planprojektion.

6. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** der mellem fastgørelsesafsnittet (2) og de strømningsaktive afsnit (3, 3A, 3B) er anbragt et orienteringsafsnit (6) til den fra fastgørelsesafsnittet (2) forskellige orientering af de strømningsaktive afsnits (3, 3A, 3B) akser (5).

7. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** fastgørelsesafsnittet (2) er dannet i et stykke med det strømningsaktive afsnit (3, 3A, 3B) og/eller et mellem fastgørelsesafsnittet (2) og det strømningsaktive afsnit (3, 3A, 3B) tilvejebragt orienteringsafsnit (6), der er anbragt til den fra fastgørelsesafsnittet (2) forskellige orientering af de strømningsaktive afsnit (3, 3A, 3B) akser (5), især som plade eller strimmel i et stykke.

8. Hvirvelelement (1) ifølge et af de foregående kravene 1 til 6, **kendetegnet ved, at** fastgørelsesafsnittet (2) og de strømningsaktive afsnit (3, 3A, 3B) er udformede med to forskellige dele (7, 8), der er koblet med hinanden, især formsluttende.

9. Hvirvelelement (1) ifølge et af de foregående kravene 1 til 5, **kendetegnet ved, at** de strømningsaktive afsnit (3, 3A, 3B) er anbragt på fastgørelsesafsnittet (2) med i det mindste i det væsentlige samme orientering af deres akser (5), især i regelmæssige afstande.

10. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** de tilstødende styreplader (4) hver især er vredet skiftevis i forskellige omdrejningsretninger til frembringelse af modsat roterende hvirvler (9A, 9B).

11. Hvirvelelement (1) ifølge et af de foregående kravene, **kendetegnet ved, at** fastgørelsesafsnittet (2) har to indbyrdes V-formigt stående arme (25), og at styrepladerne (4) hver især har to rette korte kanter (19, 20), hvor den forreste korte kant (19) er bredere end den bageste korte kant (20), og har to rette eller krummede lange kanter (21, 22), idet styrepladerne (4) er forbundet med fastgørelsesafsnittet (2) med deres bredere korte kanter (19) i området ved et forbindelsesområde (26), der forbinder de to arme (25).

12. Fremgangsmåde til fremstilling af et hvirvelelement (1) ifølge et af de foregående kravene 1 til 11 med følgende trin:

tilvejebringelse af en plade (46), især en termoplastisk fiberkompositplade eller en metallisk plade, som er tilskåret til dannelse af strømningsaktive afsnit (3, 3A, 3B);

indføring af pladen (46) i et omformningsværktøj (47), idet omformningsværktøjet (47) er udformet som omformningspresseværktøj, især varmomformningspresseværktøj; og

omformning af pladen (46) ved hjælp af omformningspresseværktøjet ved i det mindste i afsnit påføring af en vridning af pladen på mindst 10°, især indtil 90°, med hele dens tværsnit om en fælles akse (5) ved en tilsvarende form af omformningspresseværktøjet.

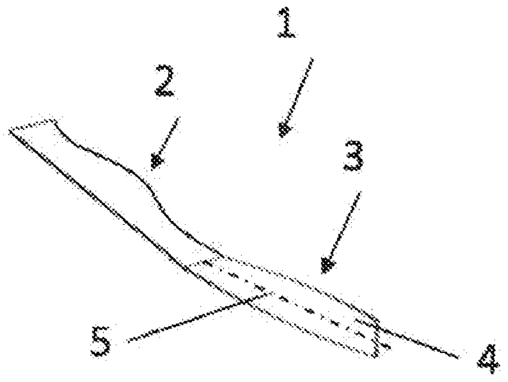


Fig. 1

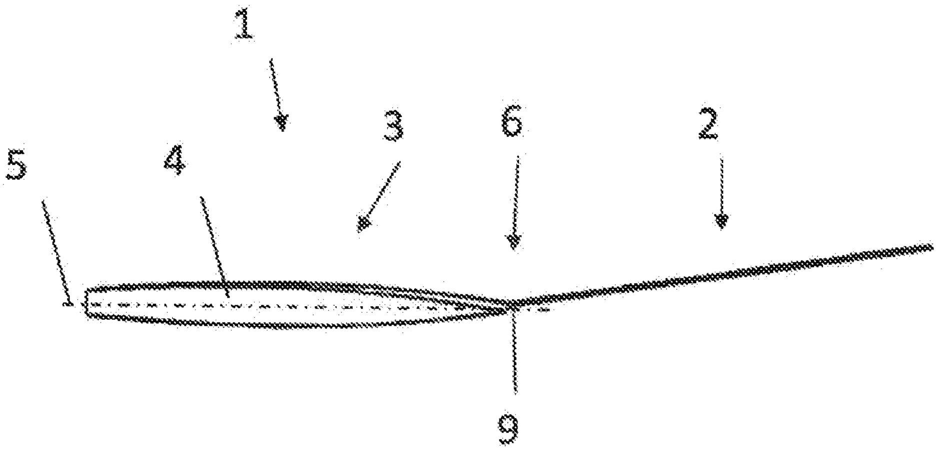


Fig. 2

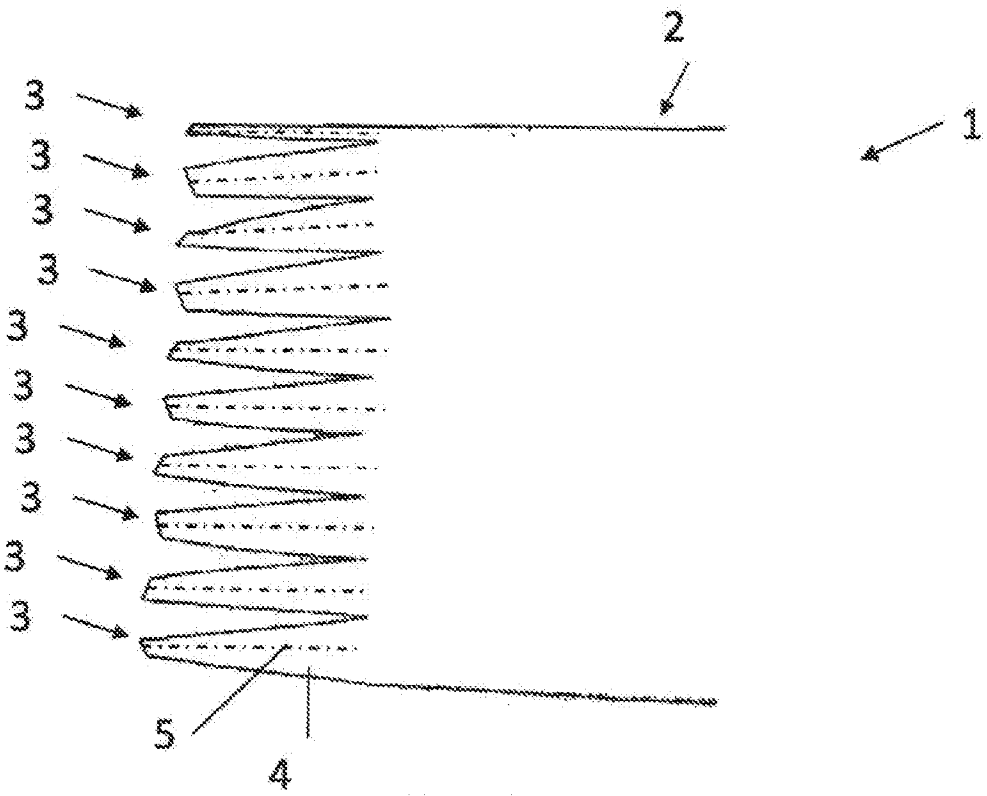


Fig. 3

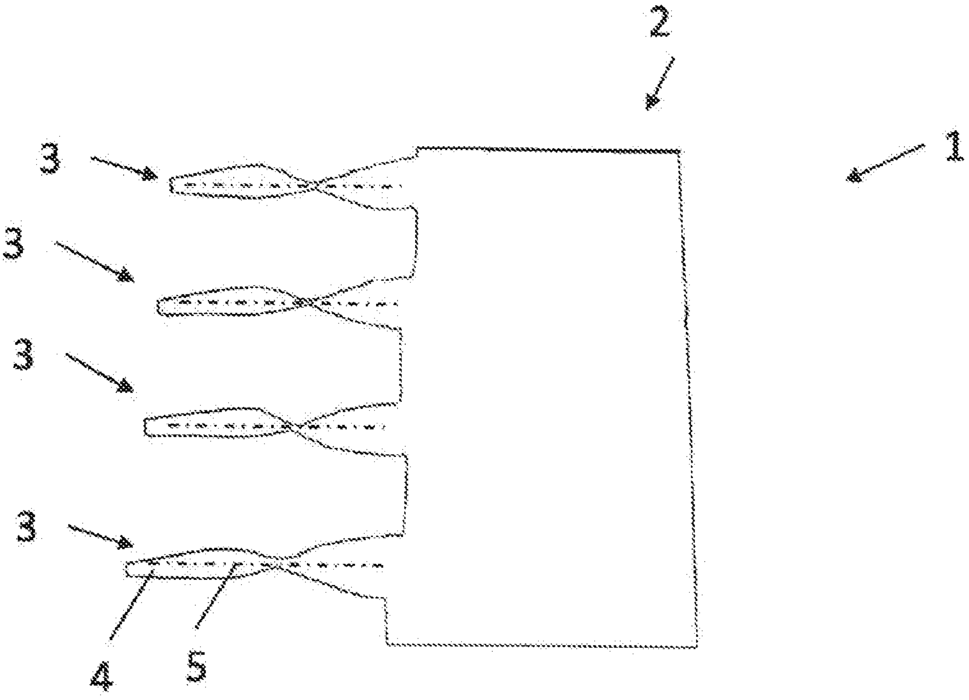


Fig. 4

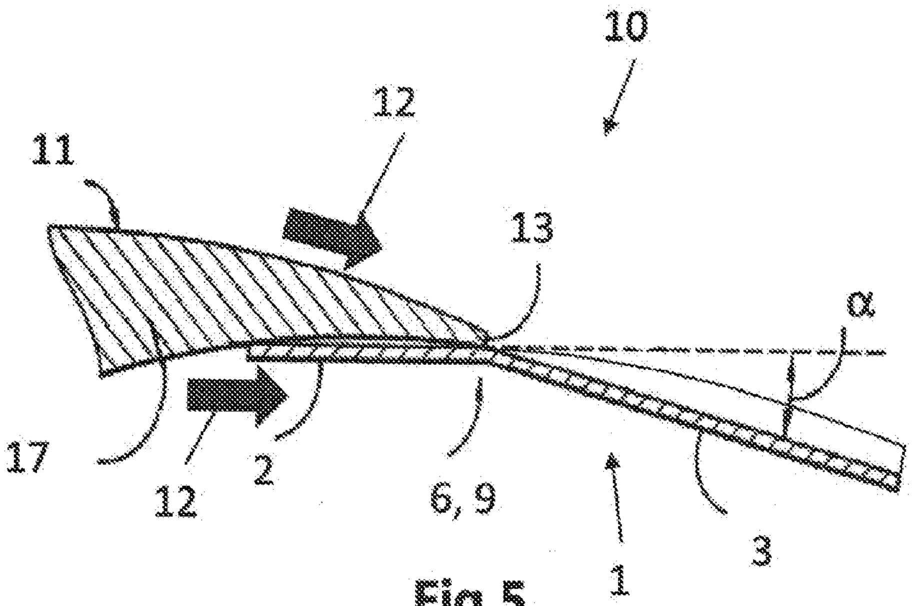


Fig.5

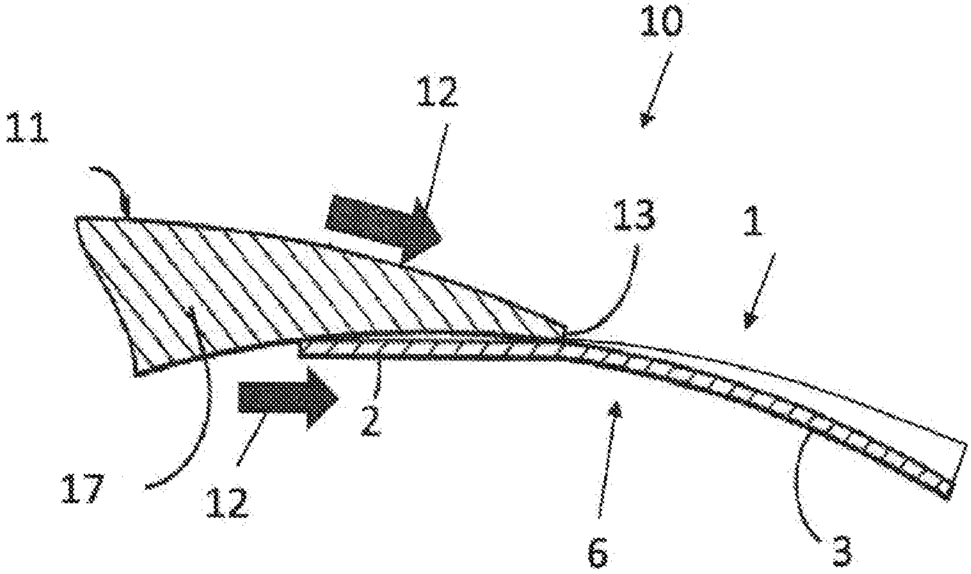


Fig. 6

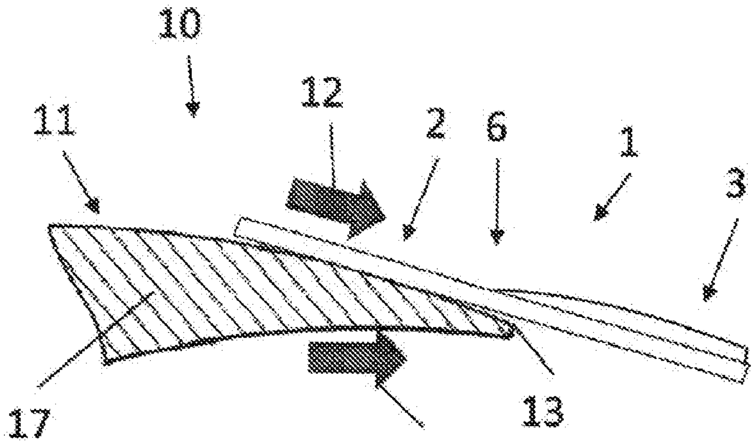


Fig. 7

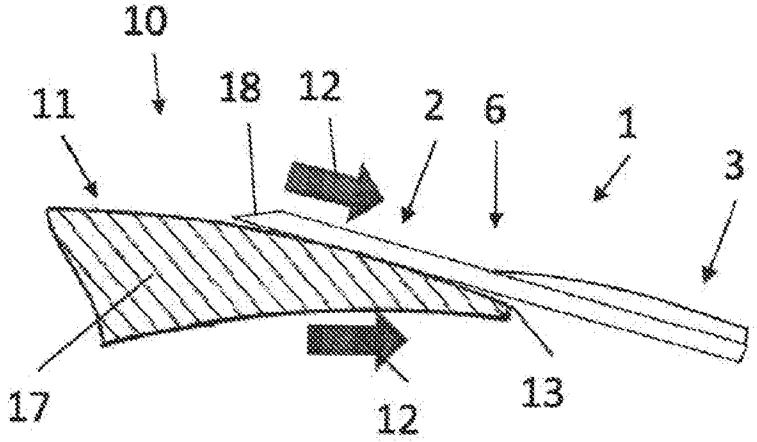


Fig. 8

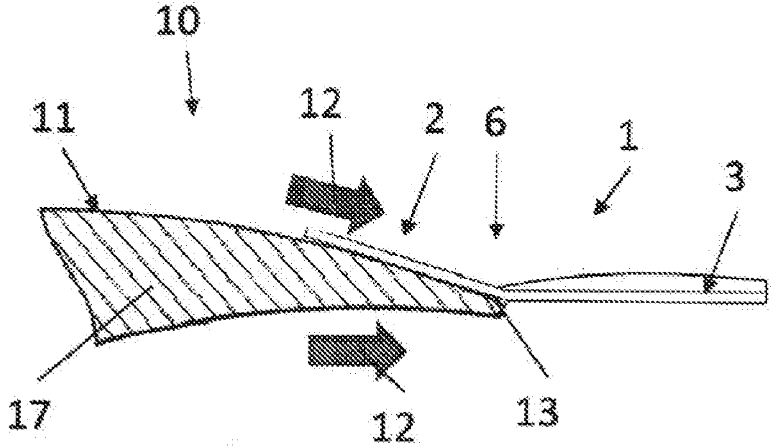


Fig. 9

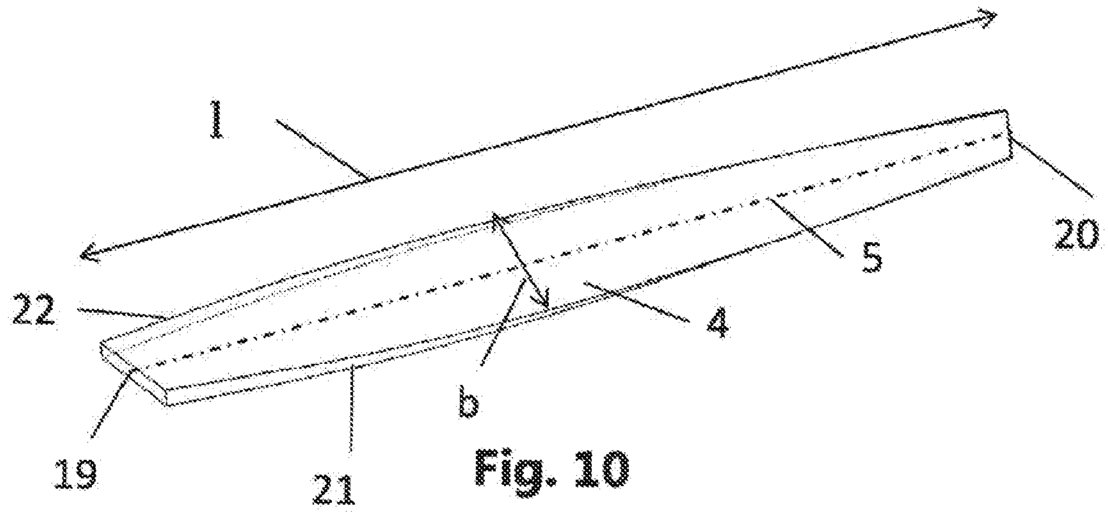


Fig. 10

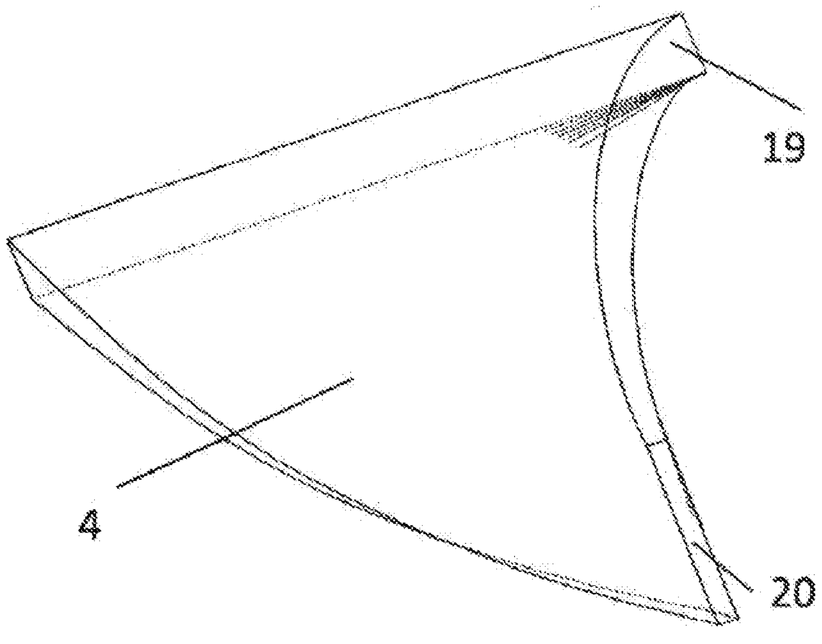


Fig. 11

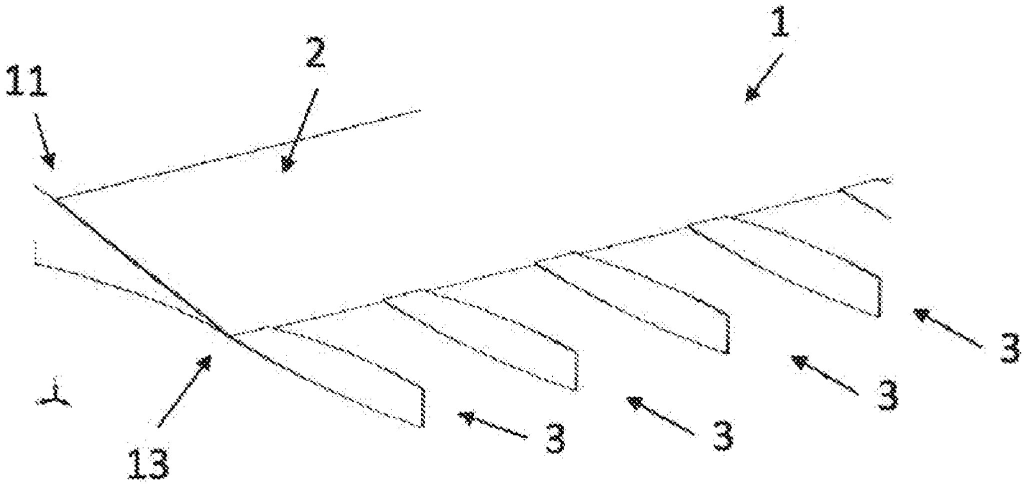


Fig. 12

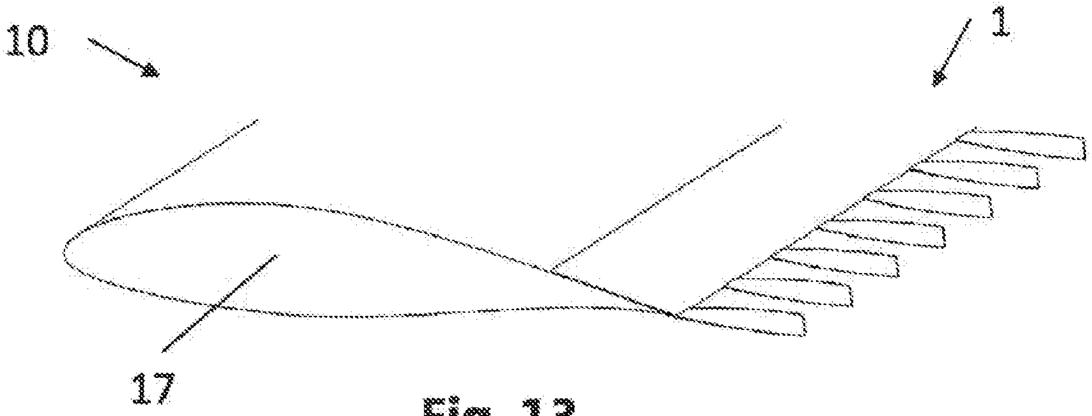


Fig. 13

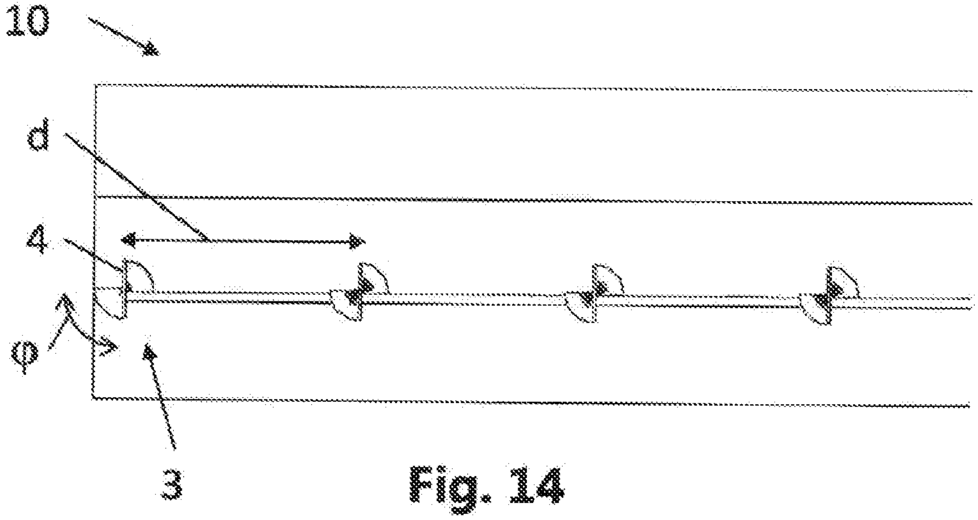


Fig. 14

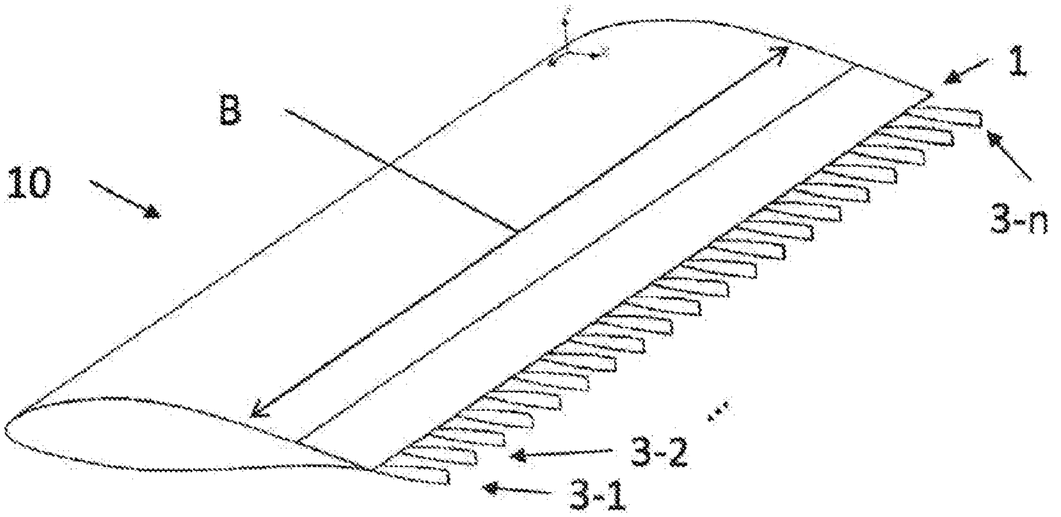


Fig. 15

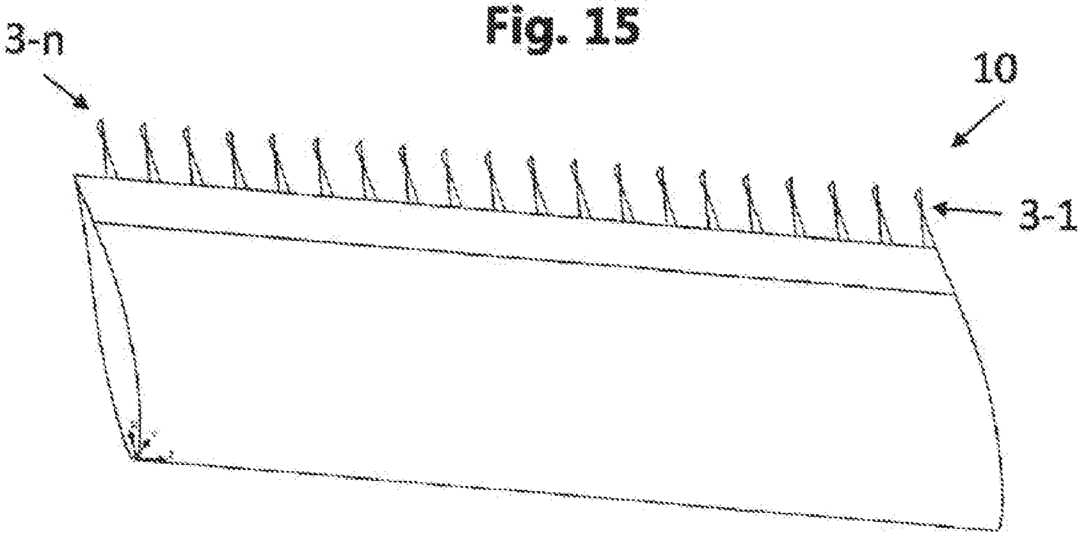


Fig. 16

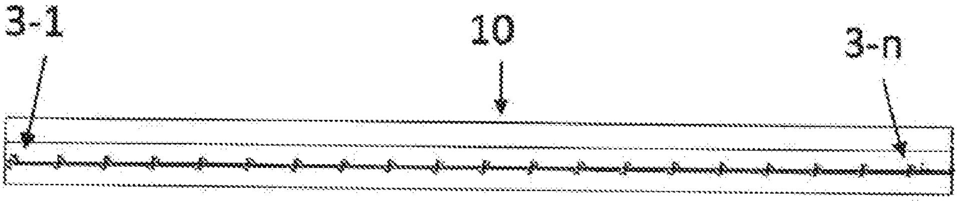


Fig. 17

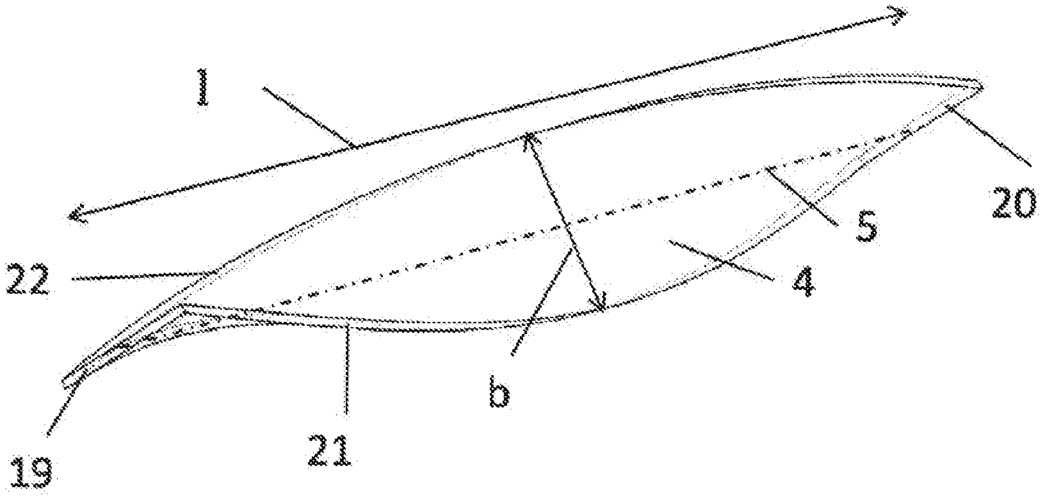


Fig. 18

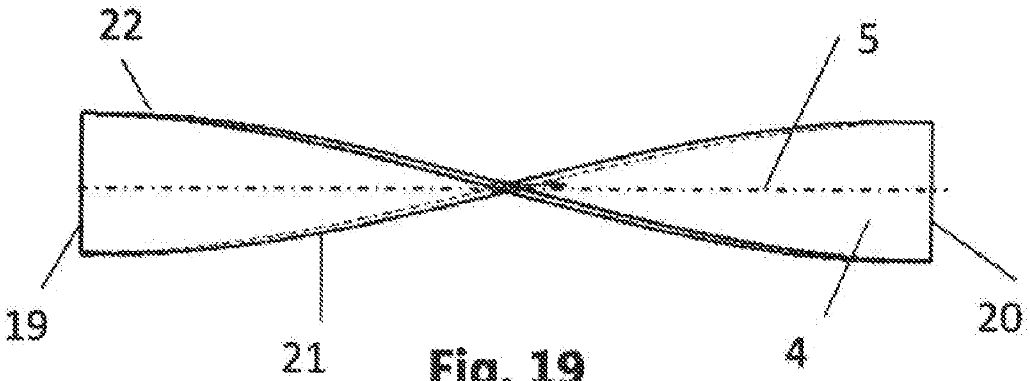


Fig. 19

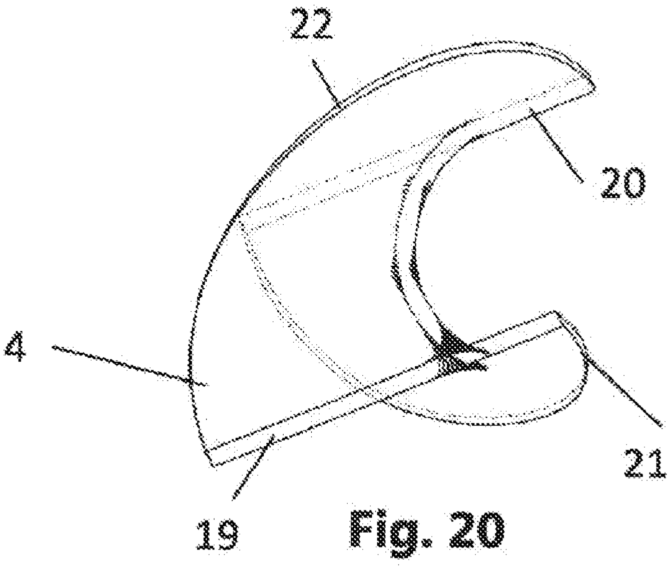


Fig. 20

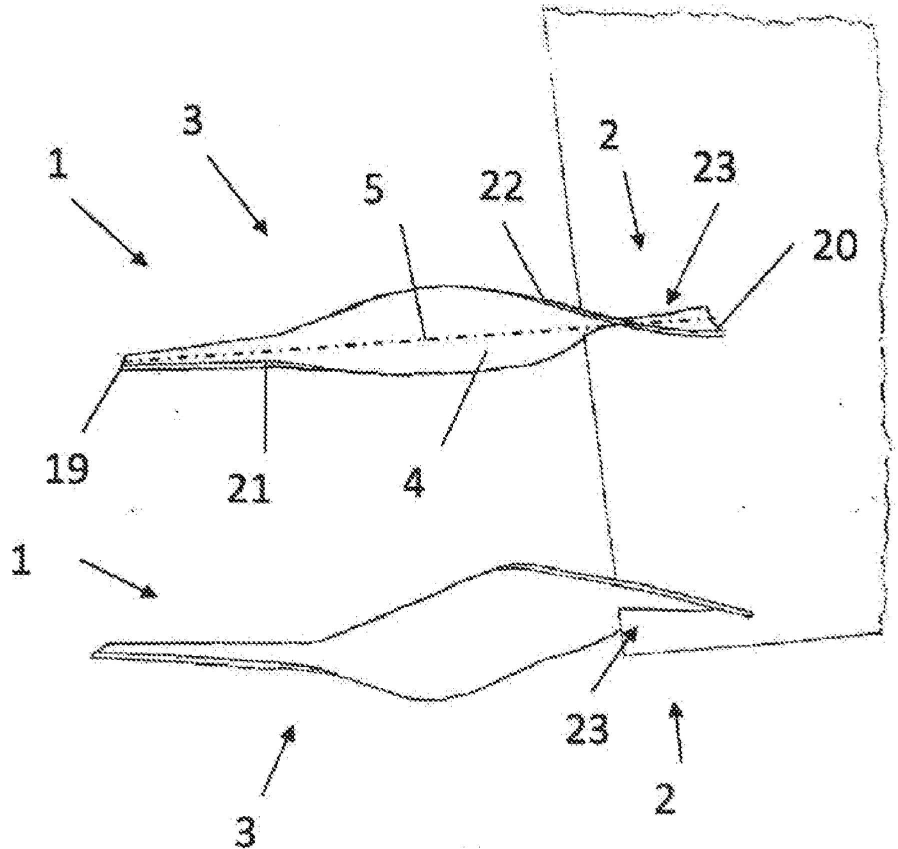


Fig. 21

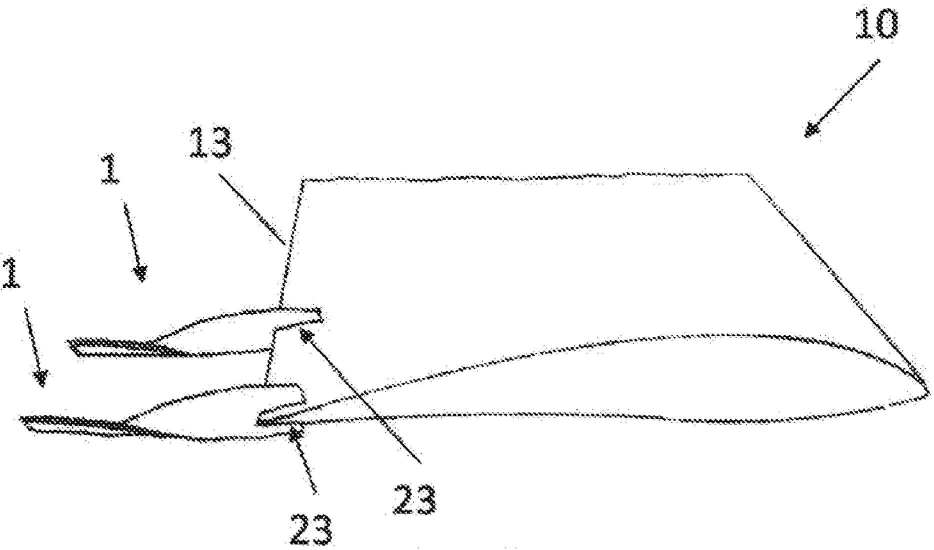


Fig. 22

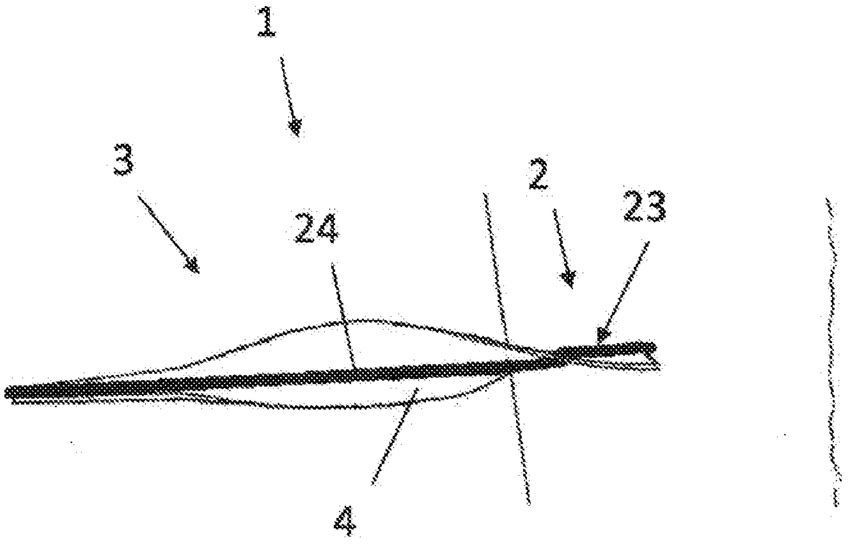


Fig. 23

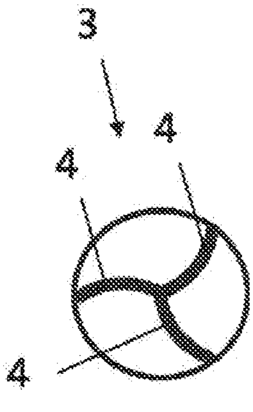


Fig. 24

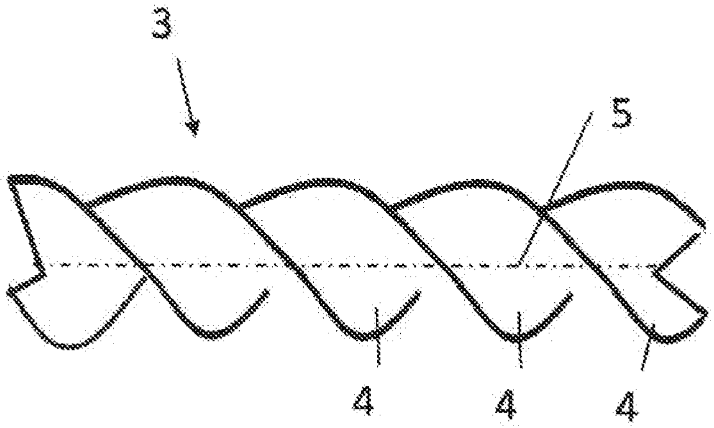


Fig. 25

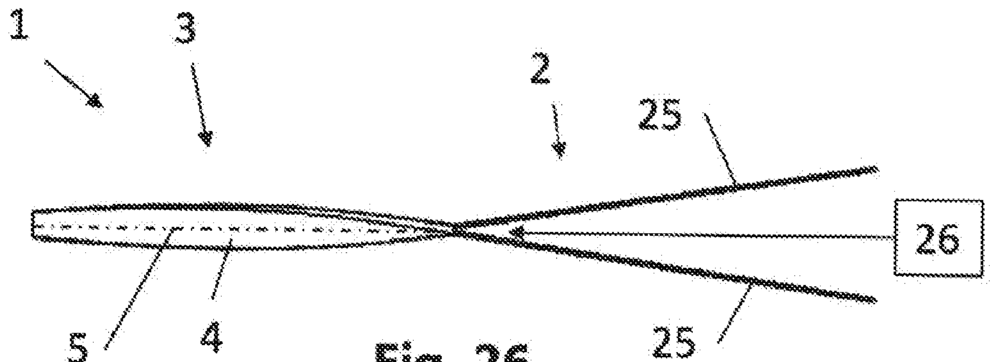
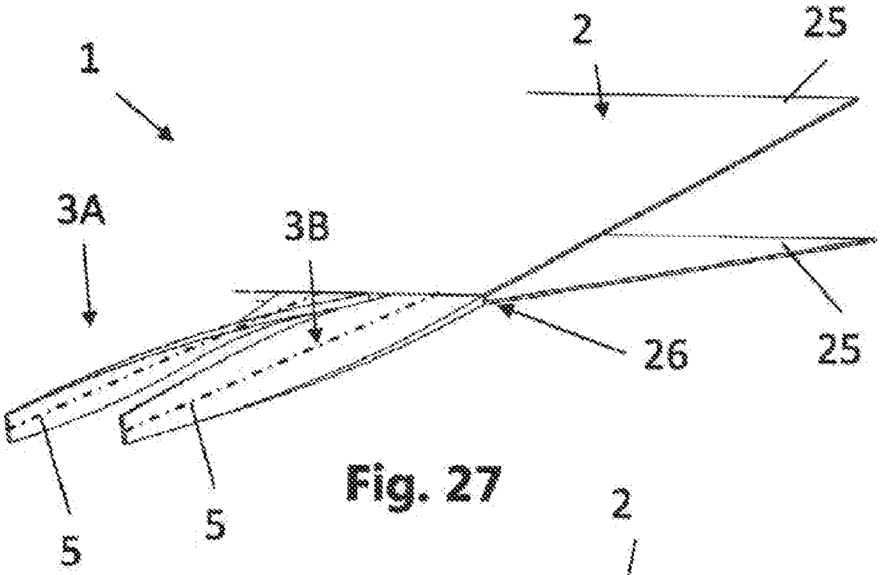


Fig. 26



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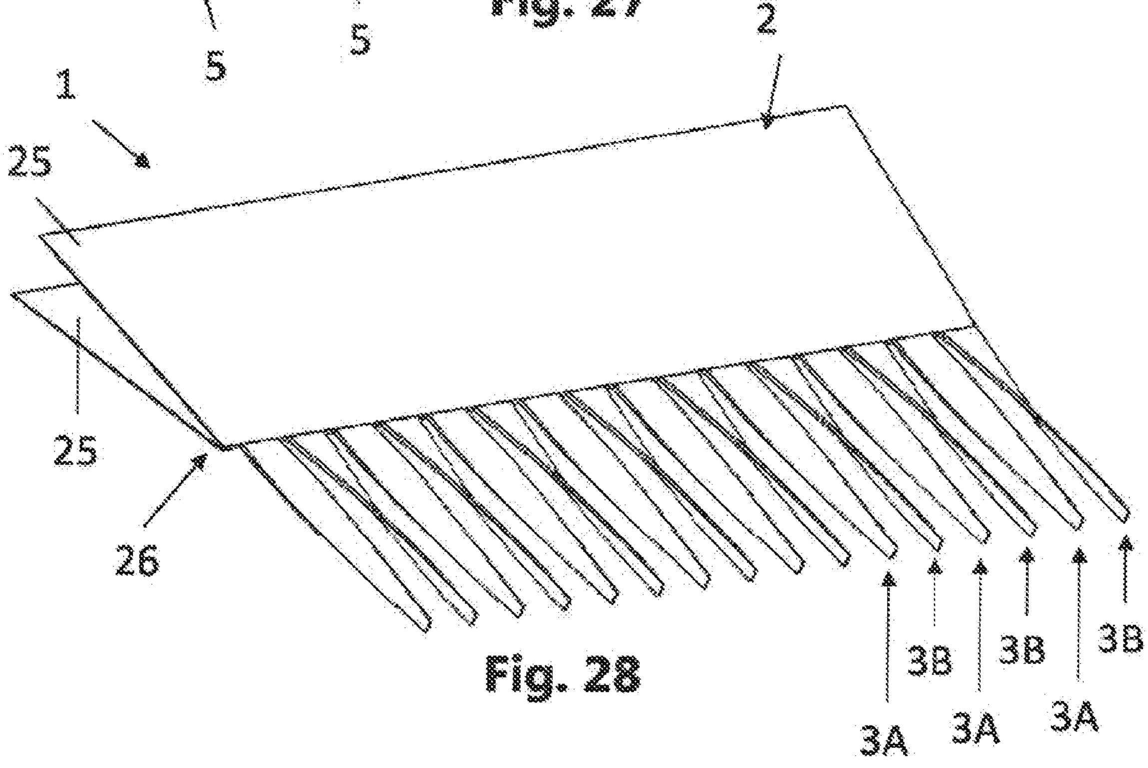

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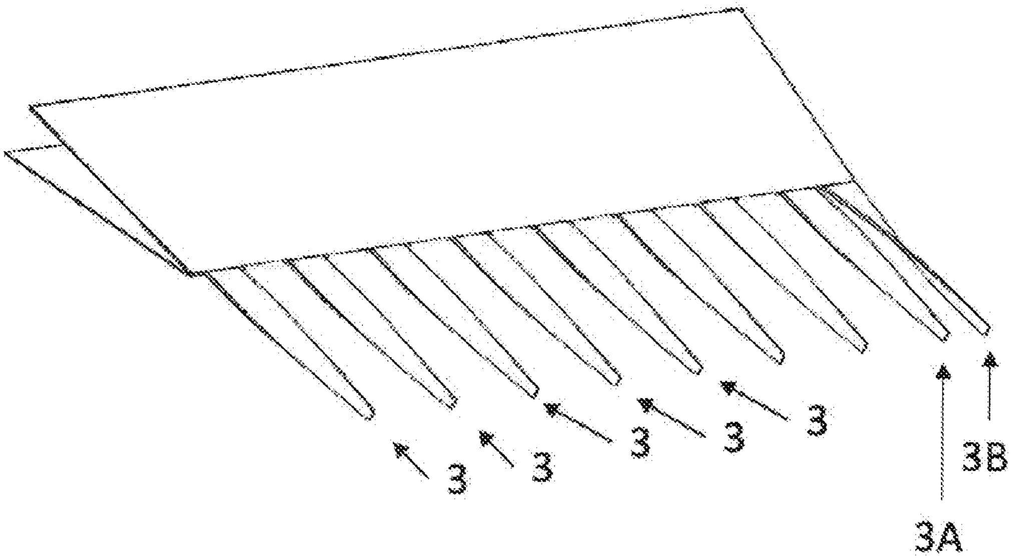

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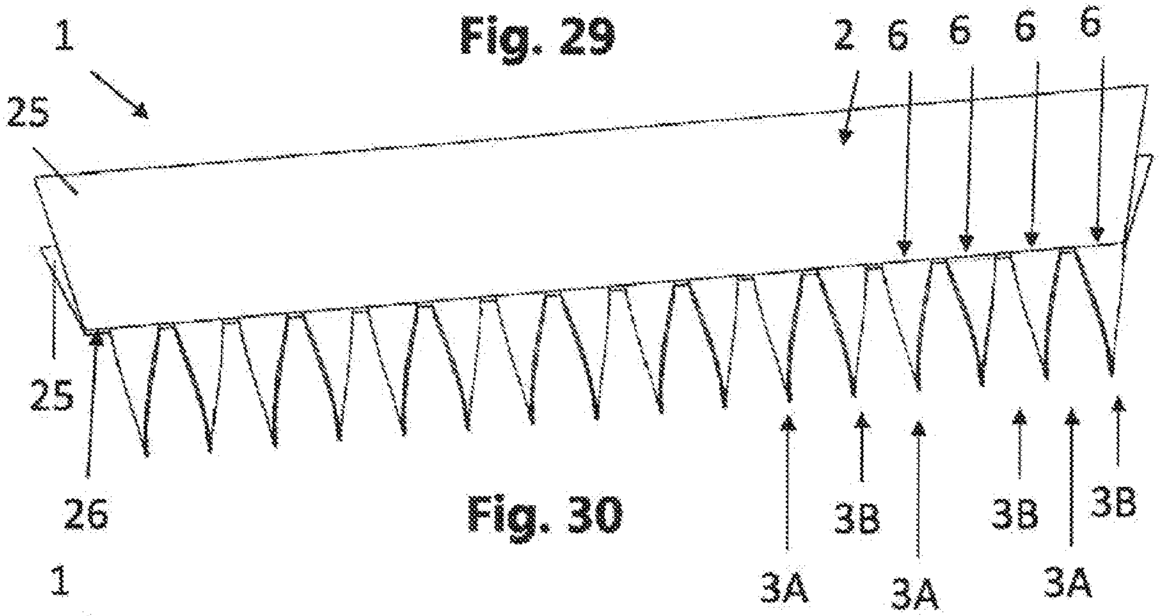


Fig. 30

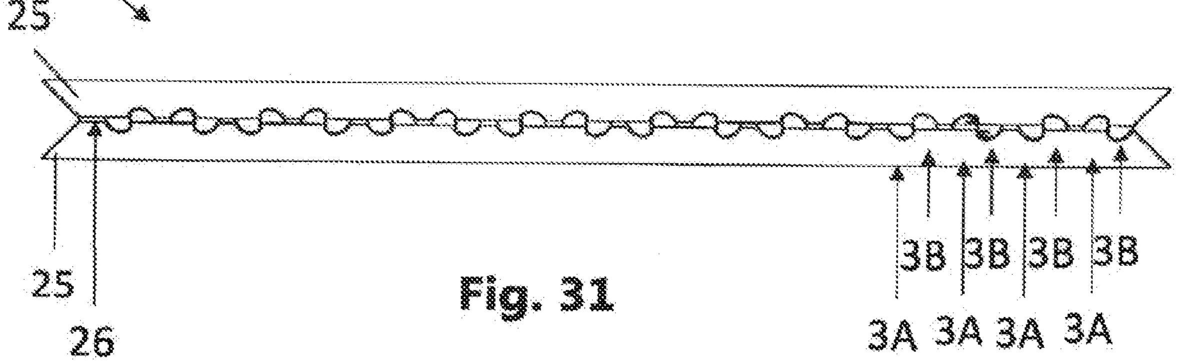


Fig. 31

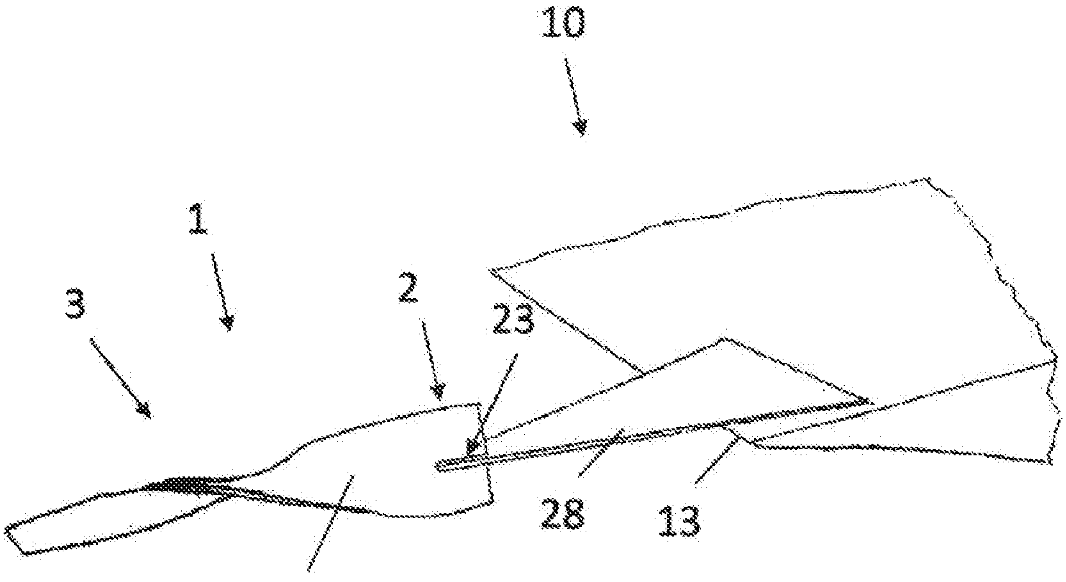


Fig. 32

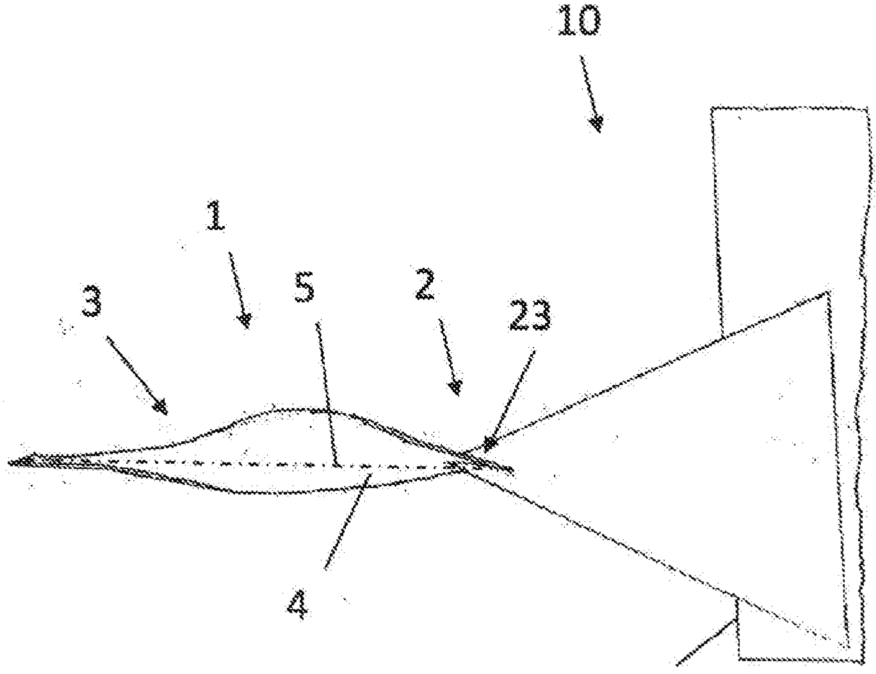


Fig. 33

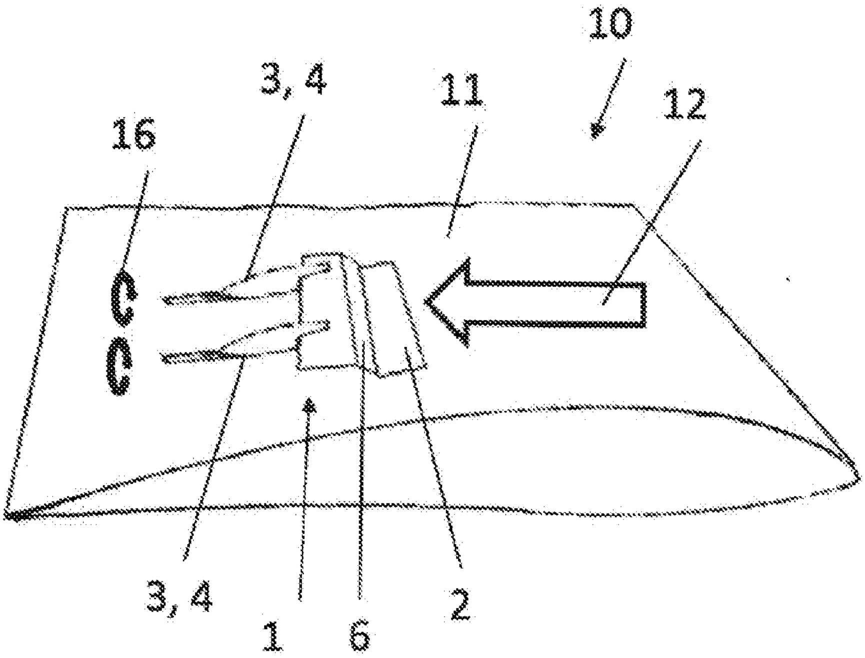


Fig. 34

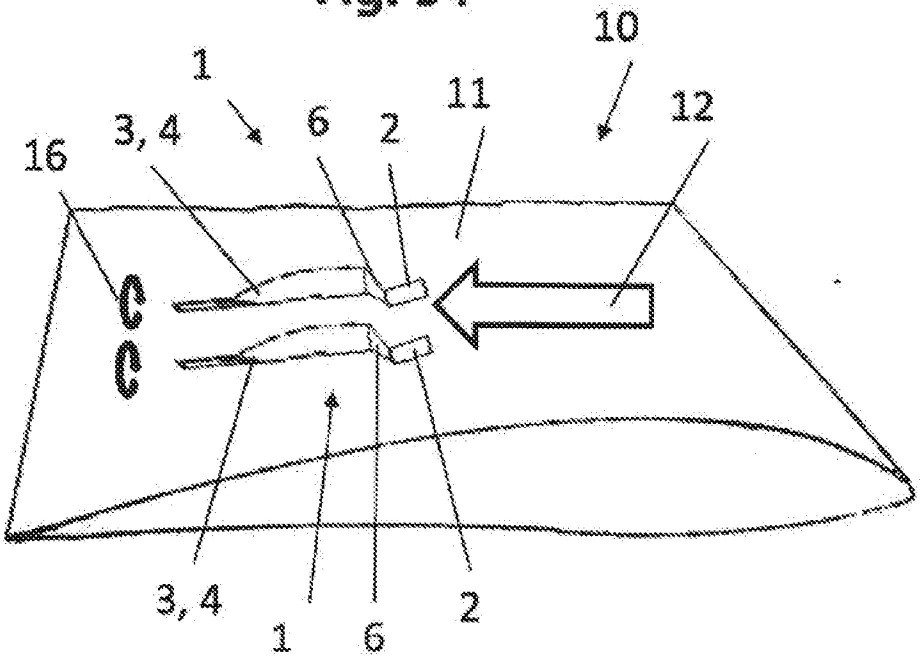


Fig. 35

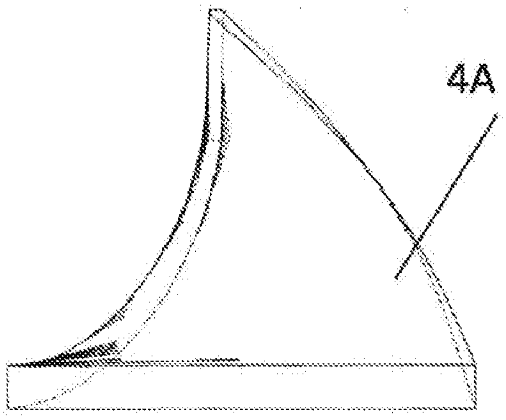


Fig. 36

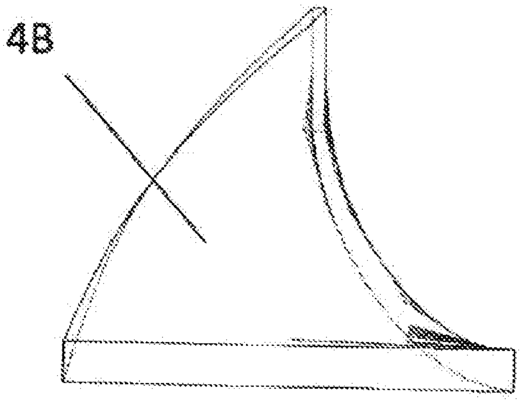


Fig. 37

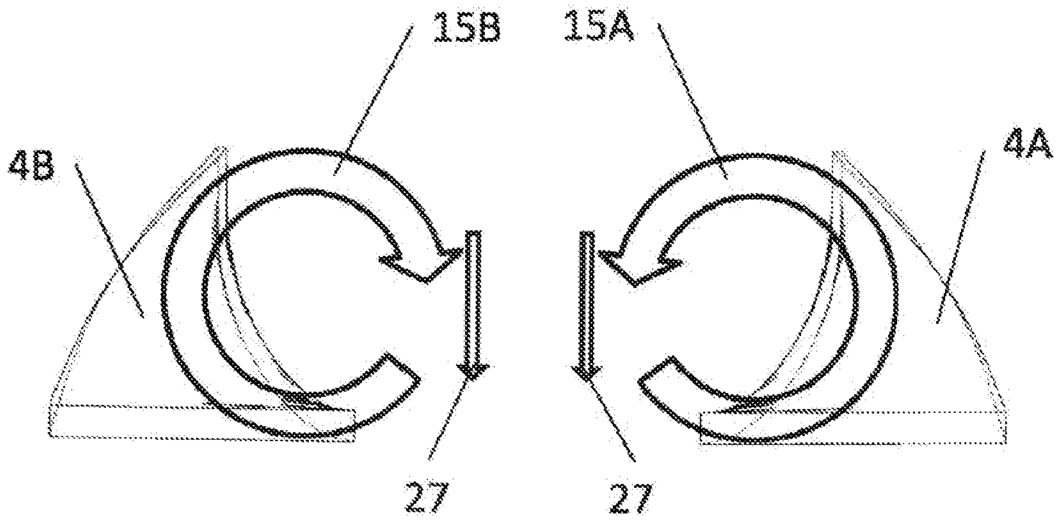


Fig. 38

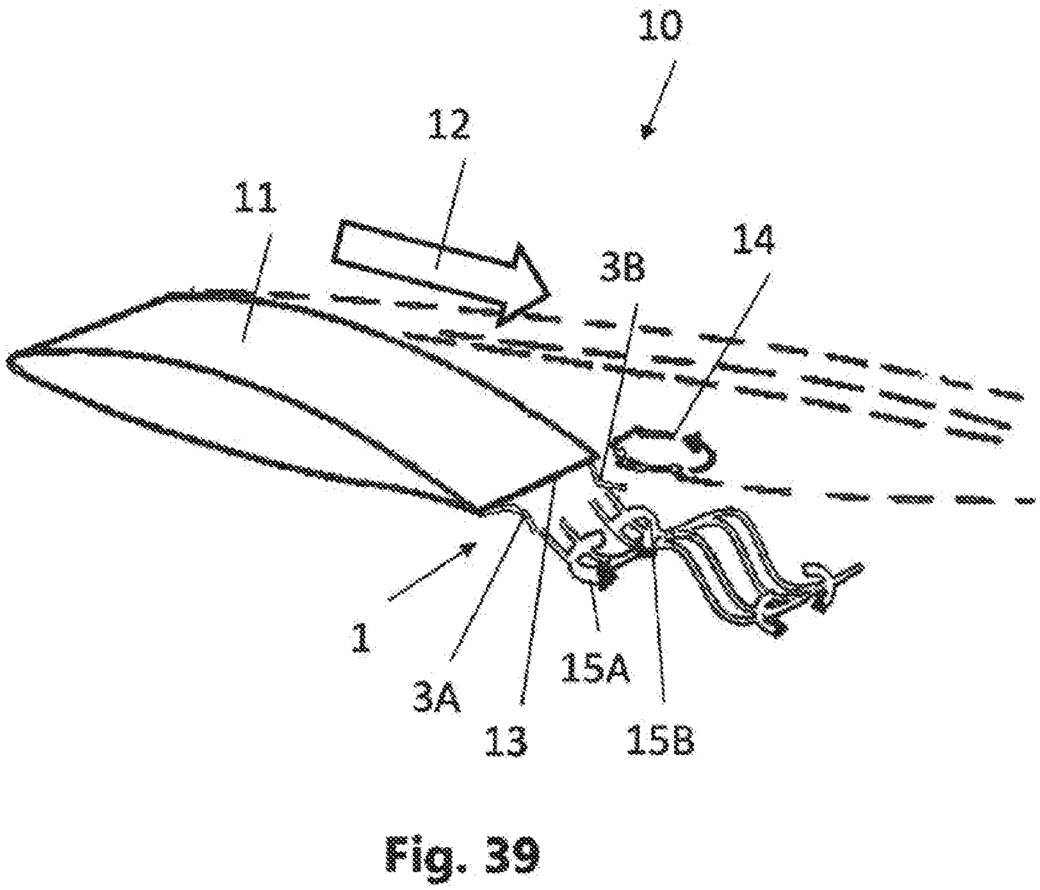


Fig. 39

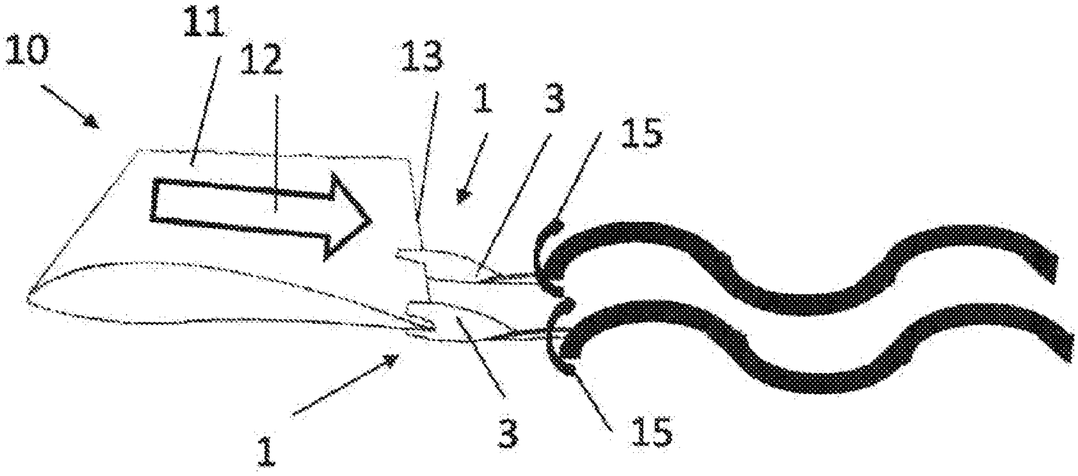


Fig. 40

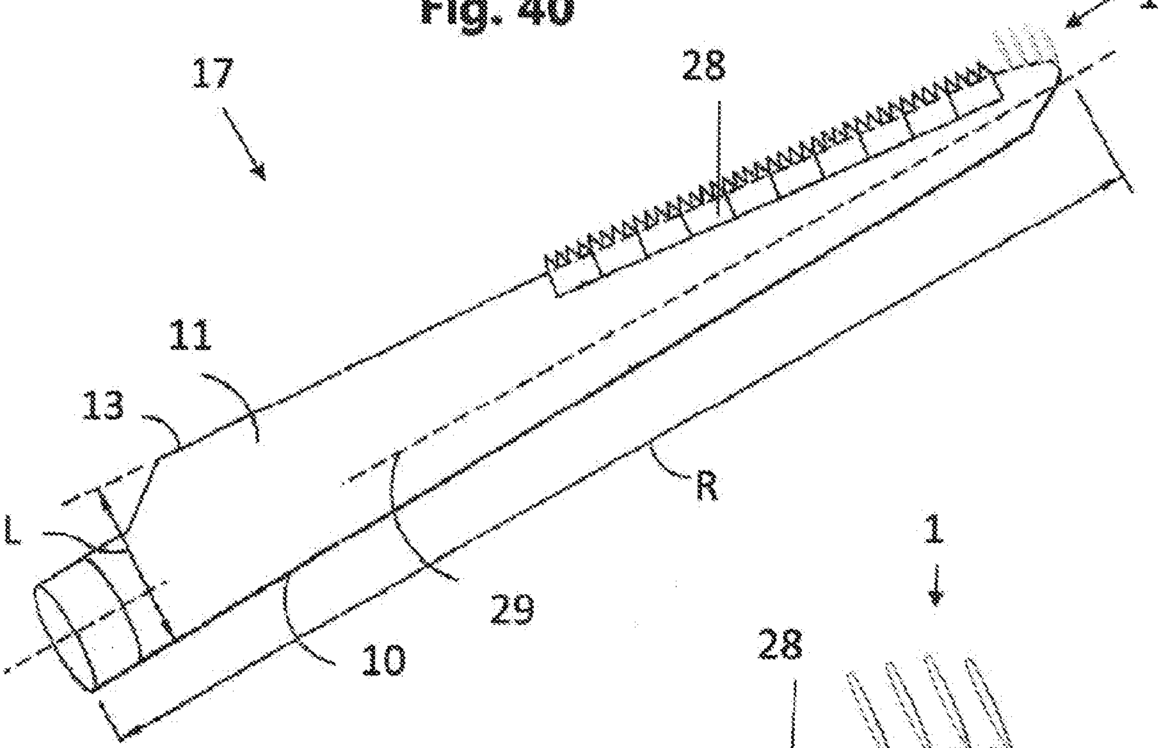


Fig. 41

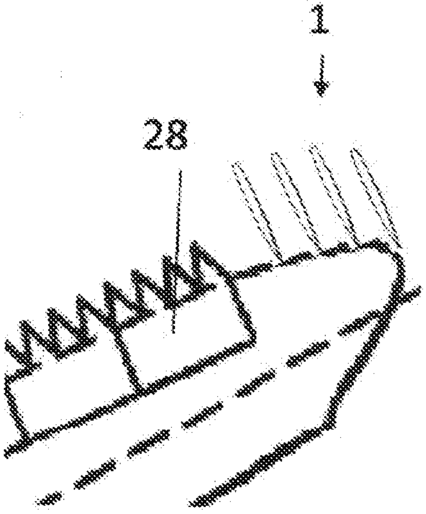


Fig. 42

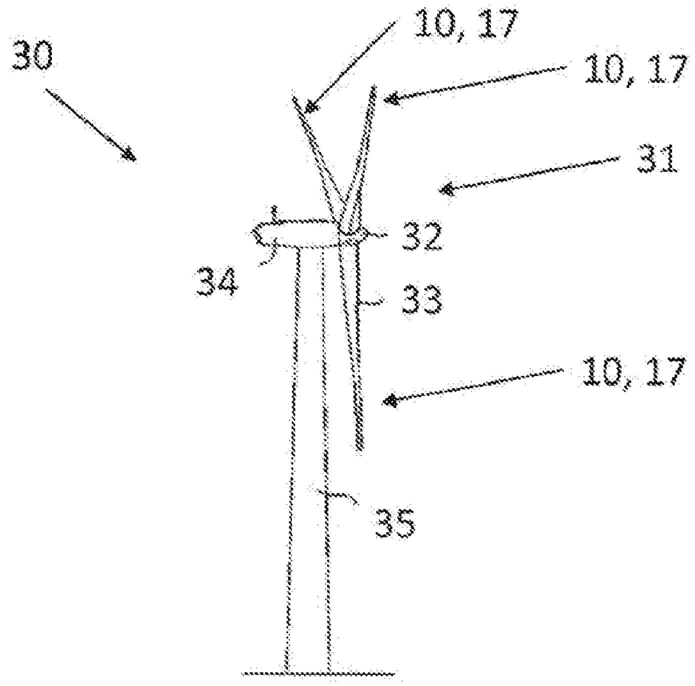


Fig. 43

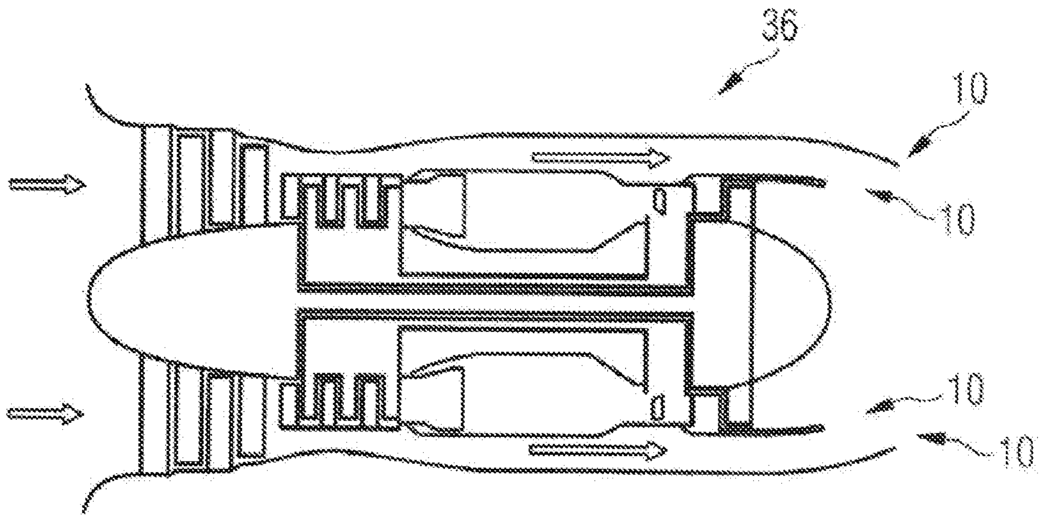


Fig. 44

ERSATZBLATT (REGEL 26)

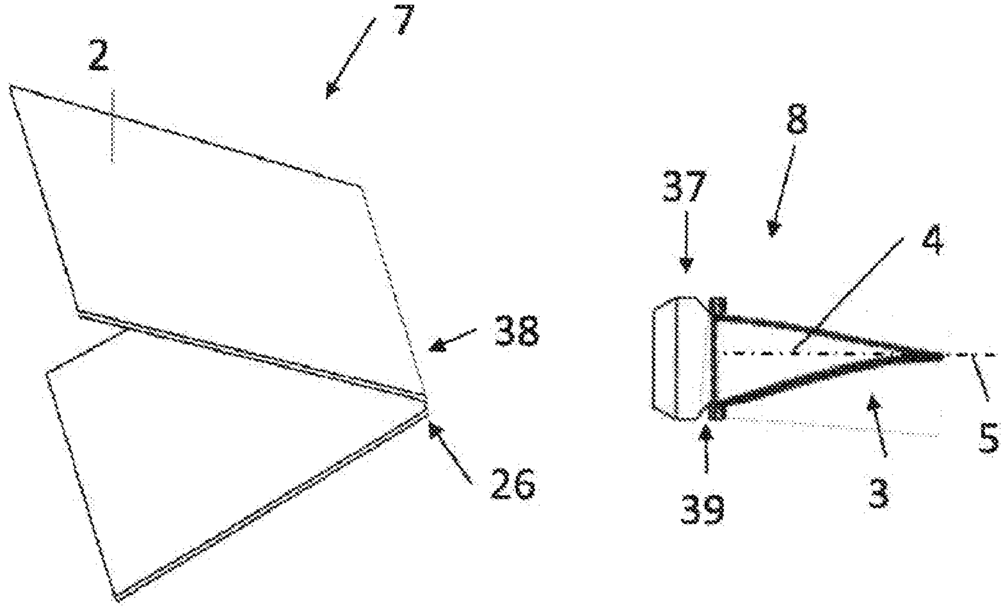


Fig. 45

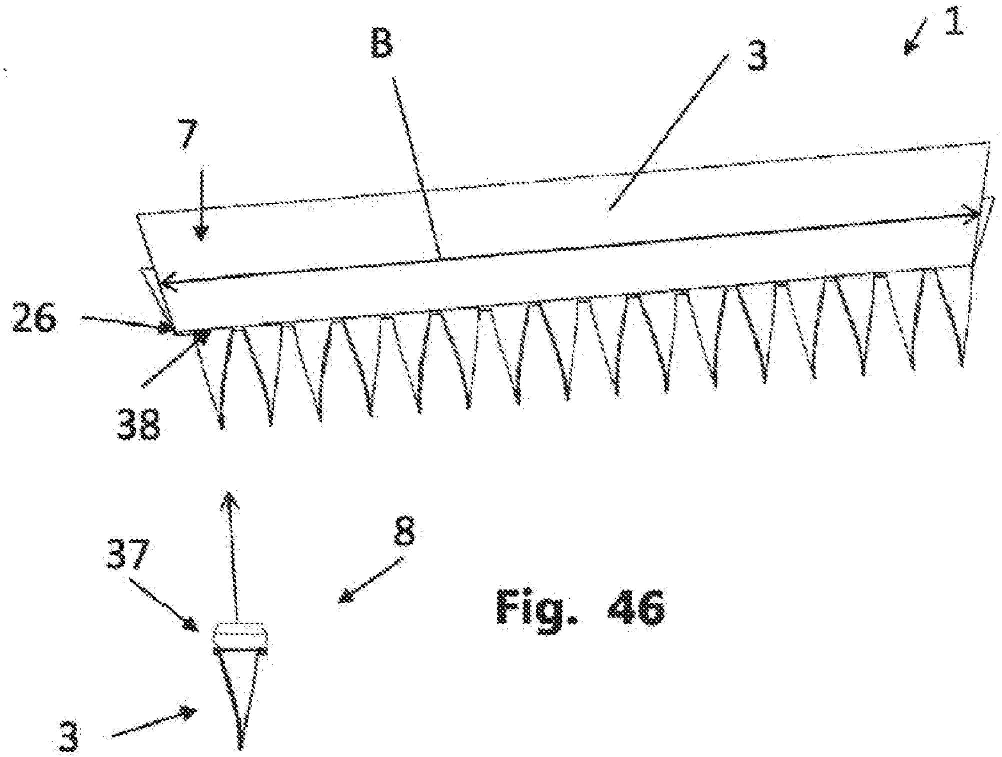


Fig. 46

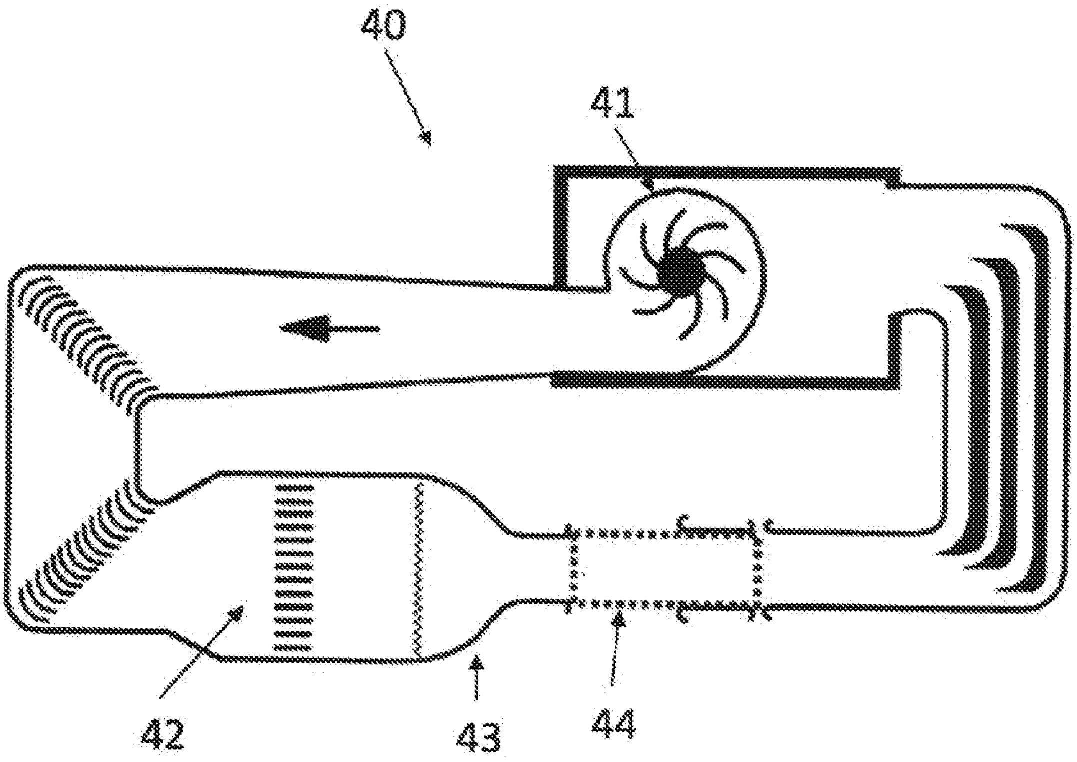


Fig. 47

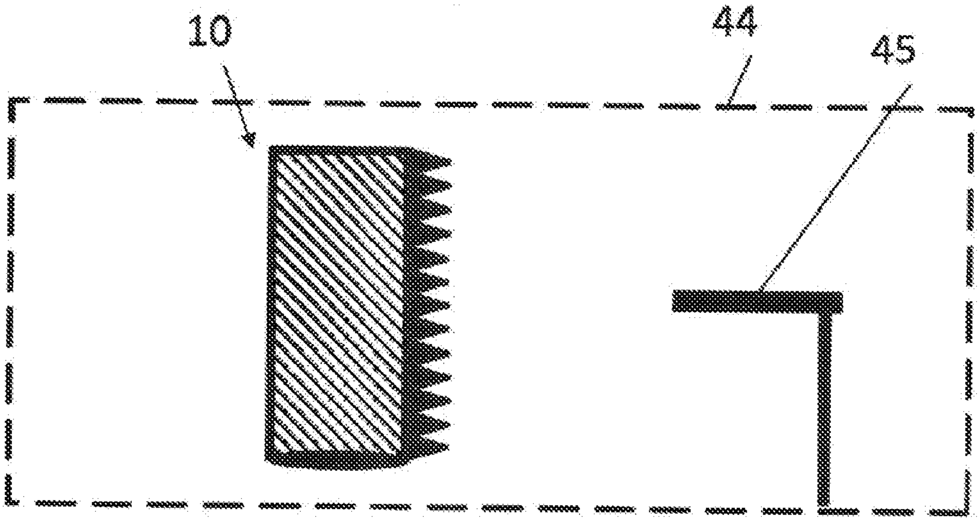
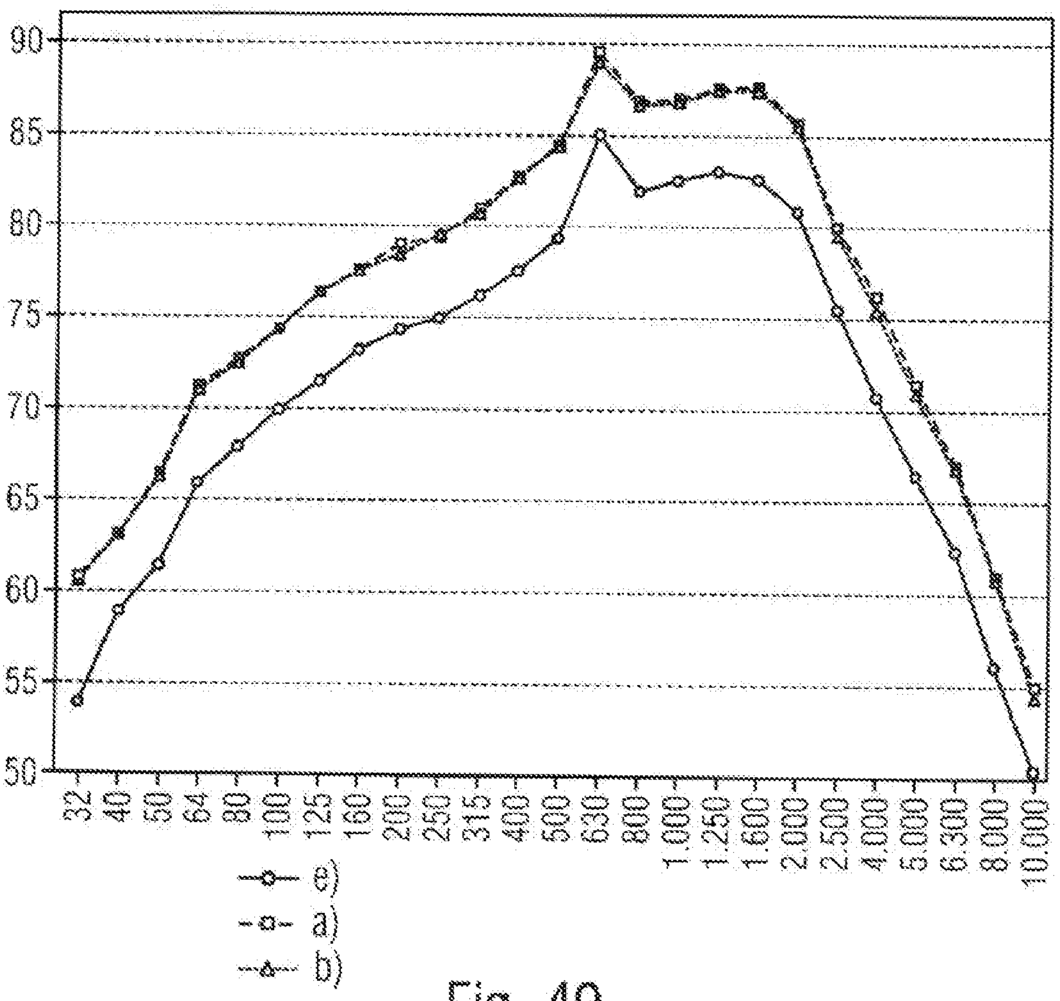


Fig. 48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64
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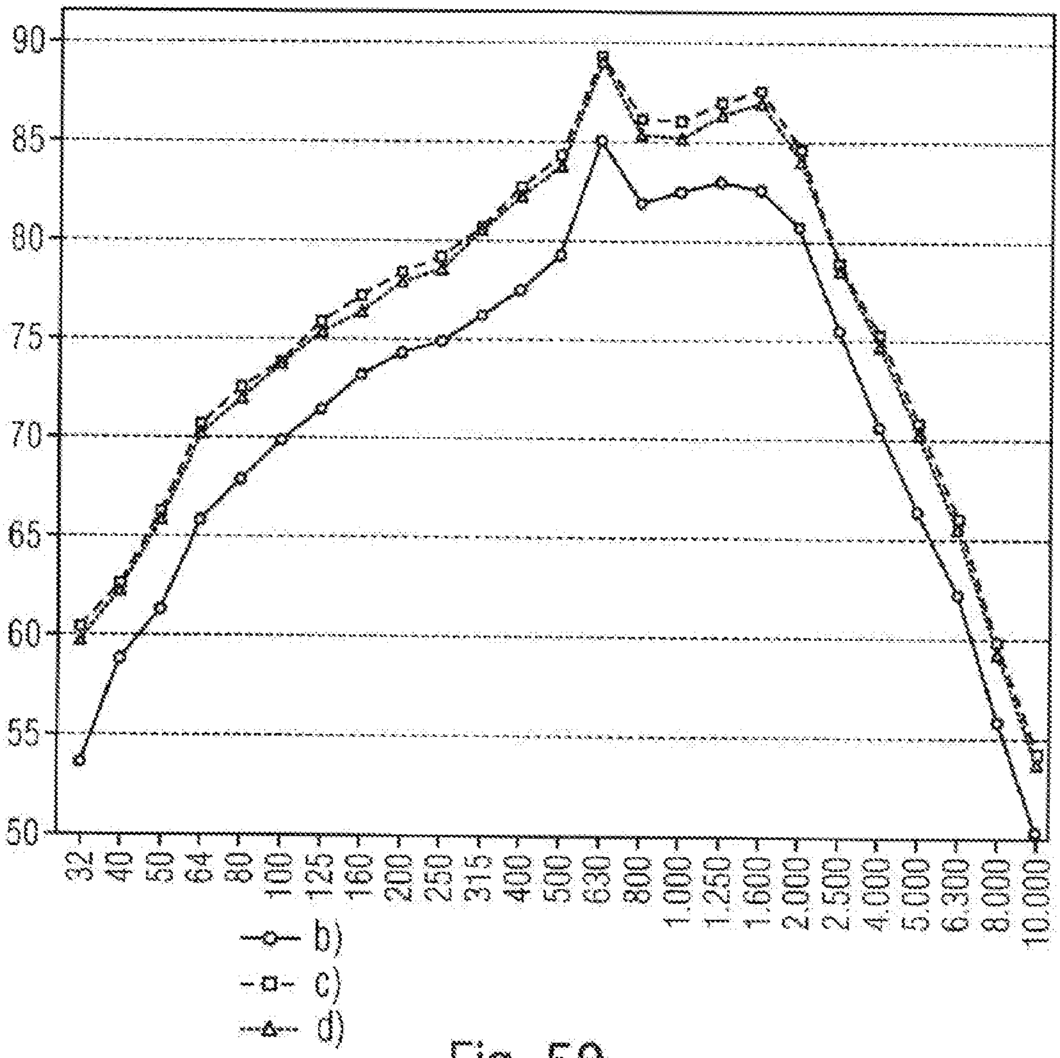
400
500
630
800
1.000
1.250
1.600
2.000
2.500
4.000
5.000
6.300
8.000
10.000
e)
a)
b)

Fig. 49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500
630
800
1.000
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4.000
5.000
6.300
8.000
10.000
b)
c)
d)

Fig. 50

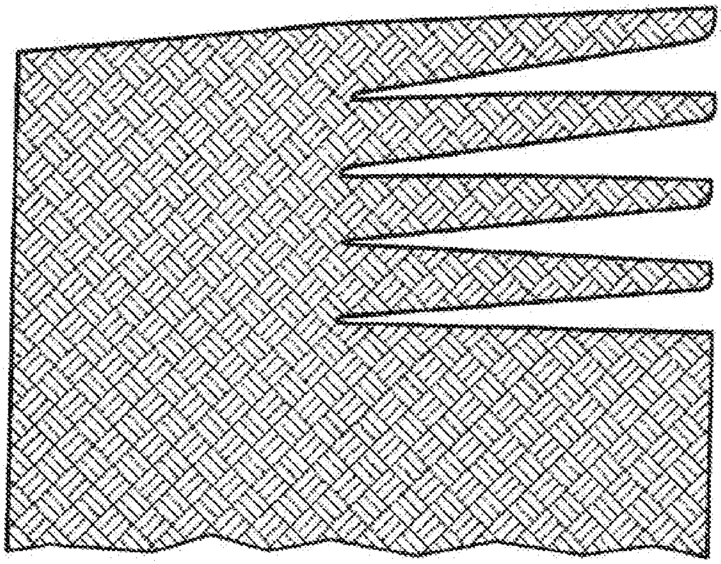


Fig. 51

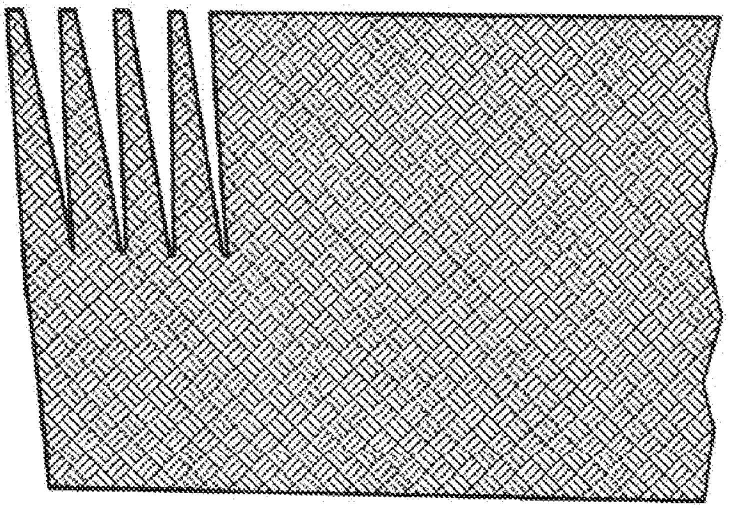


Fig. 52

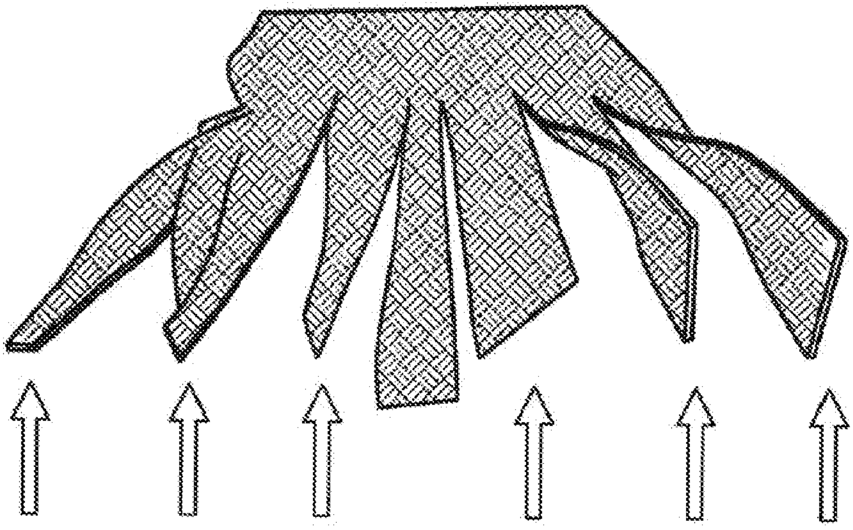


Fig. 53

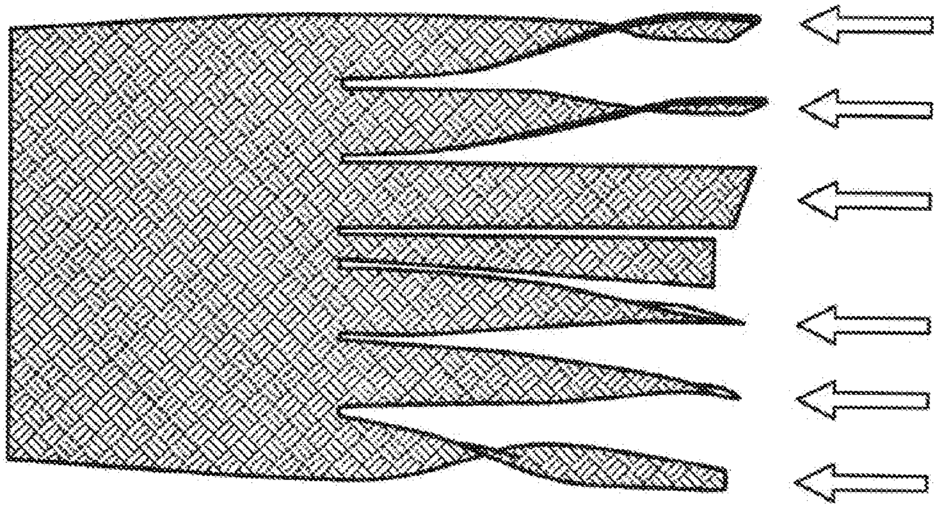


Fig. 54

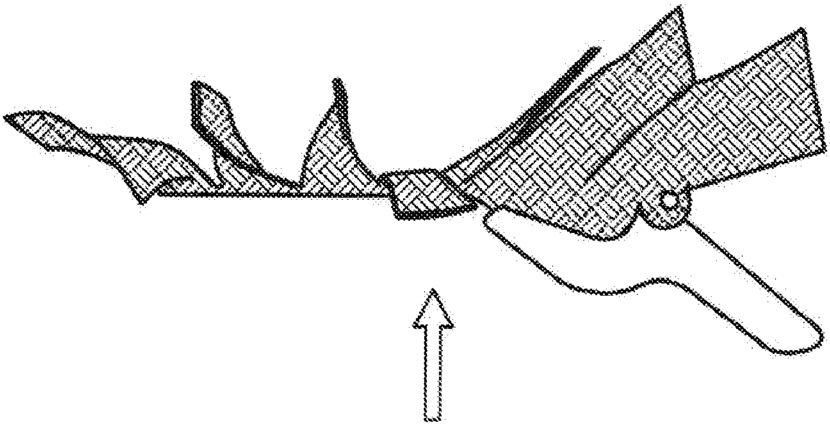


Fig. 55

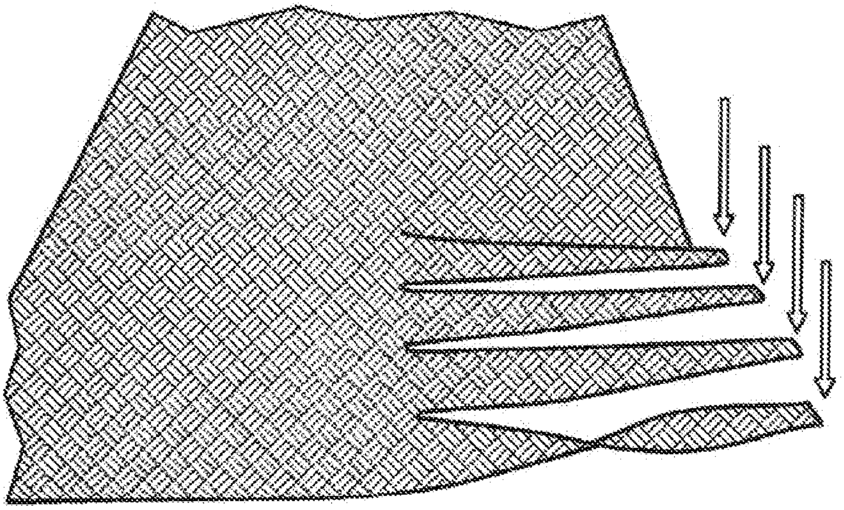


Fig. 56

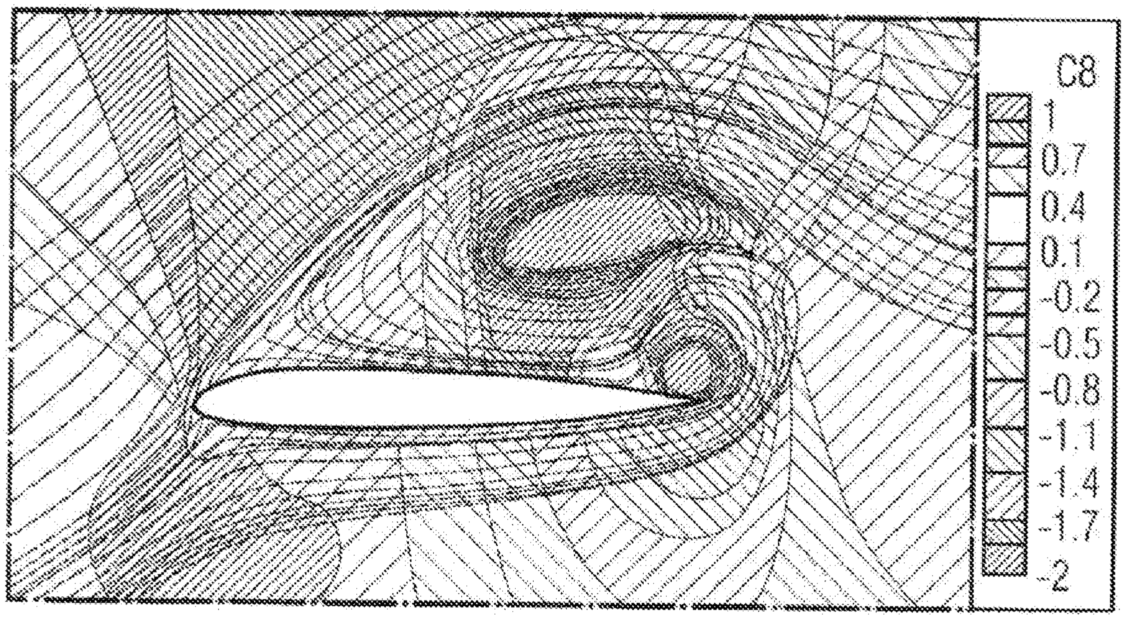


Fig. 57

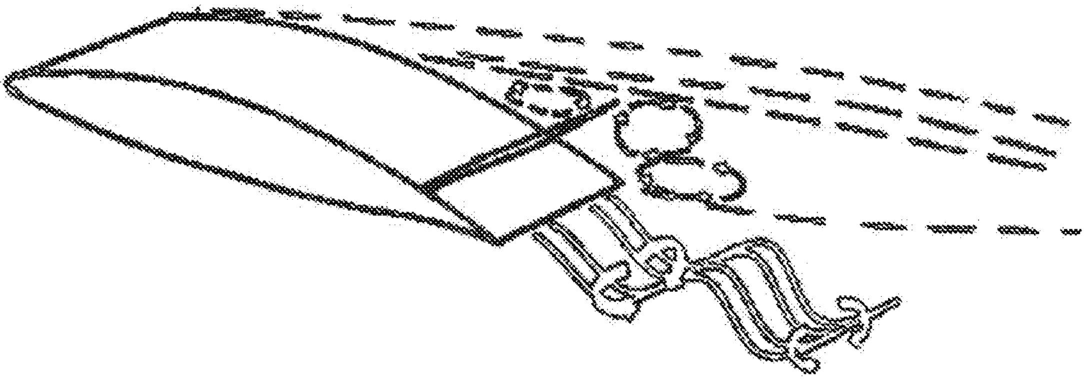
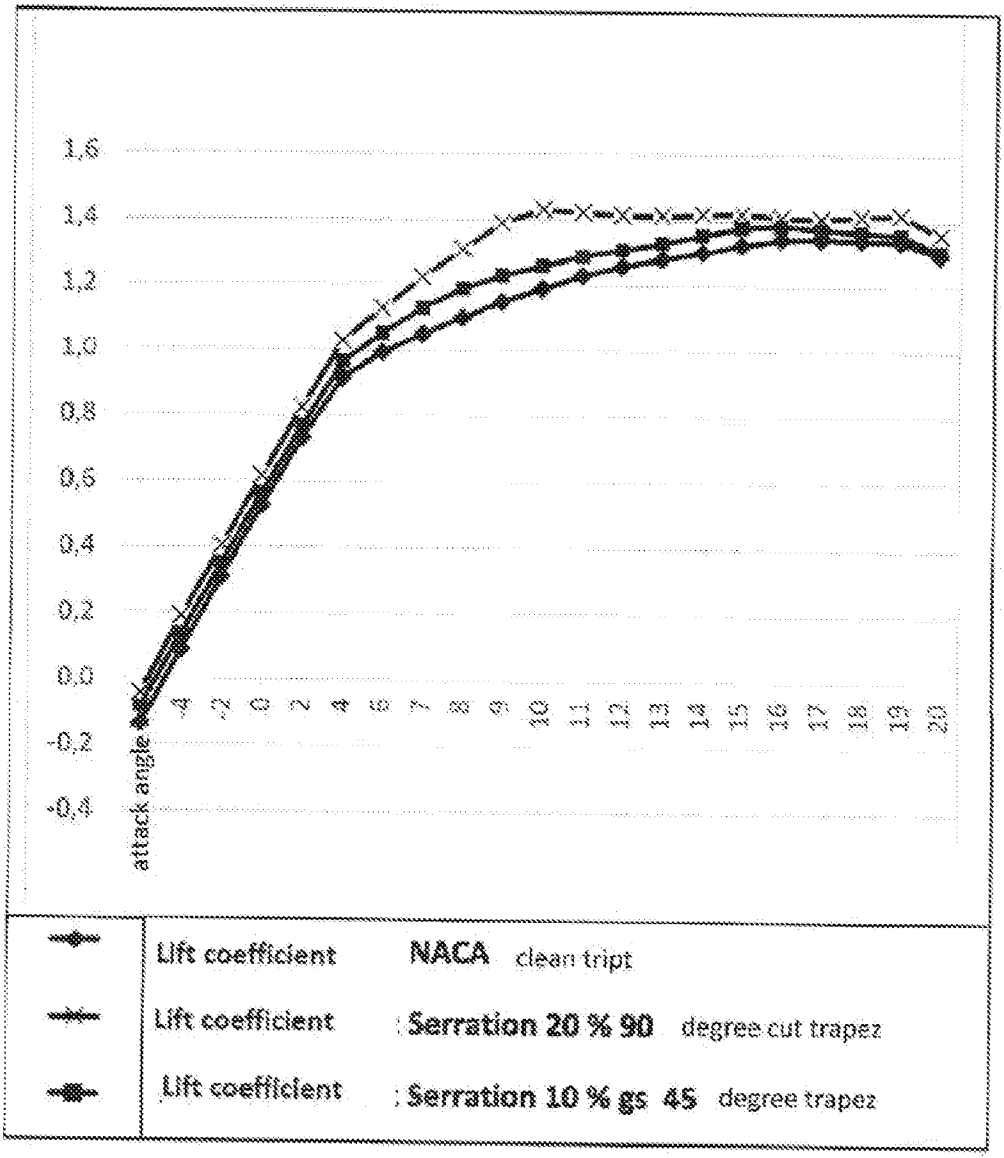


Fig. 58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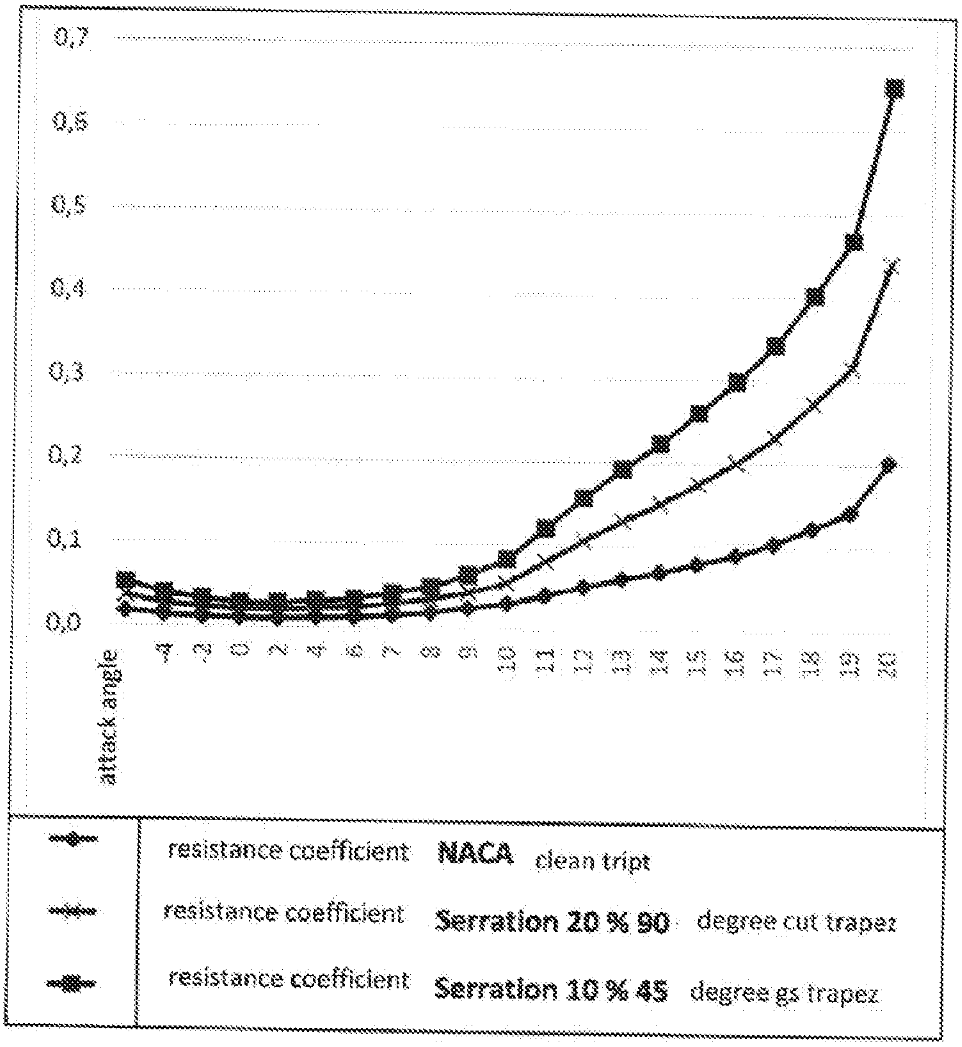
0,6
0,4
0,2
0,0
-0,2
-0,4
attack angle
-4
-2
0
2
4
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Lift coefficient NACA clean tript
Lift coefficient : Serration 20 % 90 degree cut trapez
Lift coefficient : Serration 10 % gs 45 degree trapez

Fig. 59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0,0
attack angle
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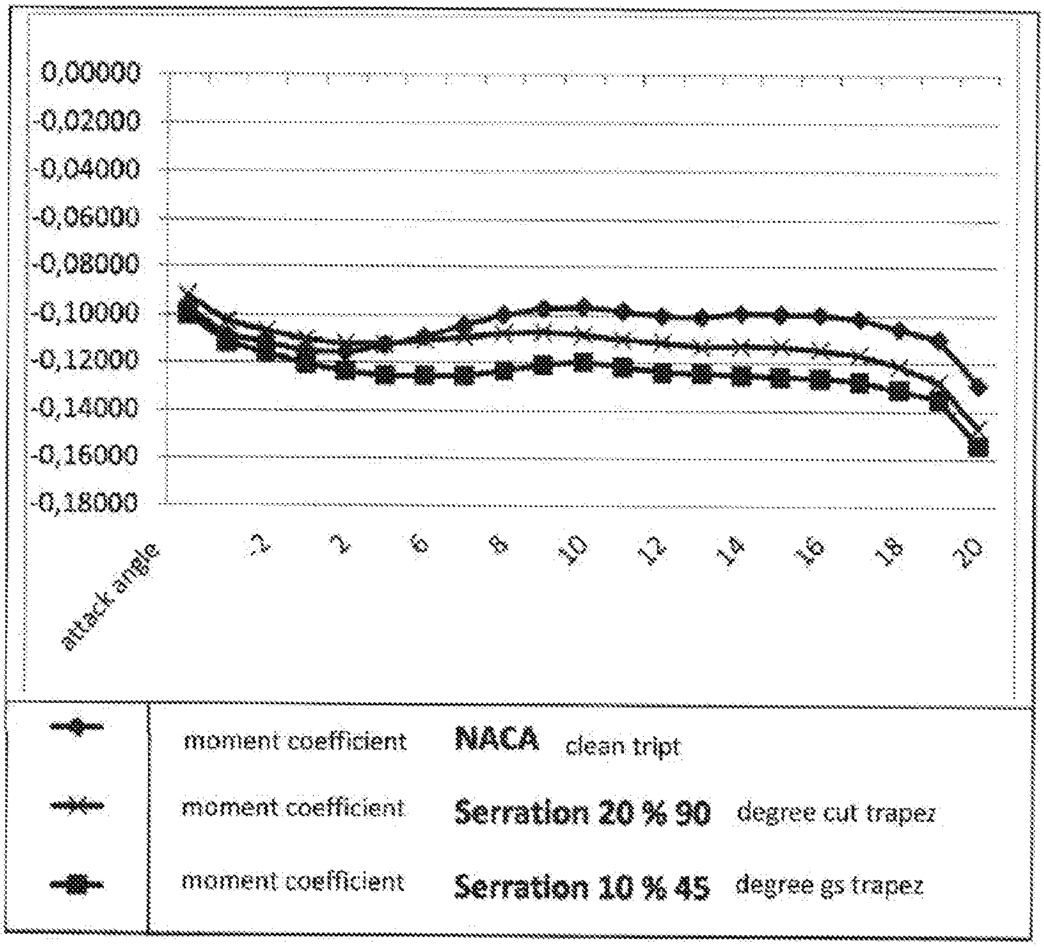
-2
0
2
4
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
resistance coefficient **NACA** clean tript
resistance coefficient **Serration 20 % 90** degree cut trapez
resistance coefficient **Serration 10 % 45** degree gs trapez

Fig. 60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attack angle
2
4
6
8
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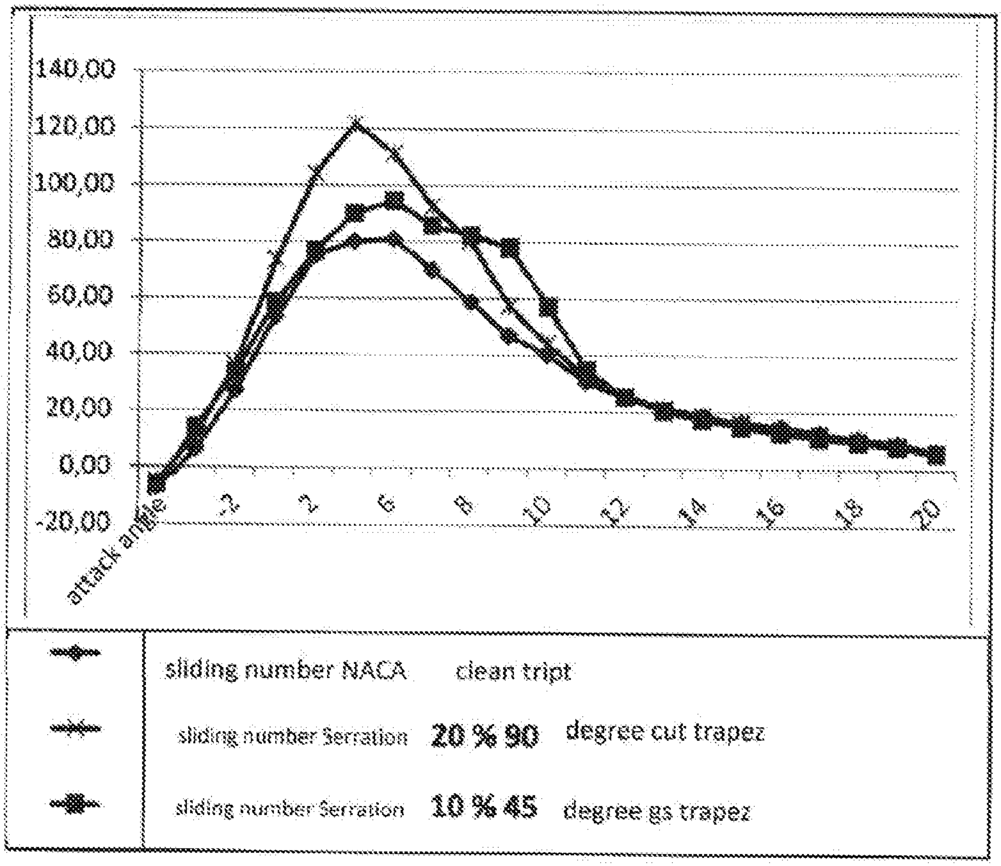
12
14
16
18
20
moment coefficient NACA clean tript
moment coefficient Serration 20 % 90 degree cut trapez
moment coefficient Serration 10 % 45 degree gs trapez

Fig. 61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attack angle
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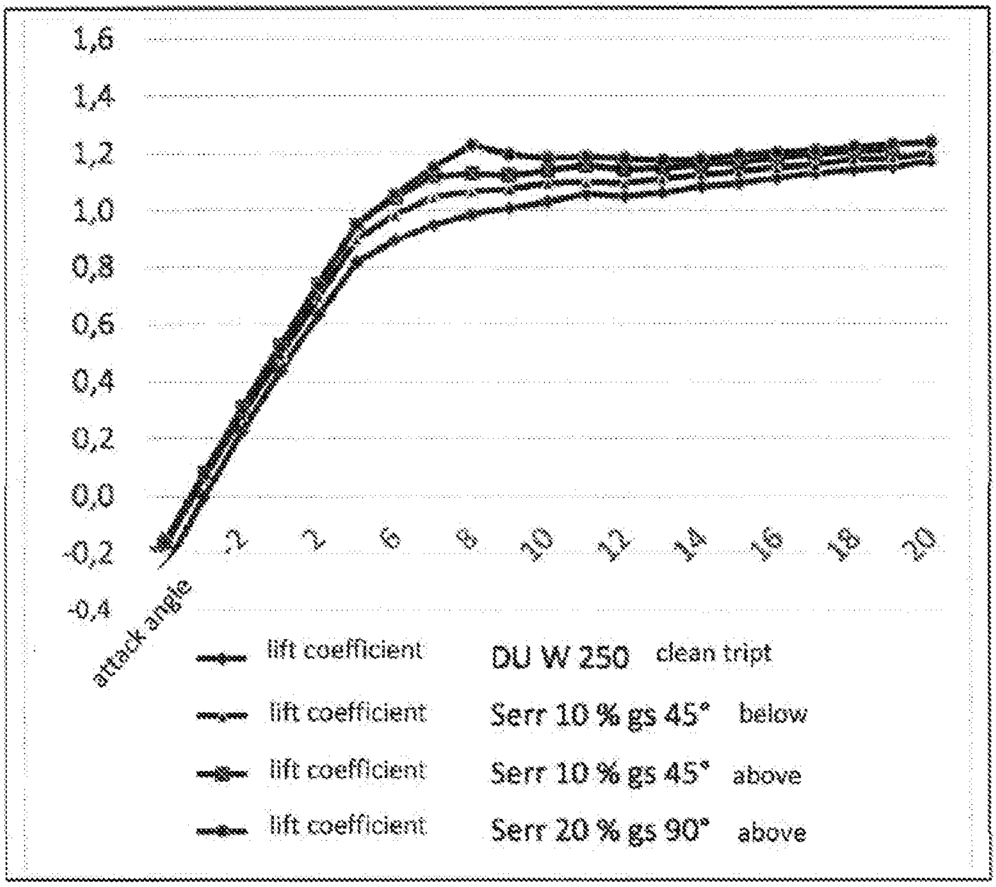
2
6
8
10
12
14
16
18
20
sliding number NACA clean tript
sliding number Serration 20 % 90 degree cut trapez
sliding number Serration 10 % 45 degree gs trapez

Fig. 62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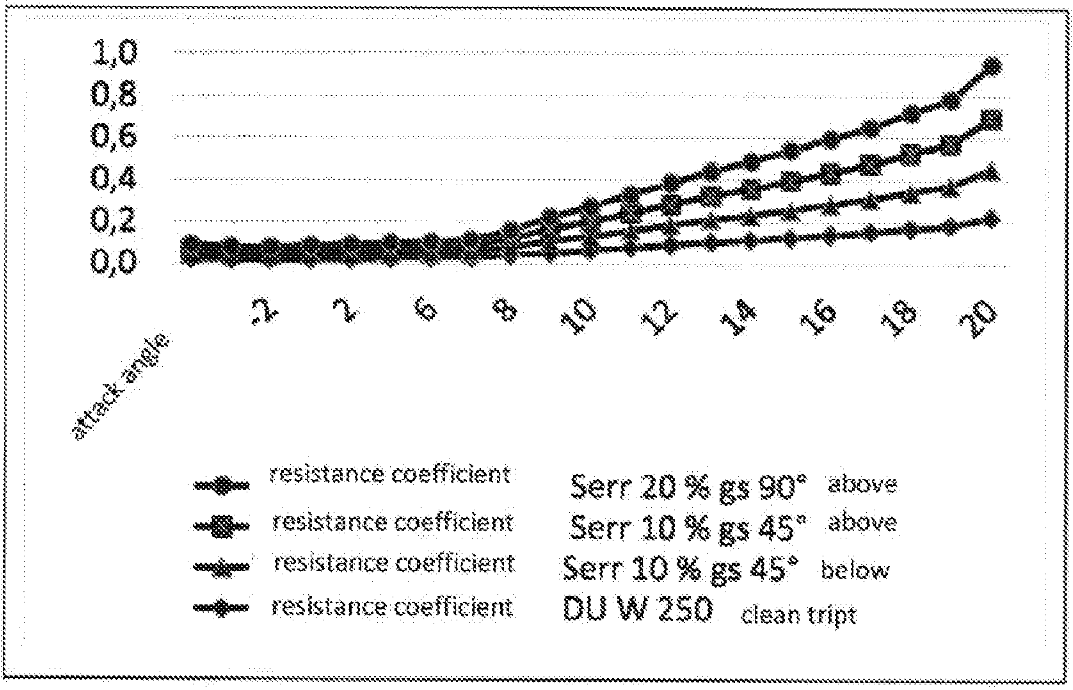
-0,4
attack angle
-2
2
6
8
10
12
14
16
18
20
lift coefficient DU W 250 clean tript
lift coefficient Serr 10 % gs 45° below
lift coefficient Serr 10 % gs 45° above
lift coefficient Serr 20 % gs 90° above

Fig. 63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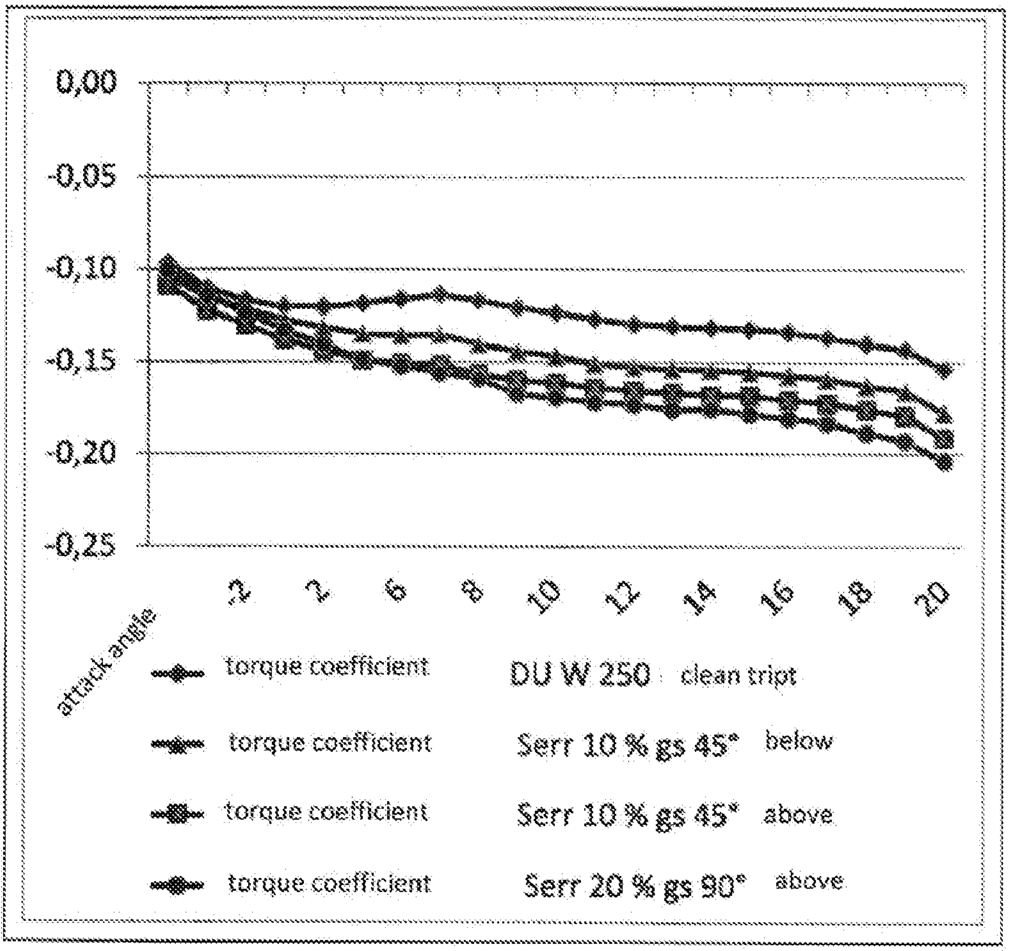
6
8
10
12
14
16
18
20
attack angle
resistance coefficient Serr 20 % gs 90° above
resistance coefficient Serr 10 % gs 45° above
resistance coefficient Serr 10 % gs 45° below
resistance coefficient DU W 250 clean tript

Fig. 64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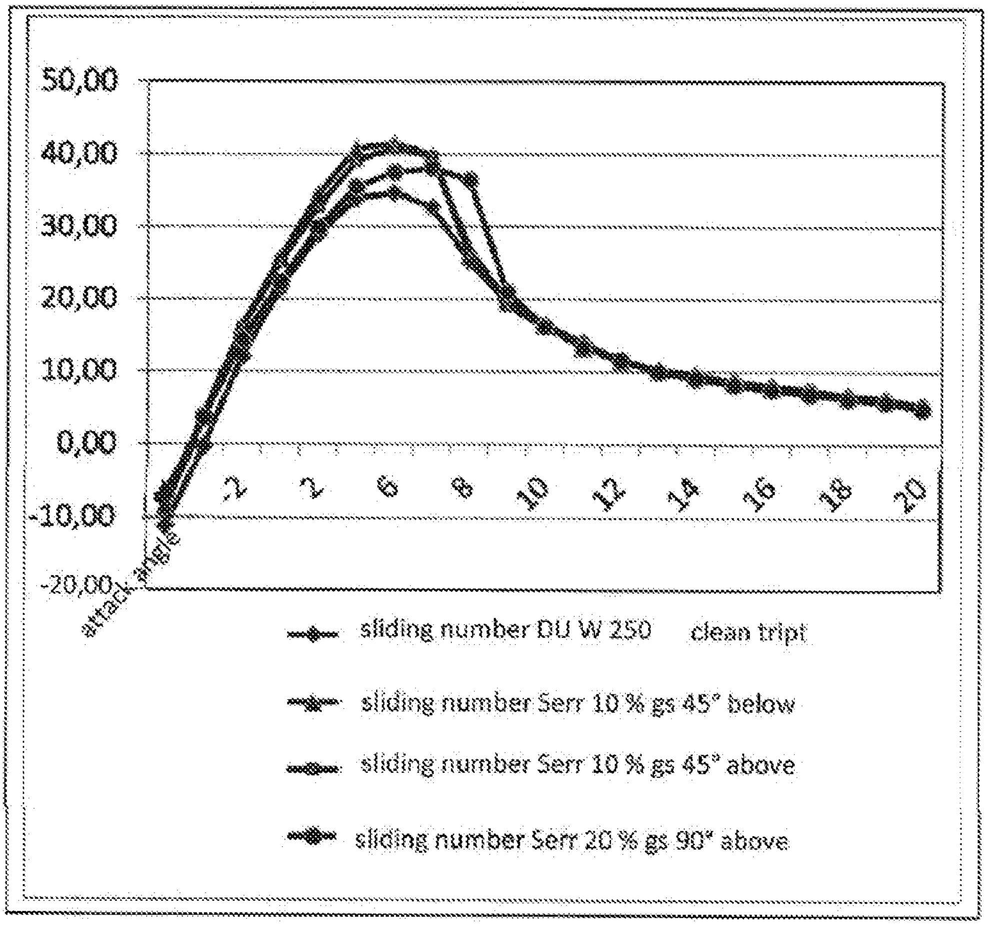
-0,25
-2
2
6
8
10
12
14
16
18
20
attack angle
torque coefficient DU W 250 clean tript
torque coefficient Serr 10 % gs 45° below
torque coefficient Serr 10 % gs 45° above
torque coefficient Serr 20 % gs 90° above

Fig. 65


50,00
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30,00
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0,00
-10,00
-20,00
attack angle
2
2
6
8
10
12
14
16
18
20
sliding number DU W 250 clean tript
sliding number Serr 10 % gs 45° below
sliding number Serr 10 % gs 45° above
sliding number Serr 20 % gs 90° above

Fig. 66

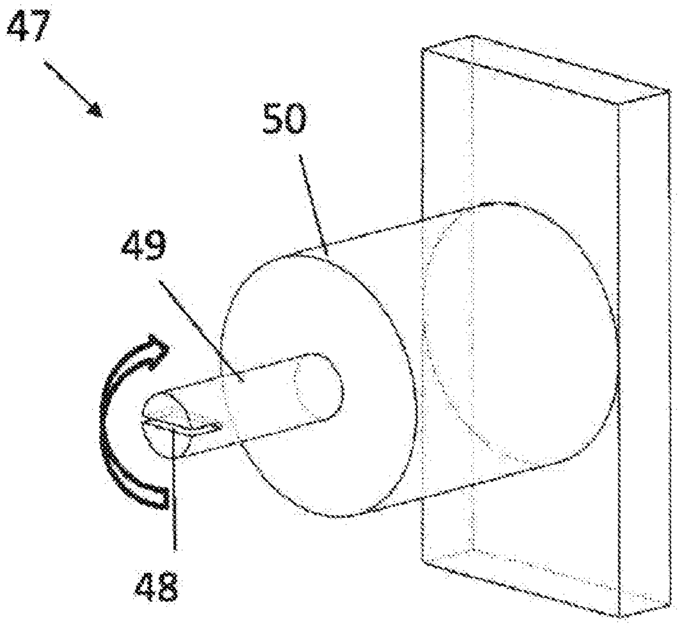

Fig. 67

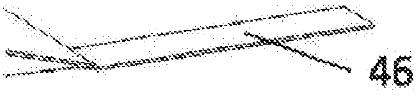

Fig. 68A

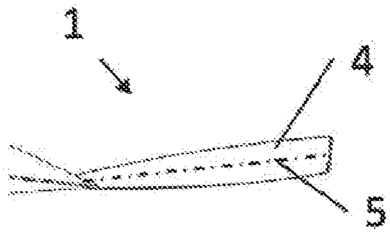

Fig. 68B