

A HYDROFOIL FOR WATER-BORNE VESSELS

The invention concerns a hydrofoil, in particular a rudder, for water-borne vessels, in particular ships, with a trailing edge.

In the current context hydrofoils are bodies that are used and/or installed in water-borne vessels, which generate lift in fluid mechanics terms. Examples of hydrofoils are rudders, keels, hydrofoil skids on hydrofoil boats, stabiliser fins or other fin-type bodies of water-borne vehicles. The hydrofoil in accordance with the invention is in particular suitable for use as a rudder, wherein use as one of the above-named bodies and/or another hydrofoil-type body is also readily possible.

Hydrofoils of known art normally have a leading edge that is assigned to a flow direction and/or aligned in the direction of travel of the water-borne vehicle, and a trailing edge that opposes the leading edge. Side faces or sidewalls of the hydrofoil are arranged between leading edge and trailing edge. The upper end region of the hydrofoil is normally securely connected with the hull of the waterborne vehicle, i.e. in the case of a rudder such that it can rotate, whereas the opposing lower end is normally designed as a free end. In the case of rudders, however, it is also of known art that these can also be supported at the lower end, (for example, in the case of rudders supported in the sole piece).

When in use on a water-borne vehicle water flows around the body of the hydrofoil from the leading edge to the trailing edge. Depending on the Reynolds number, on the flow velocity and the geometric shape of the hydrofoil or of the trailing edge of the hydrofoil, vortex separations can occur in the direction of flow behind the hydrofoil, i.e. at its trailing edge, the frequency of which is characterised by the Strouhal number. The vortices are usually generated on both sides of the body around which the fluid is flowing, their directions of rotation being opposed to one another.

The flow between them runs in the direction towards the body around which the fluid is flowing, opposed to that of the outer flow. This vortex system in the form of a wake of vortices of opposing directions of rotation, which forms on the body around which the fluid is flowing and is driven away and finally dissipated by the flow, is also known as what is called a Karman vortex street. This phenomenon occurs in particular in the case of rudders, since these are exposed to the relatively fast flow of a ship propeller. Moreover rudders that in particular have a relatively wide trailing edge tend to generate Karman vortex streets. These are in particular rudders with a fishtail profile or also a Schilling® profile, in which the end region of the rudder blade as viewed in the flow direction widens out towards the trailing edge, in particular in the form of a dovetail. In geometries of this kind the Strouhal number and thus the separation frequency of the individual vortices is particularly high, as a result of which Karman vortex streets can occur and/or are present in a particularly distinctive form.

Fig. 4 shows the formation of a Karman vortex street in the case of a hydrofoil 200 of known prior art. The hydrofoil 200 in Fig. 4 is a fishtail rudder, in which the cross-sectional profile widens out again towards the trailing edge 201. In the interests of clarity only the end region of the hydrofoil 200 is illustrated. The trailing edge 201 runs in a concave manner between the two end regions 2021a, 2021b of the side faces 202a, 202b. The pattern of the (propeller) flow is represented by a multiplicity of arrows. It can be discerned that the flow runs along the side faces 202a, 202b in an essentially laminar manner. When the flow passes the end regions 2021a, 2021b of the side faces 202a, 202b, vortices 210 separate from the flow in both the upper region of the trailing edge 201 and also in its lower region. In the upper region of the trailing edge 201, i.e. directly behind the end point 2021a of the side face, a vortex 210a has formed that is rotating in an anticlockwise direction. Obliquely underneath in the direction of flow a further vortex 210b is present that is rotating in the

opposite sense, i.e. in the clockwise direction; this has formed on the lower side face 202b, and/or directly behind it. Downstream a further vortex 210c is present that is rotating in an anticlockwise sense and slowly dissipating; this also originates from the upper side face 202a. The vortices 210a, 210b, 210c together form the vortex system of the so-called Karman vortex street. In the region of the vortices, i.e. between the vortices, the pressure is distinctly lowered compared with that of the flow around the Karman vortex street.

As a result of the formation of Karman vortex streets the efficiency of a hydrofoil is on the one hand reduced, i.e. in the case of rudders the rudder force is lowered. Also the drag of the hydrofoil, i.e. rudder, increases. On the other hand the side force of a rudder is diminished and it is possible for vibrations to occur on the hydrofoil. The latter is particularly the case if the separation frequency of the vortices essentially corresponds to the natural frequency of the hydrofoil body.

Embodiments of the present invention seek to specify a hydrofoil in which the negative effects of vortex formation in the direction of flow behind the hydrofoil, i.e. of the Karman vortex streets, are reduced.

According to a first aspect of the present invention, there is provided a hydrofoil, in particular a rudder, for water-borne vessels, in particular ships, with a trailing edge, wherein at least one rigid projecting body is arranged at the trailing edge for reducing vortex formation; and wherein the at least one projecting body comprises a "plate-shaped rib" projecting from the trailing edge.

According to a second aspect of the present invention, there is provided a water-borne vessel, in particular a ship, wherein it has a hydrofoil as defined in the first aspect.

The core idea according to embodiments of the invention is to provide a projecting body on the trailing edge by means of which vortex formation is reduced. A projecting body in the current context is a body of fundamentally any configuration that protrudes, i.e. projects, from the trailing edge of the hydrofoil. Since in a cross-sectional view the trailing edge normally runs essentially transverse to the longitudinal direction of the hydrofoil, the projecting body generally protrudes, at least approximately, in the downstream direction. This means that the at least one projecting body projects from the trailing edge

substantially in a longitudinal direction of the hydrofoil and/or in the longitudinal direction of the ship that the hydrofoil is attached to.

The trailing edge is normally a surface terminating the hydrofoil that can be of linear, concave, convex, or some other design. Hence, the area of the trailing edge is usually designed complanate or oblate. In particular, it usually does not taper and it is not designed pointed. Further, the trailing edge is usually designed continuous from top to bottom and/or from side to side and thus constitutes a single, continuous area. The projecting body now protrudes from this surface, which leads to the probability of the separation of a vortex being diminished. By this means the probability of the occurrence of a Karman vortex street can be reduced. The effectiveness of the at least one projecting body depends on various factors, for example the number of projecting bodies, the geometric configuration, as well as the exact arrangement.

In the case of the at least one projecting body we are therefore dealing with a body that does not belong to the trailing edge surface per se, but is arranged on the latter, and protrudes from the latter. In this sense therefore a projecting body is not a slight bulge from the trailing edge surface, e.g. a convex trailing edge or similar, but rather an essentially independent body, which, however, is advantageously to be connected securely with the trailing edge, i.e. with the trailing edge face. For this reason, the at least one projecting body is not molded from the (material of the) hydrofoil and also does not constitute a depression, indentation, recess, etc. in the hydrofoil. Accordingly the projecting body can, for example, be manufactured from metal, and in particular from steel, and can be connected with the trailing edge by means of welding, or other suitable methods and/or means of attachment. By means of the protrusion of a body from the trailing edge face the formation of pairs of contra-rotating vortices on the two sides of the hydrofoil, which is the prerequisite for the formation of a Karman vortex street, is in particular avoided. It is further

preferred that the at least one projecting body is designed as a rigid, non-flexible, non-elastic body. In this way the flow behaviour of the hydrofoil, in particular with regard to the creation of vortexes, mains constants.

By the provision of the at least one projecting body the probability of the occurrence of a Karman vortex street on a hydrofoil is reduced, and by this means the hydrofoil drag is improved, as is also the fuel efficiency. Moreover the risk of damage to the hydrofoil and/or the hull of the waterborne vessel as a result of vibrations is diminished. Since the at least one projecting body is arranged on the trailing edge, this also does not diminish the effective flow surface area of the hydrofoil, and since it is located outboard of the flow surface area and thus not within the main flow field, cannot trigger cavitation as a result of flow separation. Accordingly as a result of the provision of a flow body, by means of a relatively small amount of constructional effort and without any weakening of the cross-section of the actual hydrofoil in fluid mechanics terms, the advantageous effect of vortex formation reduction in the region of the trailing edge can be achieved. By means of the at least one projecting body in accordance with embodiments of the invention the process of vortex formation is impaired or prevented, as a result of which a very much more stable and/or laminar flow pattern occurs, as viewed behind the hydrofoil in the direction of flow. The at least one projecting body is in particular provided exclusively at the trailing edge and not in other areas of the hydrofoil.

With reference to the width of the trailing edge the at least one projecting body is advantageously designed such that it does not cover the whole width. Rather it projects advantageously from just a sub-region, with reference to the trailing edge width. This ensures that a blocking of the vortex flow is achieved. If the at least one projecting body were to cover the whole width of the trailing edge, in fluid mechanics terms the projecting body could act as a pure extension of the trailing edge, and the

undesirable contra-rotating vortices could separate from both sides of the projecting body.

In order to achieve as extensive a reduction of the vortex formation as possible, provision is made in a preferred form of embodiment of the invention that the at least one projecting body runs over at least 50% of the length of the trailing edge, preferably at least 75%, and in a particularly preferred embodiment essentially over the whole length of the trailing edge. By the term "length of the trailing edge" is to be understood in the current context the distance between the upper and lower ends of the hydrofoil in the region of the trailing edge. The trailing edge normally runs over the whole height of the hydrofoil. It is therefore advantageous that the at least one projecting body runs over as large a region of the trailing edge as possible, so that with reference to the height of the hydrofoil, vortex formation is reduced, i.e. impaired, as extensively as possible. It is particularly advantageous if the at least one projecting body runs from one end of the trailing edge to the other, since an impairment of vortex formation is thereby ensured over the whole height of the hydrofoil. Here the at least one projecting body can advantageously consist of a single body whose length corresponds to the length of the trailing edge, and which is attached to the trailing edge. In principle, however, it would also be possible for the at least one projecting body to be composed of a plurality of sub-bodies.

In principle the at least one projecting body can be designed to be of any form when viewed in cross-section. However, it is often advantageous if in a cross-sectional view of the hydrofoil the at least one projecting body runs essentially parallel to a centreline of the hydrofoil, or along the centreline. In this respect the at least one projecting body is preferably linear in cross-section. In corresponding tests it has been shown that by means of an alignment of the at least one projecting body of this kind a particularly good impairment of vortex formation, i.e. a particularly favourable flow

pattern, can be achieved. In particular when the at least one projecting body is arranged along the centreline a particularly regular impairment of vortex formation is achieved on both sides of the hydrofoil. If a plurality of projecting bodies is provided, all the projecting bodies are preferably designed to run parallel to the centreline. However, it is also possible for individual projecting bodies to deviate from this alignment. In particular this can be advisable in the case of a curved trailing edge, i.e. one that is of concave or convex design. In the present form of embodiment the flow line of the at least one projecting body in the cross-sectional view relates to the profile of the at least one projecting body between the trailing edge and its free end.

It is further preferred if the at least one projecting body runs essentially parallel to the longitudinal axis of the hydrofoil. Here the longitudinal axis is that axis that runs from the upper end of the hydrofoil to the lower end of the hydrofoil. In the case of rudders the longitudinal axis will often also be the axis of rudder rotation. The at least one projecting body can also run essentially parallel to the outside edges of the trailing edge. Here the outside edges of the trailing edge are also often aligned parallel to the longitudinal axis of the hydrofoil. In this manner a regular flow pattern ensues. In particular it is preferred if the at least one projecting body runs parallel to the longitudinal axis and over the whole length of the hydrofoil. By this means a particularly regular flow pattern ensues.

In a further preferred form of embodiment of the invention the at least one projecting body projects essentially at right-angles, i.e. orthogonally, from the surface of the trailing edge. Here the right angle is formed between the trailing edge and the axis along the width of the hydrofoil (transverse axis). If the trailing edge surface is plane, in the case of a plurality of projecting bodies the projecting bodies are arranged correspondingly parallel to one another. By this means the regularity of the flow in the direction of flow behind the hydrofoil is further improved. In case of arcuately shaped, non-

straight trailing edges the at least one projecting body can be arranged orthogonally with regard to the section of the trailing edge to which the at least one projecting body adjoins.

The width of the projecting body, i.e. its distance between the trailing edge and its free end, preferably corresponds to at least half the width of the trailing edge. Tests have shown that if the at least one projecting body is dimensioned in this manner particularly good results can be achieved with regard to the reduction of vortex formation.

If at least two projecting bodies are provided it is advantageous to arrange the two projecting bodies spaced apart from one another and/or running parallel to one another. As a result of the spaced apart arrangement of the at least two projecting bodies vortex formation is further hindered, since now two objects protruding independently of one another are blocking the vortex flow. The parallel alignment of the two projecting bodies improves in turn the regularity of the flow pattern.

In a further preferred form of embodiment the following formula applies: number of projecting bodies = $2n+1$, where "n" is a natural number, including 0. Particularly preferred is $n = 2$, i.e. the number of projecting bodies is 5. Furthermore in a cross-sectional view one of the projecting bodies is essentially centrally arranged on the trailing edge, and an even number of projecting bodies are arranged on each side of the centrally arranged projecting body. A symmetrical arrangement is particularly preferred, in which the centreline of the hydrofoil in the cross-sectional view forms the line of symmetry. The individual projecting bodies are advantageously arranged spaced apart from one another and/or running parallel to one another. Tests have shown that a design of this kind with an even and in particular a symmetrical distribution, in particular with 5 projecting bodies, achieves a particularly good effect with regard to the reduction of vortex formation. With this form of embodiment it is further

preferred that the centrally arranged projecting body has the largest width, i.e. the largest distance between trailing edge and free end. Optionally two projecting bodies of equal size can also be arranged in a central region. Moreover the width of the other projecting bodies can advantageously reduce progressively towards the outside, so that the projecting bodies located furthestmost outwards have the smallest width. Here too the design is advantageously of symmetrical provision, i.e. the pairs of projecting bodies arranged as mirror images in each case have the same width. By this means a gradual blocking of the vortex flow is achieved from the outside inwards.

If a plurality of projecting bodies are provided, the distances between the individual projecting bodies can in principle be designed to be the same or different. Which arrangement is most favourable in fluid mechanics terms depends on the circumstances of the individual case, in particular on the geometry and width of the trailing edge, the flow velocity, the exact design of the projecting bodies, etc.

The at least one projecting body is particularly preferably designed in the form of a plate, as a rib projecting from the trailing edge, and/or with a rectangular cross section. The rib consists advantageously of a plate, for example a steel plate or similar, one end face of which is attached to the trailing edge. If the plate is of elongated design, in particular running over a large part, or the whole, of the length of the trailing edge, the rib or plate is preferably to be arranged, i.e. attached, to the trailing edge with one longitudinal end face. With a design of this kind an arrangement of the rib in the form of a strip ensues. If a plurality of projecting bodies are provided it is advantageous to arrange these parallel to one another and parallel to the longitudinal axis of the hydrofoil. Instead of having the form of a plate the ribs could also be designed in their free end region slightly rounded off, or tapering down to their free end, or similar. The rib is preferably arranged

continuous and/or the rectangular cross-section of the at least one projecting body is constant for the entire projecting body.

The at least one projecting body is particularly advantageously provided for a hydrofoil designed as a fishtail rudder or Schilling® rudder, in which the profile in a cross-sectional view widens from a leading edge arranged opposed to the trailing edge in the direction of the trailing edge as far as a central region, which forms the widest point of the hydrofoil profile, tapers from the central region to a rear region which forms the narrowest point of the hydrofoil profile and widens once again from the rear region to the trailing edge, in particular in the form of a dovetail, where the trailing edge is preferably of linear, convex, or concave design. Because of the relative width of the trailing edge compared with other hydrofoil profiles vortex formations occur particularly frequently on the hydrofoil profiles described above. In this respect the provision of the at least one projecting body is particularly advantageous for profiles of this kind.

Further, the at least one projecting body is preferably formed as a monolithic body. That means the at least one projecting body does not comprise through holes, recesses or the like. Also, the at least one projecting body has preferably a constant cross-section.

In what follows the invention is elucidated in more detail in the drawing with the aid of various examples of embodiment. In the schematic figures:

- Fig. 1 shows a perspective view of a hydrofoil with a trailing edge and projecting bodies,
- Fig. 1A shows a detail view of the upper end region of the trailing edge of the hydrofoil from Fig. 1;
- Figs. 2A – 2E show plan views of end regions of hydrofoils with variously designed trailing edges and variously arranged, or designed, projecting body/bodies,

- Fig. 3 shows a plan view onto the end region of a hydrofoil with projecting bodies projecting from the trailing edge with a flow pattern plotted, and
- Fig. 4 shows an end region of a hydrofoil from the prior art with a flow pattern plotted.

In the various forms of embodiment of the invention described in what follows the same components are provided with the same reference symbols.

Fig. 1 shows a perspective view of a hydrofoil 100. In the present case the hydrofoil 100 is formed by a rudder with a fishtail profile or Schilling® profile. The rudder comprises a leading edge 10 and a trailing edge 20. The side face 11 runs between leading edge 10 and trailing edge 20. An end plate 14 is provided in each case at both the upper end 12 and also at the lower end 13 of the hydrofoil 100. Since the present hydrofoil 100 takes the form of a rudder with a fishtail profile, the end region 15 of the rudder widens out from a rear region 16 forming the narrowest point of the rudder towards the trailing edge 20. At the trailing edge 20 are provided a total of five projecting bodies 30 designed as plate-shaped ribs, which in each case run from the upper end 12 down to the lower end 13 and are arranged parallel to one another.

As can be discerned from the detail view in Fig. 1A the central rib 30a has the largest width. On either side of the central rib 30a two further ribs 30b, 30c are arranged in each case, where the width of these ribs decreases outwards. The plate-shaped ribs 30a, 30b, 30c are attached with their longitudinal end faces to the trailing edge 20, which is of linear design, i.e. has a plane surface. Also the transverse end faces of the ribs 30a, 30b, 30c abut against the end plates 14, and are likewise attached to these. The outer ribs 30c have the shortest width and are just slightly displaced inwards relative to the outside edge 21 of the trailing edge 20. The plate-

shaped ribs 30a, 30b, 30c protrude in each case essentially at right-angles from the trailing edge surface, and run parallel to the outside edge 21 of the trailing edge 20, i.e. to the longitudinal axis of the hydrofoil 100.

Fig. 2A shows a plan view onto the end region 15 of the hydrofoil from Fig. 1. It can be discerned that the central rib 30a has the largest width b_1 and the outer ribs 30c have the smallest width b_3 , while the ribs 30b arranged between the ribs 30a and 30c have a medium width b_2 . Furthermore the distances between the ribs 30c and 30b (a_2) and the ribs 30b and 30a (a_1) differ, the distance a_1 being larger than a_2 . The exact dimensions of the widths and distances can in each case be matched to an optimal vortex reduction effect in relation to the particular geometry of the trailing edge and the ribs 30. The rib 30a runs along the centreline 17, while the ribs 30b and 30c run parallel to the centreline 17. The centreline 17 also forms the axis of symmetry for the rib arrangement.

Figs. 2B to 2E show further examples of configurations of the end region 15 of hydrofoils 100 in accordance with the invention. Thus in Fig. 2B a central rib 30a is provided, arranged along the centreline 17. In addition two further ribs 30c are provided, each arranged in an outer location and designed to be of equal width. The ribs 30c are symmetrically arranged with reference to the centreline 17. In the three-ribs design of Fig. 2B the trailing edge 20 in a plan view or cross-sectional view is of concave design. In Fig. 2C the trailing edge in contrast is of linear design, i.e. the trailing edge forms a plane surface. Furthermore only a single rib 30a is provided, which is arranged along the centreline 17. In Fig. 2D the trailing edge 20 in a plan view or cross-sectional view is of concave design, in a similar manner to Fig. 2B. Likewise one central rib 30a is provided, which runs along the centreline 17, and also two outer-lying ribs 30c. In contrast to Fig. 2B, in which all three ribs are aligned in parallel, as in Fig. 2A, the two outer ribs 30c are not designed parallel to the centreline 17, i.e. to the central rib 30a, but run at an angle towards the latter. In particular they run

in the direction away from the trailing edge from the outside inwards. In Fig. 2E five ribs are likewise provided, where the trailing edge 20 in a plan view or cross-sectional view is of convex design. The central rib 30a, which once again has the largest width, runs along the centreline 17. The two outer ribs 30c have the smallest width. The ribs 30b, 30c arranged in each case to right and left of the centreline 17, are arranged symmetrically to one another with respect to the centreline 17. Contrary to the illustration in Fig. 2A the ribs 30b and 30c are not arranged parallel to the centreline 17, i.e. to the rib 30a, but rather protrude in each case at an angle of approx. 90° from the convex shape of the trailing edge 20, so that as viewed from the trailing edge towards the free ends of the ribs 30a, 30b, 30c an arrangement is formed in which the ribs fan outwards. All the ribs 30a, 30b, 30c shown in Figs. 2A to 2E are designed as plates.

Fig. 3 shows a plan view onto an end region 15 of a hydrofoil 100 in accordance with the invention. In a plan view or cross-sectional view the trailing edge 20 is of linear design. The five ribs 30a, 30b, 30c protruding from the trailing edge 20 are essentially arranged and designed in accordance with the arrangement in Fig. 2A, where in the representation shown in Fig. 3, which differs from that of Fig. 2A, the distance between the ribs 30c and 30b is larger than that between the ribs 30b and 30a. The flow pattern is represented by the multiplicity of arrows plotted. Thus with the hydrofoil design in accordance with the invention an essentially laminar flow pattern is established in the region of the sidewalls 11 downstream from the hydrofoil 100. Between the upper rib 30b and the central rib 30a a vortex 40 is forming; this is rotating in an anticlockwise sense. Moreover it can be discerned how vortex formation cannot take place in the intermediate spaces between the individual ribs because of the blocking action caused by the ribs 30a, 30b, 30c. In the direction of flow a laminar flow pattern is already being established over the whole width of the hydrofoil 100 a short distance behind the vortex 40. Furthermore only a single vortex 40 is produced and thus the formation of

a Karman vortex street, in each case formed by pairs of vortices rotating in opposite directions, is suppressed.

Reference symbol list

100	Hydrofoil
10	Leading edge
11	Side face
12	Upper end
13	Lower end
14	End plate
15	End region
16	Rear region
17	Centreline
20	Trailing edge
21	Outside edge
200	Hydrofoil (prior art)
201	Trailing edge
202a, 202b	Side faces
2021a, 2021b	Side face end points
210	Vortex
30	Projecting body
40	Vortex

CLAIMS

1. A hydrofoil, in particular a rudder, for water-borne vessels, in particular ships, with a trailing edge,
wherein at least one rigid projecting body is arranged at the trailing edge for reducing vortex formation; and wherein the at least one projecting body comprises a "plate-shaped rib" projecting from the trailing edge.
2. The hydrofoil according to Claim 1,
wherein the at least one projecting body extends over at least 50% of the length of the trailing edge, preferably over at least 75%, particularly preferably essentially over the whole length of the trailing edge.
3. The hydrofoil according to Claim 1 or 2,
wherein in a cross-sectional view of the hydrofoil the at least one projecting body extends essentially parallel to a centreline of the hydrofoil, or along the centreline.
4. The hydrofoil according to one of the preceding claims,
wherein the at least one projecting body extends essentially parallel to the longitudinal axis of the hydrofoil.
5. The hydrofoil according to one of the preceding claims,
wherein the at least one projecting body projects essentially orthogonally from the surface of the trailing edge.
6. The hydrofoil according to one of the preceding claims,
wherein the width of the projecting body corresponds to at least half the width of the trailing edge.

7. The hydrofoil according to one of the preceding claims, wherein at least two projecting bodies are provided, and wherein the projecting bodies are arranged spaced apart from one another and/or extending parallel to one another.
8. The hydrofoil according to one of the preceding claims, wherein the number of projecting bodies is $2n+1$, in particular 5, and in a cross-sectional view one projecting body is arranged essentially centrally on the trailing edge and an even number of projecting bodies are arranged on either side of the centrally arranged projecting body, in particular symmetrically.
9. The hydrofoil according to Claim 8, wherein the centrally arranged projecting body has the largest width and optionally the width of the other projecting bodies reduces progressively towards the outside.
10. The hydrofoil according to one of the preceding claims, wherein a number of projecting bodies are provided, and wherein the distances between the individual projecting bodies are the same or different.
11. The hydrofoil according to one of the preceding claims, wherein the profile of the hydrofoil widens in a cross-sectional view from a leading edge arranged opposed to the trailing edge in the direction towards the trailing edge

to a central region, which forms the widest point of the hydrofoil profile, the profile tapers from the central region to a rear region which forms the narrowest point of the hydrofoil profile, and the profile widens again from the rear region to the trailing edge, in particular in the form of a dovetail.

12. The hydrofoil according to Claim 11,
wherein the trailing edge is of linear, convex, or concave design.
13. A water-borne vessel, in particular a ship,
wherein it has a hydrofoil according to one of the preceding claims.