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(54) **WINGSAIL STRUCTURE FOR WIND-ASSISTED PROPULSION OF A MARINE VESSEL**

(57) The present invention relates to a wingsail structure (100) for wind-assisted propulsion of a marine vessel (1), comprising a wingsail frame (101) and a foundation (20). The wingsail frame (101) is rotatably connected via a first longitudinal axis of rotation (111) to the foundation (20) and comprises a main wingsail (110) and an aft flap (120), each having an airfoil shape and comprising rigid or semi-rigid sidewalls and comprising a main wingsail supporting frame (310) and a flap supporting frame (320), each of them extending longitudinally along the respective main wingsail (110) and aft flap (120). At least one coupling member connects the main wingsail and the flap. The flap is arranged rotatable around a second longitudinal axis of rotation (112) to bring the flap (120) to an inclined position in respect of the main wingsail. The second axis of rotation (112) is located in a cross-sectional view within an area defined by the sidewalls (221, 222) of the flap (120) and outside the periphery of the supporting frame (320) of the flap.

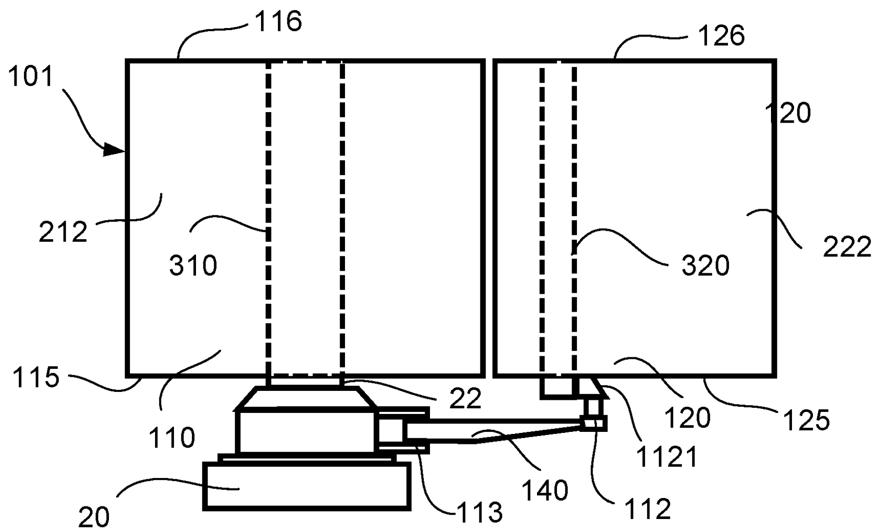

Fig. 5

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Description

TECHNICAL FIELD

[0001] The present disclosure relates to a wingsail structure for a wind-assisted propulsion arrangement of a marine vessel as defined in the appended claims.

BACKGROUND

[0002] Sails have been known for a long time as means of propulsion of ships. Traditionally, flexible sails have been mounted on masts to harness the power of wind and propel the ship. The modern merchant vessels commonly use fossil fuels and combustion engines to propel the vessel. Use of wind propulsion has been suggested to reduce the overall consumption of fossil fuels. For this purpose, rigid sails can be used. The amount of power being generated is related to many interlinked factors, but wing area and other geometric aerodynamic characteristics are primary performance indicators. A possible geometric setup can be achieved by combining a main wing with a flap that can generate a large propulsive force given the wing size, compared to a wing without a flap. High efficiency wingsail arrangement and structure that can generate a large amount of propulsive force given its absolute size can be obtained for example by adjusting a camber formed by the main wingsail and the flap. When aerodynamic propulsive force from the wingsails is not desired or the force should be limited, the vessel stability, vessel safety and operability should be taken into consideration. This adds complexity and challenges in using rigid wingsails as ship propulsors. In addition to this, the vessel performance is related to the prevailing wind strengths and directions. Due to the statistical distribution of for example wind strength, during the majority of time the wind speed is fairly moderate. Therefore, the wing characteristics should be configured so that the wingsail can utilize low wind speeds and at the same time be able to cope with more rarely occurring high wind speeds in a safe manner.

[0003] The use of rigid sails has been discussed in the prior art. For example, US10906620B2 discloses a reefable double airfoil, having shape members for the respective fore and aft flap, which are traversed by a fore mast while being able to turn around an axis defined thereby. Even though reefing solutions exist, there is still room for improvements.

SUMMARY OF THE INVENTION

[0004] In context of the present invention, it has been noted that reefing of large rigid or semi-rigid wingsails is demanding. It has been realized that there is a problem in finding a suitable way or reefing and stowing the wingsails when they are not used onboard of a marine vessel, due to a height and large total area of such rigid wingsails.

[0005] In view of the problem above, it is an aim with the present invention to facilitate the reefing of rigid wingsails. A wind-assisted propulsion arrangement of the present disclosure at least partially solves the problems with the known solutions.

[0006] It is thus an objective of the present invention to provide a wingsail structure, which can be reefed in a robust manner. Further, it is objective to provide a wingsail structure which can be stowed in a neutral non-propulsive position in a robust and space-saving manner. It is further an objective to facilitate maintenance and service of the wingsail structures.

[0007] The above objectives are attained by the present invention as defined in the appended independent claims.

[0008] According to a first aspect of the invention, the present invention relates to a wingsail structure for a wind-assisted propulsion arrangement of a marine vessel and comprises a wingsail frame, which is rotatably connected via a first longitudinal axis of rotation to the foundation. The wingsail frame comprises:

- a main wingsail and an aft flap, each having an airfoil shape and comprising rigid or semi-rigid sidewalls extending between a top end and a bottom end and having a leading edge and a trailing edge,
- a main wingsail supporting frame and a flap supporting frame, each of them extending longitudinally along the respective main wingsail and flap,
- at least one coupling member connecting the main wingsail and the flap, wherein

[0009] The flap is arranged rotatable around a second longitudinal axis of rotation to bring the flap to an inclined position in respect of the main wingsail. The second axis of rotation is located in a cross-sectional view within an area defined by the sidewalls of the flap and outside the periphery of the supporting frame of the flap.

[0010] By the present construction, it is possible to bring the flap in proximity of the main wingsail when the flap is folded towards the main wingsail.

[0011] The at least one coupling member may be connected to the second axis of rotation. This way, the structure will be robust and simple.

[0012] The second axis of rotation may be connected to the flap supporting frame via a connecting member. In this way a compact and robust flap construction can be provided.

[0013] The second axis of rotation may be located between the flap supporting frame and the trailing edge of the flap in a cross-sectional view. In this way, the flap may be folded to proximity of the main wingsail.

[0014] The flap may be further arranged rotatable around a third axis of rotation arranged to bring the flap to an inclined, folded and/or parallel position in respect of the main wingsail. The third axis of rotation may be located in a cross-sectional view within an area defined by the sidewalls of the main wingsail. This may provide for structural robustness.

[0015] The third axis of rotation may be connected to the at least one coupling member, thus leading into a more compact and robust construction. Further, the third axis of rotation may be located between the supporting frame of the main wingsail and the trailing edge of the main wingsail in a cross-sectional view. This provides for further flexibility of the structure during folding of the flap towards the main wingsail.

[0016] The main wingsail may have a main wingsail centerline and the flap may have a flap centerline, which centerlines extend in a cross-sectional view between the respective leading edges and trailing edges. Thus, the main wingsail and the flap may have a symmetrical shape in respect of the respective centerline. However, the leading edge may have a different shape compared to the trailing edge, as is common in airfoil shapes.

[0017] The second axis of rotation may coincide with the flap centerline in a cross-sectional view. In this way forces affecting the flap during the rotation can be equally divided.

[0018] Further, the third axis of rotation may be located along the main wingsail centerline in a cross-sectional view. In this way forces affecting the main wingsail during the rotation of the flap can be equally divided.

[0019] The flap may be configured to be inclined:

- from/to a neutral position, in which the flap centerline is aligned with the main wingsail centerline,
- from/to a propulsive position, in which the flap centerline is inclined in respect to the main wingsail centerline, and/or
- from/to a folded non-propulsive position, in which one sidewall of the flap faces one sidewall of the main wingsail.

[0020] Thereby, the inclination and folding of the flap can be used to decrease the area of the wingsail frame, thereby providing a controllable reefing of the wingsail frame or structure.

[0021] The at least one coupling member may be a lower coupling member, and thereby be close to the foundation. The wingsail frame may further comprise an upper coupling member. The upper coupling member may have a similar construction, although mirror-imaged as the lower coupling member, whereby a further more robust construction for the wingsail frame may be provided.

[0022] Each of the main wingsail and flap supporting frames may have a hollow structure and is located inside the respective main wingsail and the flap. Each of them may be further connected to an inner surface of the side wall of the respective main wingsail and the flap. Thereby, robust support for the main wingsail and the flap is provided.

[0023] The wingsail structure may further comprise a tilting arrangement configured to bring the wingsail frame from a standing position to a tilted position in respect of the foundation. The wingsail frame may thus be stored in the tilted position when no propulsive forces are provided. Thus, a complete reefing of the structure is possible. In the tilted position, the wingsail provides substantially no propulsive forces, which may be required for example when the vessel is in harbor or in case of heavy wind.

[0024] To further improve the robustness of the structure, the wingsail frame may comprise at least one intermediate coupling member located along the longitudinal extension of the main wingsail and the flap between the upper and lower ends of the respective main wingsail and flap. The intermediate coupling member connects the main wingsail and flap.

[0025] The invention also relates to a wind-assisted propulsion arrangement comprising at least one wingsail structure as described above.

[0026] Further, the invention relates to a marine vessel comprising the wind-assisted propulsion arrangement.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027] Further features and advantages of the present invention will be described with reference to the appended drawings in which:

Fig. 1 illustrates a marine vessel comprising a wind-assisted propulsion arrangement in a standing propulsive position in a perspective view.

Fig. 2 illustrates the marine vessel of Fig. 1 in which the wind-assisted propulsion arrangement is in a folded standing position in a perspective view.

Fig. 3 illustrates the marine vessel of Fig. 1 in which the wind-assisted propulsion arrangement is in a folded and tilted in a horizontal position in a perspective view.

Fig. 4 illustrates the marine vessel of Fig. 1 in which the wind-assisted propulsion arrangement is in a folded and tilted in a vertical position in a perspective view.

Fig. 5 illustrates an embodiment of the wingsail structure of the present invention in a partially cut schematical side view.

Fig. 6 illustrates a view from above of the embodiment of Fig. 5 in a propulsive position, in which the main wingsail and flap form a camber.

Fig. 7a illustrates the embodiment of Fig. 5 from above with the flap inclined in respect of the main wingsail to form camber.

Fig. 7b illustrates the embodiment of Fig. 5 from above in a folded position, in which the flap is inclined through a left curve towards the sidewall on the right-hand side in respect of the leading edge of the main wingsail.

Fig. 7c illustrates the embodiment of Fig. 5 from above in a folded position, in which the flap is folded towards the main wingsail in a substantially parallel manner.

DETAILED DESCRIPTION

[0028] To utilize wind as power for ship propulsion, the wingsails are formed so that they can in itself or together with an engine of the vessel generate sufficient propulsive forces to overcome the ship resistance forces. In this application, a wingsail is generally defined as a rigid or semi-rigid structure having an airfoil shape. The wingsail may be similar to an aircraft wing, and which can be fixed vertically on a marine vessel to provide propulsive force from the action of the wind. When such rigid wingsails are or cannot be used due to for example rough weather, limitation in height in the chosen route or during cargo operation, safety aspects should be ensured.

[0029] According to the present invention, a double wingsail configuration, herein referred to as a wingsail frame, comprising a main wingsail and a flap is provided. The wingsail structure comprises the wingsail frame and a foundation. One or more wingsail structures can be used in a marine, or maritime vessel used as a means of transportation on water. The main wingsail and the flap have walls of a rigid or semi-rigid material and have an aerofoil shape. Both the main wingsail and the flap have sidewalls, a leading edge and a trailing edge and a top end and a bottom end. By "rigid" material is meant a material, which may be a composition of several materials, that is not foldable "Semi-rigid" material is a material which is partly rigid and has some degree of flexibility

[0030] By "aerofoil" shape is in this application meant a wing profile having an aerodynamic shape when looked in a transverse section in the fore-to-aft direction, i.e. from a leading edge to a trailing edge direction. The aerodynamic aerofoil shape is advantageous, since it lets the air to pass over wingsail more easily. The shape may be asymmetric in said direction, but it can involve symmetric sections, or the shape may be a symmetric aerofoil. The aerofoil shape may be for example defined according to NACA standardized series, but the shape is not limited thereto.

[0031] During sailing, the flap can be rotated along at least one vertical rotation axis in respect of the main wingsail to provide a camber providing propulsive force. By providing a flap, which is rotatable in respect of the main wingsail it is possible to adjust the amount of generated power by adjusting a camber formed by the main wingsail and a flap. To prevent or reduce the propulsion provided by the wingsails, the wingsail area needs to be reduced, which is also called reefing. To reduce the area for capturing the wind, the flap can be folded towards the main wingsail. In this way a projected area of a wingsail frame can be reduced. Thus, also the space required by the wingsail frame is reduced on board a vessel. When the flap is folded towards the main wingsail, also the generated forces are reduced. In this way, a minimum power configuration can be obtained in desired conditions, which may be important for vessel safety, structural integrity, and operability.

[0032] Thus, reefing is used to prevent or reduce the propulsion provided by the wingsails. When no force needs to generate for propulsion of the vessel, the wingsail frame can be tilted horizontally towards the deck to a tilted position. To provide the tilted position the wingsail frame is thus tilted from a vertical standing position towards a horizontal position. By the "tilted" position is meant a position in which the wingsail frame is inclined towards a horizontal position and/or can lean towards a deck of the vessel or towards a support on the deck. The wingsail frame can be stowed in this position and the position is herein also referred to as a stowage position. In the tilted position and when the main wingsail and the flap are in a folded position, space can be saved on the deck of the vessel compared to the main wingsail and the flap not in a folded position. In the tilted position, the wingsail frame may be positioned in a horizontal or vertical tilted position. This is also illustrated in the appended drawings.

[0033] According to the present invention to minimize the space required, the wingsail and the flap are brought from a first unfolded standing position, in which the wingsail and flap provide propulsive forces to the vessel or in which the main wingsail and the flap are aligned and in a neutral position, to a second folded standing position. By folded standing position is meant that the main wingsail and/or the flap are rotated in respect of one or multiple vertical axis/axes towards one another. The vertical axis is essentially parallel to the longitudinal axis of the wingsail frame in the standing position. When located towards one another, the main wingsail and the flap are in an overlapping position when looking in a transversal plane, i.e. directly in front of the wing structure. The wingsail frame is then tilted in respect of a transversal or horizontal rotation axis, which is perpendicular to the vertical rotation axis, and is tilted towards the deck of the vessel. The folding can be obtained by for example rotating the flap to overlap the main wingsail. In this way, the wingsail frame may be stowed in a neutral, non-propulsive, position. Further, a transversal extension of the wingsail frame is reduced compared to when the wingsail frame is in a propulsive standing position. This is a huge advantage, since the space onboard a marine vessel is limited. The wingsail frames are typically, but not necessarily, folded in an upright position before the wingsail frame is tilted. Further advantage is that the lifting force from wind will be reduced which can be useful in strong winds to reduce the stress on the components. The wingsail can be tilted down on the deck and stored either in a flat horizontally lying position or in a vertical upright position.

[0034] For better understanding of the invention of the present disclosure, it will now be described with reference to the appended drawings, which are provided to illustrate non-limiting example embodiments of the invention.

[0035] Generally, in the drawings, all reference signs are not included in all drawings for the reason of clarity. However, it is clear for the skilled person that the same reference signs apply to same elements throughout the drawings. For example, the reference sign 110 applies for the main wingsail 110 in connection with all wingsail frames 101 in Fig. 1, although only one is depicted with 110. Referring to Fig. 1, a marine vessel 1 comprising a wind-assisted propulsion arrangement 10 with three wingsail structures 100 is shown. Each of the wingsail structures 100 comprises a wingsail frame 101, schematically shown by a rectangle with dotted lines in connection with one wingsail frame in Fig. 1. The wingsail frame comprises a main wingsail 110 and a flap 120 and at least one coupling member, which may be the lower coupling member 140 and/or the upper coupling member 130. Both the main wingsail 110 and a flap 120 are rigid or semi-rigid.

[0036] Reference is further made to Fig. 5, which illustrates a schematical and partially cut side view of the wingsail structure 100 comprising a foundation 20 and the wingsail frame 101. The wingsail frame 101 further comprises an upper coupling member 130 (see Fig. 1) and a lower coupling member 140, which are configured to rotatably connect the main wingsail 110 and the flap 120 in respect to each other. At least one coupling member is needed for the main wingsail 110 and/or the flap 120 to be rotated around one or more vertical axis/axis so that the flap can be rotated towards the main wingsail. The wingsail frame 101 can be connected to the foundation 20 for example via a shaft 22. The center of the shaft 22 may define a first vertical axis of rotation 111 (Fig. 6), around which the whole wingsail frame 101 can rotate in respect to the foundation 20. The main wingsail is suitably attached to the shaft in a non-rotatable manner. Instead, the shaft is arranged to the foundation in a rotatable manner, and when the shaft rotates, the whole wingsail frame rotates, thereby providing a suitable angle for the wingsail frame against the wind.

[0037] Referring further to Fig. 1 and Fig. 6, it can be seen that both the main wingsail 110 and the flap 120 have an aerofoil shape and comprise rigid or semi-rigid sidewalls. The main wingsail has a leading edge 117, a trailing edge 118 (Fig. 6), a top end 116 and a bottom end 115 (Fig. 1 and 5), and the side walls 211 and 212 extend therebetween. In a similar way, the flap 120 has a leading edge 127 and a trailing edge 128 and a top end 126 and a bottom end 125 (Fig. 1 and 5), and the side walls 221 and 222 extend therebetween (Fig. 6). The aerofoil shape has generally a tapering shape from the leading edge towards the trailing edge. As shown in Fig. 5 and 6, the side walls 211, 221 and 212, 222 of the respective main wingsail 110 and the flap 120 extend in the longitudinal direction L between the respective top ends 116, 126 and bottom ends 115, 125. The side walls 211 and 212 of the main wingsail and 221 and 222 of the flap shown in Fig. 6 are connected or integrated to form the aerofoil shape of the respective main wingsail and the flap with the respective leading edge 117 and 127 and the respective trailing edge 118 and 128.

[0038] The sidewalls may be formed of modules attached to each other permanently or detachably. Thus, the main wingsail and flap profiles can be designed in different modular elements which can be combined to achieve different size of the sails. The modules may together form the integrated main wingsail or flap with the aerofoil shape. The main wingsail and the flap may comprise any suitable material, such as a moldable polymeric material, glass fiber material, carbon fiber material and/or a composite material, but is not limited thereto.

[0039] The wingsail frame 101 further comprises at least one coupling member 140, which in the illustrated example of Fig. 5 is a lower coupling member placed in association with the bottom end 115 of the main wingsail 110 and the bottom end 125 of the flap 120. The wingsail frame may additionally or alternatively comprise an upper coupling member 130 associated with the top end 116 of the main wingsail 110 and the top end 126 of the flap 120. The coupling members 130, 140 may have a similar construction both on the top and the bottom, or the construction may be different from each other and/or mirror-imaged. The coupling members 130, 140 are configured to connect the main wingsail 110 and the aft flap 120.

[0040] The wingsail structure 100 further comprises the foundation 20, which is arranged to be fixed to a body or deck 3 of the vessel 1. The foundation 20 is associated with the wingsail frame 101 such that it supports the frame when the wingsail frame is in an upright, vertical standing position, either in a propulsive or neutral position (I) or in the folded position (II). Fig. 2 illustrates that the foundation comprises or is connected to means to tilt 300 the wingsail frame 101 to a tilted position, in which the wingsail frame may be lying in a horizontal or vertical position (IIIa; IIIb), as shown in Fig. 3 and 4, respectively.

[0041] In the first unfolded standing position (I) illustrated in Fig. 1, the wingsail frame is shown in a propulsive position. The propulsive force provided by the main wingsail and the flap can be varied by altering the camber C, i.e. the convexity of the curve the main wingsail and the flap form from the leading edge of the main wingsail to the trailing edge of the flap.

[0042] Fig. 6 illustrates in a view from above the main wingsail and the flap in a substantially neutral position, in which the flap centerline (FCL) is aligned with the main wingsail centerline (MCL).

[0043] Fig. 7a illustrates an example of a propulsive position in which the main wingsail and the flap form a camber (C), illustrated by a curve C, to provide a propulsive position, when the wingsail frame is in a standing position (I).

[0044] In Fig. 2 the wingsail structures 100 are shown in the second, folded standing position (II). In the standing position, the longitudinal axis L of the wingsail structure, which is shown only in connection with one structure 100, is essentially parallel with a general vertical axis V, which is perpendicular to a horizontal axis H of the vessel 1. The horizontal axis H can extend substantially in the same direction as the deck 3. The wingsail structure also has an extension in a depth direction D, which is perpendicular to the plane formed by the two-dimensional longitudinal L and transversal T directions. The extension in the depth direction may increase when the flap is folded towards the main wingsail.

[0045] According to the present disclosure, a space saving, tilted stowage horizontal position IIIa (Fig. 3) or vertical position IIIb (Fig. 4) can be obtained for the wingsail frame 101, when the flap 120 is first folded towards the main wingsail 110, and the wingsail frame 101 is brought to a second folded standing position (II) as illustrated in Fig. 2. The wingsail frame can then be tilted to the tilted position, which may be a substantially horizontal position IIIa in respect to the deck 3 of the vessel 1 and in which the wingsail frame 101 lies towards the deck, as shown in Fig. 3. Alternatively, the wingsail frame can be tilted to the tilted position, which may be a substantially vertical position IIIb in respect to the deck 3 of the vessel 1 and in which the wingsail frame 101 lies towards the deck in a vertical position as shown in Fig. 4.

[0046] To provide the tilted position IIIa illustrated in Fig. 3 and the tilted position IIIb illustrated in Fig. 4, the wingsail frame 101 is tilted around a transversal rotation axis RT, which is perpendicular to the longitudinal axis L and thus essentially horizontal. The arrow RT illustrates the direction of the tilting in respect of the deck 3 and is shown in Fig 2. In the tilted position, the longitudinal axis L of the wingsail frame is thus essentially parallel with the horizontal axis H, or is nearly parallel. The tilting can be obtained by a schematically shown hydraulically operated tilting arrangement 300 connected to the foundation 20 shown in Fig. 2.

[0047] Further, for structural integrity, each of the main wingsail 110 and the flap 120 comprises a longitudinally, along the length of the respective main wingsail 110 and aft flap 120, extending respective supporting frame 310, 320, as best shown in Fig. 5. The main wingsail supporting frame 310 is arranged inside the sidewalls of the main wingsail 110 and a flap supporting frame 320 is arranged inside the sidewalls of the flap 120. Each of the supporting frames 310, 320 has a hollow structure and can be connected to an inner surface of the side wall 211, 212, 221, 222 of the respective main wingsail 110 and the flap 120 as shown in Fig. 6. The purpose of the frame structure is to provide support for the wingsail and thereby provide a robust construction. The frame structure may be provided in modules or as a one-piece construction.

[0048] As further shown in Fig. 5 and Fig. 6, the wingsail frame is arranged in a neutral unfolded standing position (I). As can be seen, the main wingsail 110 and the flap 120 are arranged successively after each other and are positioned in the same direction. The main wingsail 110 has a main cross-sectional centerline MCL and the aft flap 120 has a flap cross-sectional centerline FCL, which centerlines extend between the respective leading and trailing edges. The flap centerline (FCL) is aligned with the main wingsail centerline (MCL). In this position, the main wingsail 110 and the flap 120 may have a common cross-sectional centerline CL, which coincides with the main cross-sectional centerline MCL and the flap centerline FCL.

[0049] Reference is further made to Fig. 7a-7c. To provide propulsive forces, the main wingsail and the flap are arranged to form a camber C having a convex arc-shape, as shown in Fig. 1. The whole wingsail frame 101 can be rotated around the first vertical rotation axis 111 to adjust the position of the wingsail frame 101 against the wind. To provide the camber shape C, the flap 120 is rotated in respect of a second vertical rotation axis 112 and/or a third axis of rotation 113 to bring the flap and the flap centerline FCL to an inclined position in respect of the main wingsail centerline MCL. The second axis of rotation 112 is arranged outside the supporting frame 320 of the flap 120, but inside the sidewalls 221 and 222 of the flap 120. The second rotation axis 112 is connected to the lower coupling member 140. The second rotation axis 112 may additionally or alternatively be connected to the upper coupling member 130 in a corresponding way. The second axis of rotation 112 is further connected to the supporting frame 320 of the flap 120 via a connecting member 1121 as shown in Fig. 5. By having the second axis of rotation outside the periphery or boundaries of the supporting frame, it is possible to vary the construction and the position of the rotation axis of the flap in a more flexible way.

[0050] As shown by an arrow R in Fig. 7a, the flap can thus be rotated towards the main wingsail 120 to a second, folded position (II) shown in Fig. 7b. To enable folding to an even more compact position, the flap can be further arranged rotatable around a third axis of rotation 113 to bring the flap and the flap centerline (FCL) thereof to an inclined, folded and/or parallel position in respect of the main wingsail 110. The third axis of rotation 113 may be in a cross-sectional view within the area defined by the sidewalls 211, 212 of the main wingsail 110 as shown in Fig. 7a-7c. The third axis of rotation 113 may be connected to the lower coupling member 140. By providing the second and third individual rotating axes associated with the upper and lower coupling members, a robust connection of the main wingsail and flap is obtained while a flexible and fine adjustment of e.g. a camber is obtained.

[0051] In this second folded position (II) the side wall 221 on the right-hand side of the flap 120 (in respect of the leading edge) is folded towards the side wall 211 of the main wingsail 110. The flap 120 could be alternatively folded in the opposite direction so that the side wall 222 of the flap 120 is folded towards the sidewall 212 of the main wingsail 110. In this second folded position (II), the flap 120 faces the main wingsail 110 in an opposite direction, i.e. the leading edge 127 of the flap faces substantially opposite direction compared to the leading edge 117 of the main wingsail 110. By folding the flap towards the main wingsail, the transversal extension T of the wingsail frame 101 can be reduced.

[0052] Fig. 7c shows a further variant of folding obtained by the third axis of rotation 113 which can be provided in the lower coupling member 140 as shown in Fig. 5 and/or upper coupling member 130. The flap 120 is rotated in respect of the third rotation axis 113 in a counter-clockwise or clockwise direction so that the main wingsail 110 and the flap 120 are positioned parallelly or nearly parallelly. In the parallel position the centerlines MCL and FCL are parallel or nearly parallel and the side wall 222 of the flap 120 on the left-hand side, seen in respect of the leading edge of the flap 120, faces towards the side wall 211 on the right-hand side of the main wingsail 110, seen in respect of the leading edge 117 of the main wingsail 110. Also, the trailing edges 118 and 128 of the main wingsail 110 and the flap 120, respectively, are brought into proximity of each other. In this second folded position (II), the flap 120 faces the main wingsail 110 in the same direction.

[0053] Generally, the main wingsail, the flap and the upper and lower coupling means may comprise suitable arrangement configured to provide the rotating movement in respect of the rotation axes, and may comprise e.g. shafts, bearings e.g. roller bearings and drive means. The first, second and third vertical axes are parallel to the longitudinal axis of the wingsail frame, when the wingsail frame is in a standing propulsive position (I) or standing folded position (II). The rotation of the wingsail frame, main wingsail and/or the flap can be controlled by incorporating e.g. hydraulically or electrically controllable means to each rotation axis. A control unit can then be connected to the drive arrangement to regulate the rotation of the wingsail frame, main wingsail and/or the flap. The degree of rotation of the wingsail frame, main wingsail and/or the flap is adapted to prevailing surrounding conditions. The rotating arrangement and each of the vertical rotation axes for the main wingsail and flap can be arranged with stop means so that the degree of rotation is angularly limited to a certain degree. By limiting the rotation degree, uncontrolled rotation of the parts of the wingsail frame can be avoided, for example in case of change in the prevailing wind/weather conditions.

[0054] It should be noted that in the drawings Fig. 3 and 4 that illustrate the tilted positions, the foundation is separated from the shaft 22 due to illustration means. However, the foundation 20 and the shaft 22 may be connected to each other also when tilted, for example via the tilting arrangement 300 shown in Fig. 2. Additionally, or alternatively, other connecting means or additional rotation means could be used.

[0055] The detailed description and the drawings are aimed to facilitate the understanding of the embodiments of the inventions, but do not limit the scope of the invention. The scope is limited by the appended claims.

Claims

1. A wingsail structure (100) for wind-assisted propulsion of a marine vessel (1), the wingsail structure (100) comprising a wingsail frame (101) and a foundation (20), the wingsail frame (101) being rotatably connected via a first longitudinal axis of rotation (111) to the foundation (20), wherein the wingsail frame (101) comprises:

   - a main wingsail (110) and an aft flap (120), each having an airfoil shape and comprising rigid or semi-rigid sidewalls (211, 212; 221, 222) extending between a top end (116; 126) and a bottom end (115; 125) and having a leading edge (117; 127) and a trailing edge (118; 128),
   - a main wingsail supporting frame (310) and a flap supporting frame (320), each of them extending longitudinally along the respective main wingsail (110) and aft flap (120),
   - at least one coupling member (130; 140) connecting the main wingsail and the flap, wherein

   the flap (120) is arranged rotatable around a second longitudinal axis of rotation (112) to bring the flap (120) to an inclined position in respect of the main wingsail, and wherein the second axis of rotation (112) is located in a cross-sectional view within an area defined by the sidewalls (221, 222) of the flap (120) and outside the periphery of the supporting frame (320) of the flap.

2. The wingsail structure (100) according to claim 1, wherein the at least one coupling member (130; 140) is connected to the second axis of rotation (112).

3. The wingsail structure of claim 1 or 2, wherein the second axis of rotation (112) is connected to the flap supporting frame (320) via a connecting member (1121).

4. The wingsail structure (100) according to any one of the preceding claims, wherein the second axis of rotation (112) is located between the flap supporting frame (320) and the trailing edge (128) of the flap in a cross-sectional view.

5. The wingsail structure (100) according to any one of the preceding claims, wherein the flap is further arranged rotatable around a third axis of rotation (113) arranged to bring the flap to an inclined, folded and/or parallel position in respect of the main wingsail (110), and wherein the third axis of rotation (113) is located in a cross-sectional view within an area defined by the sidewalls (211, 212) of the main wingsail (110).

6. The wingsail structure (100) according to claim 5,

wherein the third axis of rotation (113) is connected to the at least one coupling member (130; 140).

7. The wingsail structure (100) according to claim 5 or 6, wherein the third axis of rotation (113) is located between the main wingsail supporting frame (310) and the trailing edge (118) of the main wingsail in a cross-sectional view.

8. The wingsail structure (100) according to any one of the preceding claims, wherein the main wingsail (110) has a main wingsail centerline (MCL) and the flap has a flap centerline (FCL), which centerlines extend in a cross-sectional view between the respective leading edges (117; 127) and trailing edges (118; 128).

9. The wingsail structure (100) according to claim 8, wherein the second axis of rotation (112) coincides with the flap centerline (FCL) in a cross-sectional view.

10. The wingsail structure (100) according to any one of the preceding claims 8 or 9, wherein the flap centerline FCL) is arranged rotatable around the third axis of rotation (113) so that the flap centerline (FCL) is brought to an inclined or parallel position in respect of the main wingsail centerline (MCL).

11. The wingsail structure (100) according to claims 10, wherein the third axis of rotation (113) is located along the main wingsail centerline (MCL) in a cross-sectional view.

12. The wingsail structure (100) according to any one of the preceding claims 8-11, wherein the flap is configured to be inclined:

- from/to a neutral position (I), in which the flap centerline (FCL) is aligned with the main wingsail centerline (MCL),
- from/to a propulsive position (II), in which the flap centerline (FCL) is inclined in respect to the main wingsail centerline (MCL), and/or
- from/to a folded non-propulsive position (III), in which one sidewall of the flap faces one sidewall of the main wingsail.

13. The wingsail structure (100) according to any one of the preceding claims, wherein the at least one coupling member is a lower coupling member (140) and/or an upper coupling member (130).

14. The wingsail structure (100) according to any one of the preceding claims, wherein each of the main wingsail and flap supporting frames (310; 320) has a hollow structure and is located inside the respective main wingsail (110) and the flap (120) and is connected to an inner surface of the side wall of the respective main wingsail and the flap.

15. The wingsail structure (100) according to any one of the preceding claims, wherein the wingsail structure (101) further comprises a tilting arrangement (300) configured to bring the wingsail frame (101) from a standing position (II) to a tilted position (IIIa; IIIb) in respect of the foundation (20).

16. A wind-assisted propulsion arrangement (10) comprising at least one wingsail structure (100) according to any one of the preceding claims 1-15.

17. A marine vessel (1) comprising the wind-assisted propulsion arrangement (10) according to claim 16.

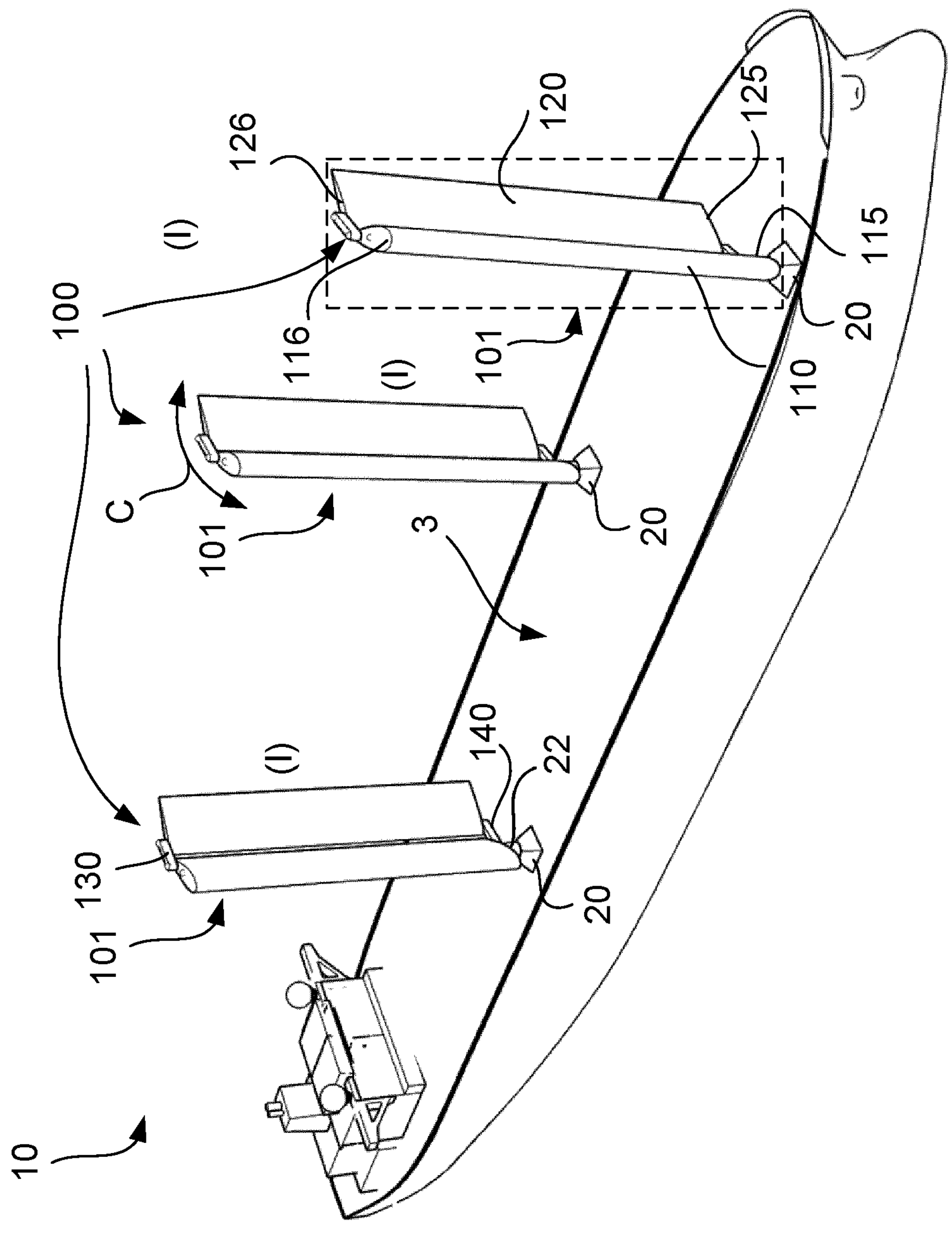

100
(I)
126
120
125
116
115
20
110
101
C
(I)
101
20
3
10
101
130
(I)
140
22
20

Fig. 1

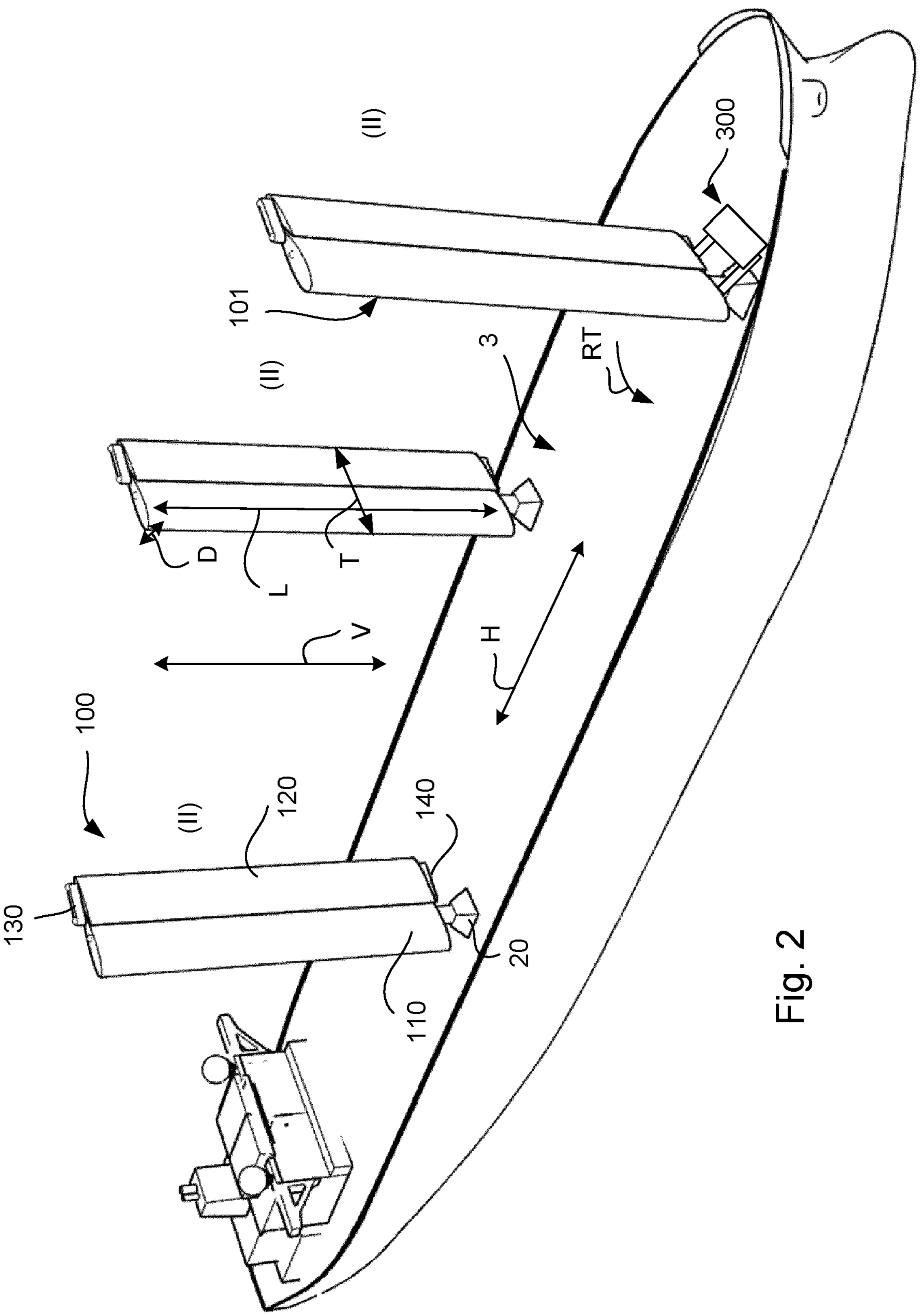


Fig. 2

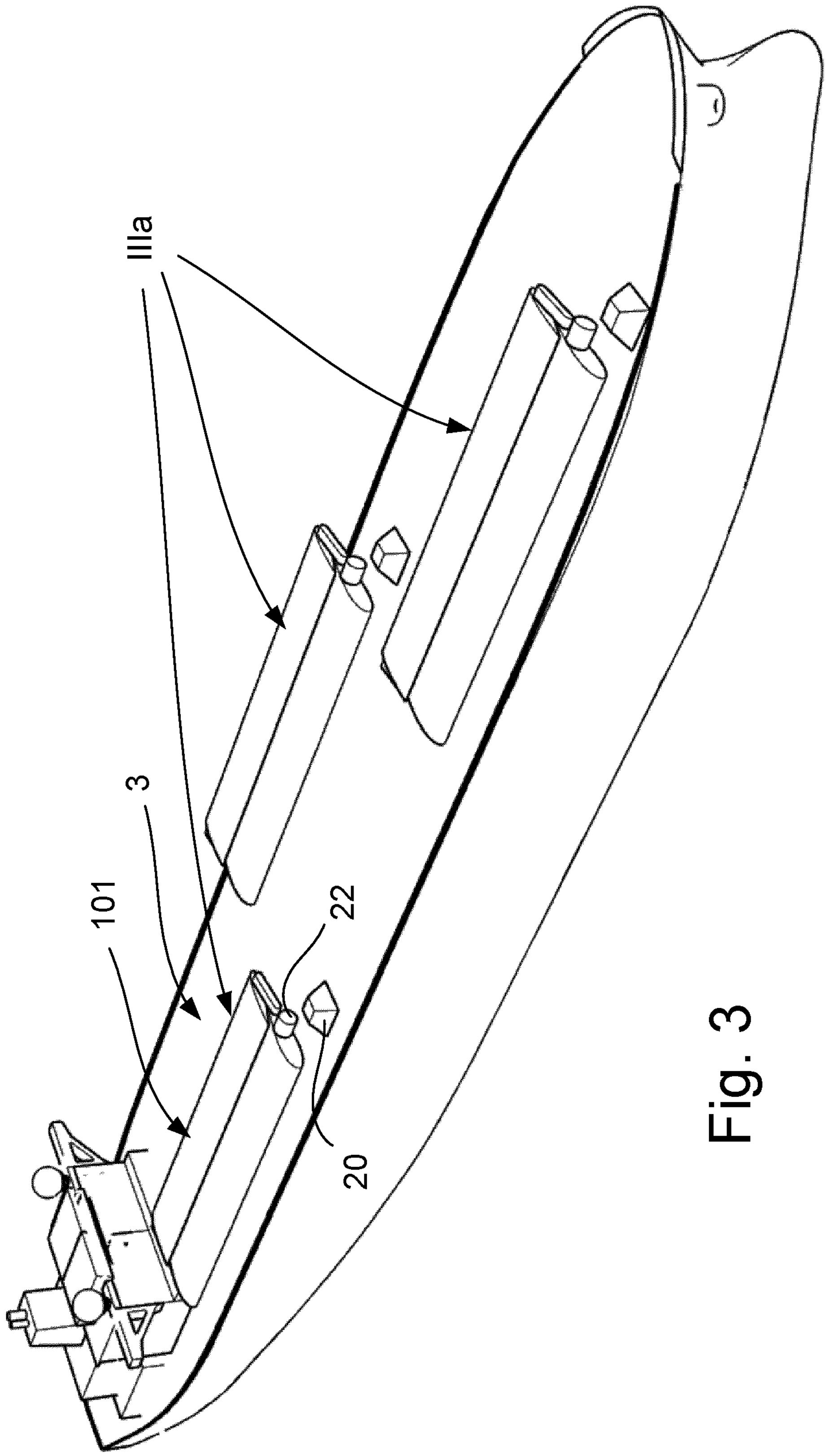


Fig. 3

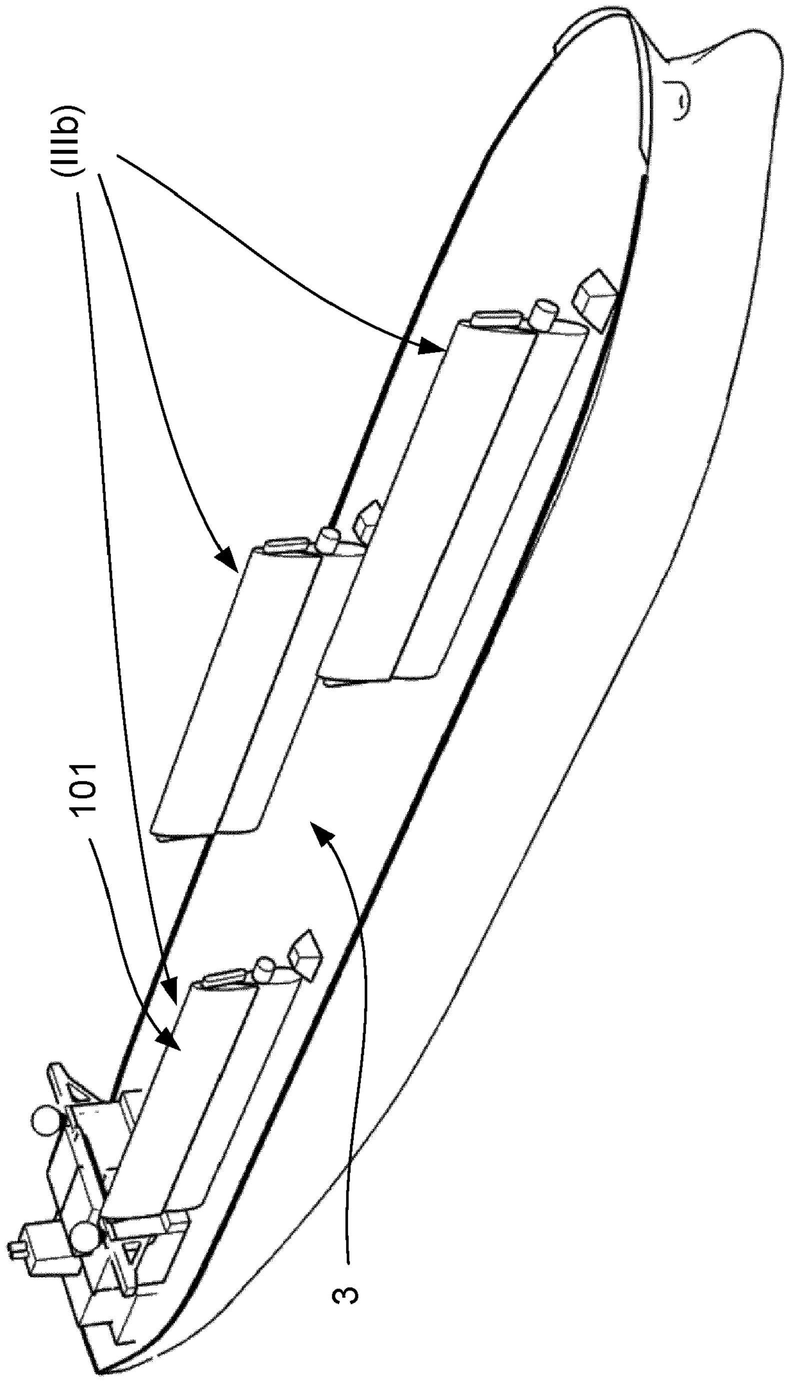


Fig. 4

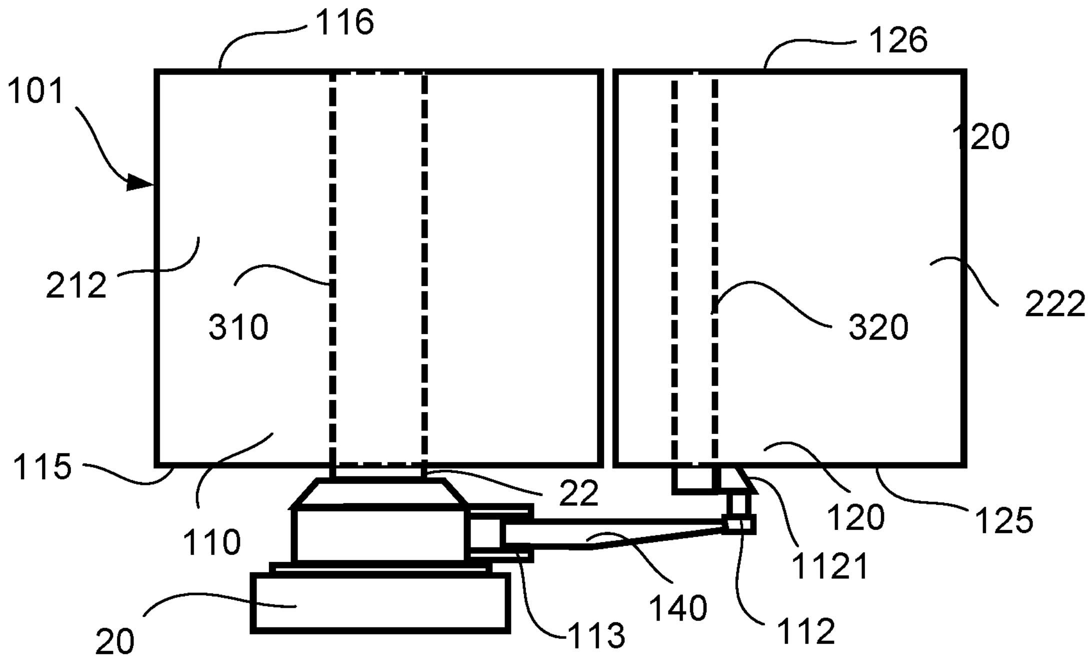
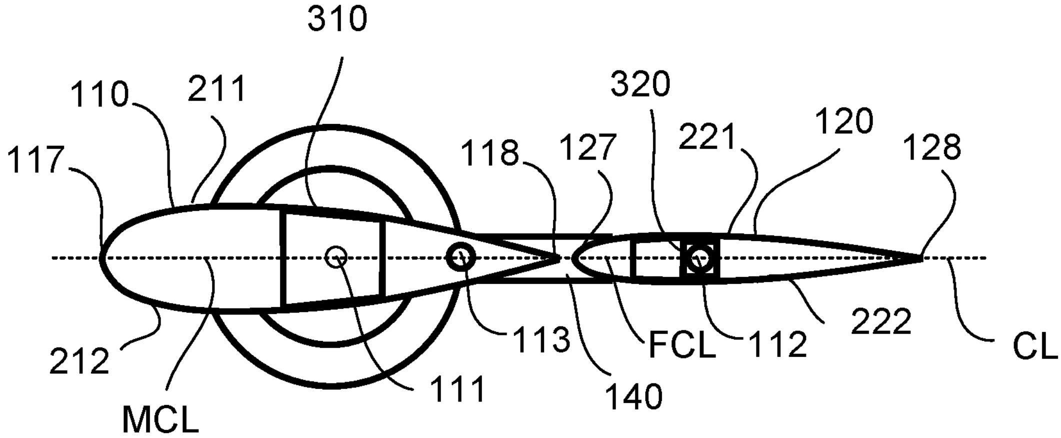

116
126
101
120
212
310
320
222
115
110
22
120
125
1121
140
112
113
20

Fig. 5


310
110
211
320
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118
127
221
120
128
212
MCL
111
113
140
FCL
112
222
CL

Fig. 6

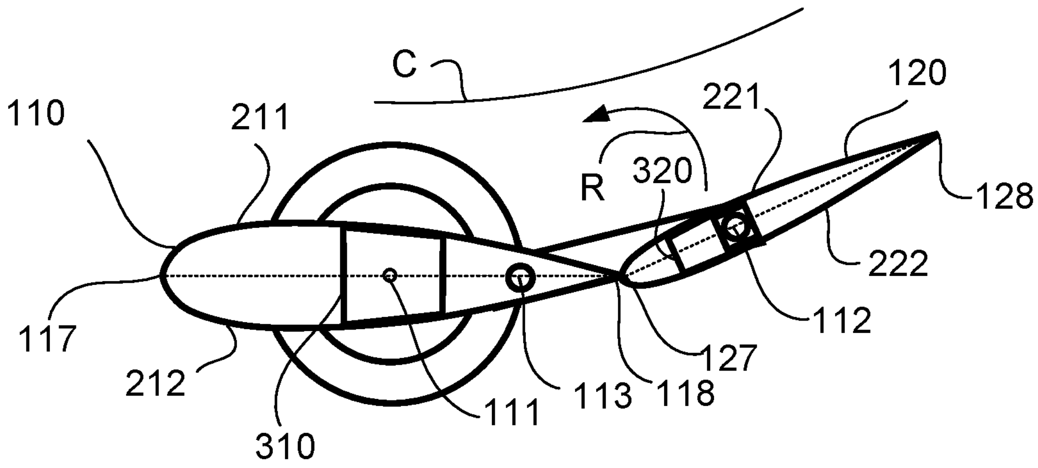

Fig. 7a

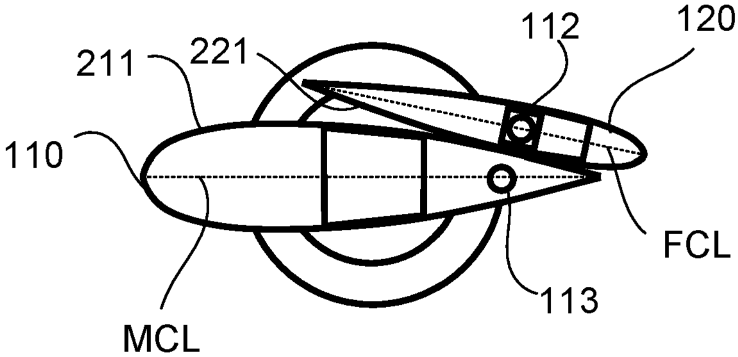

Fig. 7b

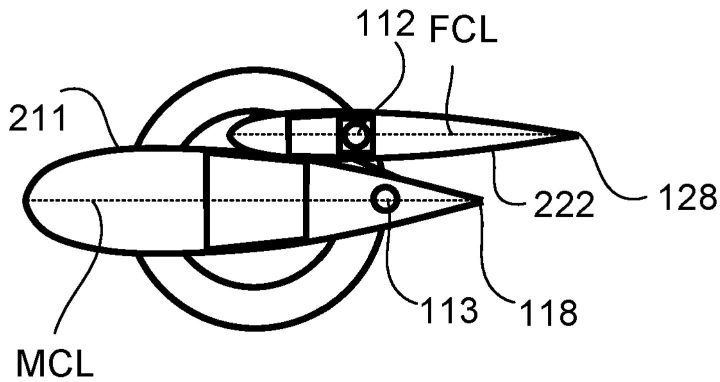

Fig. 7c

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EUROPEAN SEARCH REPORT

Application Number
EP 22 21 1633

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B63H

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	24 May 2023	Mauriès, Laurent

CATEGORY OF CITED DOCUMENTS

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