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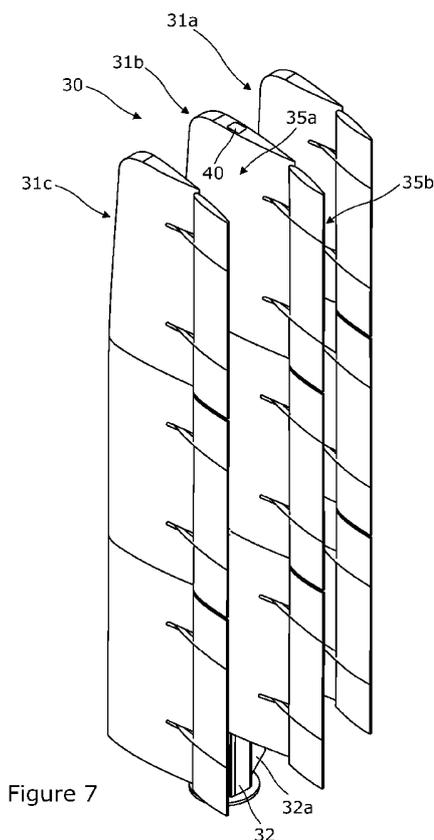
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(54) Title: AEROFOIL SAIL



(57) Abstract: An aerofoil sail (30) for providing motive power to a waterborne vessel, the sail comprising a leading aerofoil portion (35a) and a trailing aerofoil portion (35b), and the sail comprising a spar (32), at least one of the aerofoil portions rotatably positionable, and the sail comprising a controller to control individually the angular position of at least one of the aerofoil portions relative to the spar, and the spar rotationally positionable about its longitudinal axis.



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AEROFOIL SAIL

Technical field

5 The present invention relates generally to propulsion of waterborne vessels. In one embodiment, there is provided an aerofoil sail the control of which is substantially automated.

Background

10 Any discussion of the prior art throughout the specification should in no way be considered as an admission that such prior art is widely known or forms part of common general knowledge in the field.

15 The current level of fuel consumption, and the resulting Co2 emissions, and other hydrocarbon bi-products, resulting from commercial shipping is extremely high. We have realised that there is a need to address this issue and we have devised an auxiliary power supply for commercial shipping to help reduce both fuel consumption and emissions.

Summary

20 Unless the context clearly requires otherwise, throughout the description and the claims, the words 'comprise', 'comprising' and the like are to be construed in an inclusive sense as opposed to an exclusive or exhaustive sense; that is to say in the sense of "including but not limited to".

25 According to a first aspect of the invention there is provided an aerofoil sail for providing motive power to a waterborne vessel, the sail comprising a leading aerofoil portion and a trailing aerofoil portion, and the sail comprising a spar structure, at least one of the aerofoil portions rotatably positionable, and the sail comprising a controller to control individually the angular position of at
30 least one of the aerofoil portions relative to the spar structure, and the spar structure rotationally positionable about its longitudinal axis.

[followed by page 1a]

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5 The controller preferably performs automated control of the least one aerofoil portion and the spar, preferably with no or minimal manual intervention. The controller may use feedback signals from one or sensors (incorporated, associated with or affecting the sail) in order to determine a suitable control signal.

10 One of the aerofoil portions may be rigid with the spar, and the other aerofoil portion may be rotatably positionable about the spar.

[followed by page 2]

The spar may be capable of being rotatably positionable, about its longitudinal axis, to a required (angular) position.

Both of the aerofoil portions may be pivotably positionable about the spar.

5

When aligned, the leading portion and the trailing portion may form an aerofoil profile.

10

A space or gap between the heading portion and trailing portion is provided to allow the flow of air therethrough, preferably substantially unimpeded.

The trailing portion is preferably longer than the leading portion when viewed in plan. The leading portion may be longer than the trailing portion when viewed in plan.

15

The leading portion may have greater width at its widest point compared to the greatest width of the trailing portion, when viewed in plan.

20

The sail wing preferably comprises multiple sets of leading portions and trailing portions, each set of a leading portion and a trailing portion arranged one above the other.

Each set of a leading portion and a trailing portion is at substantially the same vertical position.

25

Each of the trailing portions and the leading portions comprises a leading flap and a trailing flap.

30

Preferably at least one of the leading and trailing portions is pivotable through around sixty degrees.

Each of the leading and trailing portions may be driveable on a curved track.

The leading and trailing portions may be viewed as flaps.

5 Preferably each of the leading and trailing portions are pivotable by way of toothed gear arrangements. Preferably each of toothed gear arrangements comprises a rack and pinion.

10 Preferably a centre of effort of the sail is located anterior of a centreline of the spar.

15 The internal volume of the spar is sized so as to allow an operative access therinto. The spar is preferably sized so as to allow an operative access within the spar for a major portion of the length of the spar. The internal space of the spar preferably comprises at least one ladder to allow access to different parts of the spar.

20 In one embodiment of the invention maintenance of the sail underway is completed either at deck level or internally in the main spar. A man sized hatch may be positioned above the top bearing near working deck level to allow access to the internal area of the spar. A series of staggered ladders are positioned to reduce the danger of falling too far within the internal space. All the systems and motors that need maintenance whilst at sea or alongside can be accessed from the internal ladders. Harness lines and track systems may be supplied for health and safety.

25 Another aspect of the invention relates to a sail assembly/rig comprising multiple sails of the first aspect of the invention.

30 In one embodiment, the spar rotates on two bearings in the ship and can be rotated by a geared motor at deck level. The leading edge (LE) and trailing edge (TE) flaps are preferably mounted on two tracks per flap which are attached to the main spar. The flaps are lifted in to position at approximately

ninety degrees to the centreline of the main spar and the sliders on the flap engaged with the tracks on the main spar. Once located, the flap is rotated so that the centrelines line up.

- 5 The sail is preferably a substantially rigid structure. The leading and trailing portions are preferably rigid structures.

In one embodiment of the invention the sail comprises a main central spar that rotates on two bearings set in the ships main deck and internal structure and can be rotated with a geared motor. The sail has multiple LE and TE flaps that are rotatable around the main spar, again driven by geared motors. The LE and TE flaps can be driven to produce an asymmetric lifting surface from either the port or starboard side of the vessel. The flaps can also be arranged so that whilst being an efficient lifting surface they can also move the centre of effort of the sail to line up with the central axis of the main spar and 'self balance'. The centre of effort of the sail with the LE and TE flaps on centreline is preferably sufficiently far behind the centreline of the main spar and hence always weather cocks/ aligns with the wind as a fail safe position.

- 20 The sail may include one or more features as shown in the detailed description and/or in the drawings.

According to a third aspect of the invention there is provided a waterborne vessel comprising at least one sail of the first aspect of the invention.

25

The vessel may be a cargo vessel.

In a further aspect, there is provided an aerofoil sail assembly for providing motive power to a waterborne cargo vessel comprising at least two aerofoil sails,

30

[followed by page 4a]

each sail comprising a leading aerofoil portion and a trailing aerofoil portion, and the aerofoil sail assembly comprising a single spar which supports the aerofoil sails, at least one of the aerofoil portions rotatably positionable, and the aerofoil sail assembly comprising a controller to control individually the
5 angular position of at least one of the aerofoil portions relative to the spar, and the spar rotationally positionable about its longitudinal axis, and wherein the leading portion is longer than the trailing portion in a transverse direction when viewed in plan, and a gap is provided between the leading portion and the trailing portion, and wherein the aerofoil sail assembly comprises at least two
10 of the aerofoil sails provided in a side-by-side spaced apart relationship.

The above or further aspects of the invention may include a combination of the above features and/or any of the features mentioned in the detailed description and/or drawings.

15

[followed by page 5]

Brief Description of the drawings

Various embodiments of the invention will now be described, by way of example only, with reference to the following drawings in which:

5 **Figure 1** is a side view of an aerofoil sail,

Figure 2 is a lateral cross-section of the sail of Figure 1 in a first condition,

10 **Figure 3** is a lateral cross-section of the sail of Figure 1 in a second condition, and

Figure 4 is a perspective view of the sail of Figure 1,

15 **Figure 5** is a side view of a vessel provided with the aerofoil sail of Figure 1,

Figure 6 is front perspective view of a sail assembly,

20 **Figure 7** is a rear perspective view of a sail assembly,

Figure 8 is a plan view of a leading and trailing edge in a first position of a sail of the sail assembly of Figure 7,

25 **Figure 9** is a plan view of a leading and trailing edge in a second position of a sail of the sail assembly of Figure 7,

Figure 10 is a plan view of a leading and trailing edge in a third position of a sail of the sail of the sail assembly of Figure 7,

30

Figure 11 is a side view of a vessel provided with sail assemblies of Figure 7, and

Figure 12 is a power curve graph.

Detailed Description

5 With reference initially to Figure 1 there is shown an aerofoil, or 'wing', sail 1, for a ship or waterborne vessel, and in particular for a cargo vessel. As will be described below, the sail provides auxiliary power to a propeller driven vessel and thereby reduces the fuel required to power the propeller. Broadly, the principle of operation is to harness the power of the wind using a highly
10 efficient wing rig which can be simply controlled, largely automatically, from the bridge of the ship and be maintained underway.

The sail 1 comprises a spar 2 to which are mounted sets of leading and trailing portions, each leading portion and each trailing portion forming a respective
15 pair, located at a respective height of the spar 2. Each of leading and trailing portions is formed of a rigid material, and may be hollow or solid. There are provided leading and trailing edge portions 3a and 3b, leading and trailing edge portions 4a and 4b, and leading and trailing edge portions 5a and 5b. As can be seen in Figure 1, the lowermost sets of leading and trailing portions, 3a, 3b, 4a
20 and 4b are of parallel profile, whereas the uppermost set 5a and 5b are of tapered profile.

The uppermost part of the trailing portion 5b is provided with a winglet 14.

25 The leading and trailing edge portions are mounted for pivotable or rotatable movement about the spar by way of rack and pinion arrangements, shown generally at 10, so that the angular position of each of the portions can be controlled. Each such arrangement may be in the form of a rack and slider. Each leading and trailing edge portion comprises an upper rack and pinion
30 device and a lower rack and pinion device. Each pair of rack and pinion devices arranged to control the angular position of the portion relative to the spar 2. For each rack and pinion device one of the rack component and the

pinion component is attached to the leading/trailing portion, and the other of the rack component and the pinion component is attached to the spar.

5 The angular position of each of the leading and trailing edge portions is individually controllable by way of the respective rack and pinion arrangement, or other actuator. A driver for each pair of the rack and pinion arrangements is provided by hydraulic pressure source or electrical pressure source, which provides a directional driving force.

10 With reference to Figures 2 and 3, the angular extent of movement for each portion is shown, in this case, each leading and trailing edge portion is capable of movement through sixty degrees, thirty degrees to each side of a centreline. As can be seen, the trailing edge portions are longer than the leading edge portions. When the portions are aligned, an overall aerofoil shape is formed.

15 The spar 2 is of substantially hollow construction, and comprises a basal portion 2a, which is of tapered shape. The basal portion 2a is received in an aperture in the deck 20 and is arranged for rotational movement about its longitudinal axis. There is provided a upper bearing and a lower bearing which allow the rotational movement. The rotational movement is brought about by way of a drive arrangement, which may be powered hydraulically. The drive arrangement (not shown) may comprise a toothed collar provided around the spar which is driven by a drive cog, or similar. The drive arrangement provides a geared motor.

25 In order to permit maintenance of the sail, the spar comprises an opening which allows an operative to enter into the spar 2. The internal volume of the spar 2 is such that an operative can move within the internal space and access different heights therein by way of staggered ladders (not shown) attached to the internal walls of the spar. Advantageously, in this way an operative can perform maintenance work more safely than if he had to access the sail externally. For example, by allowing such internal access, the operative can

30

work on repairing, replacing or checking the rack and pinion devices from the relative safety of within the spar 2.

5 For installation of each leading and trailing portion of the sail 2, once the portion is positioned on centreline the motor gear is fitted from inside the spar and meshed with the semi circular horizontal racked gear on the aft surface of the flap. As the motor gear rotates the flap slides on the track to the desired position. The tracks and sliders are machined to be self aligning to advantageously allow for the spar to bend and still operate under load.

10

A further embodiment of the invention is now described which comprises a sail assembly 30.

15 The sail assembly 30 comprises three spaced apart aerofoil sails (arranged in side-by-side arrangement) 31a, 31b and 31c. Each sail comprises sets of leading and trailing portions, each leading portion 35a and each trailing portion 35b forming a respective pair, located at a respective height of the spar 2. Each of leading and trailing portions is formed of a rigid material, and may be hollow or solid.

20

The sail 31b is a central sail, and is supported by a spar 32. Support members 32a which extend from the spar 32, support the sails 31a and 31c. The spar 32 extends through the sail 31b, and support members 32a support spars (not illustrated) which extend through the leading portions of the outer
25 sails 31a and 31c. The sails are maintained in a spaced-apart relationship by way of connection portions 37 which connect the leading portions of the outer sails to the leading portions of the central sail.

30 The trailing edge portions are mounted for pivotable or rotatable movement (for example, by way of rack and pinion arrangements), such that the angular position of each of the portions can be controlled. Each such arrangement may be in the form of a rack and slider.

The angular position of each of the trailing portions is individually controllable by way of a respective actuator. A driver for each trailing portion may be provided by hydraulic pressure source or electrical power, which provides a directional driving force.

With reference to Figures 8, 9 and 10, the angular extent of movement for each trailing portion is shown, in this case, each trailing edge portion is capable of movement through sixty degrees, thirty degrees to each side of a centreline. As can be seen, the leading portions are longer than the trailing portions. The actuator 36 may comprise a reciprocable rod, for example comprising a ram.

Each of the leading and trailing portions forms an aerofoil shape. Each trailing portion is connected to its respective trailing edge by way of two arms 35c. A distal end of each arm 35c is connected to a pivot 37, and the arm being capable of being controllably driven about the pivot. With the trailing portion and the leading portion in an aligned position (as shown in Figure 10), said portions are spaced from one another. The position of the pivot connection 37 is preferably at a position of ten to thirty percent along the overall length of the sail (ie from the distal end of the trailing portion to the distal end of the leading portion).

The spar 32 is of substantially hollow construction, and comprises a basal portion (similar to the basal portion 2a), which is of tapered shape. The basal portion is received in an aperture in the deck 20 and is arranged for rotational movement about its longitudinal axis. There is provided an upper bearing at deck level and a lower bearing at below deck level, which allow the rotational movement of the spar. The rotational movement is brought about by way of a drive arrangement, which may be powered hydraulically. The drive arrangement (not shown) may comprise a toothed collar provided around the spar which is driven by a drive cog, or similar. The drive arrangement provides a geared motor. This allows the entire sail assembly to be controllably rotated.

The sail assembly is provided on spherical bearings, which are preferably provided with a constant recirculating oiling pump to keep bearings lubricated.

5 A maintenance hatch 40 is provided at the top of the spar to allow attachment or release of lifting strops.

The sail assembly 30 advantageously provides an increase in efficiency with accelerated flow over the trailing portion allowing the coefficient of lift to be increased significantly. We have found that the lift coefficient of the sail
10 assembly 30 is 2.5 in comparison to 1.4 for the sail 1.

The or each sail can be made from a combination of ferrous and non ferrous metals and also from composites such as fibre reinforced plastics. It is envisaged that due to the force the sail will experience at sea that high
15 strength steels will be best suited.

It will be appreciated that although three pairs of leading and trailing portions are shown for the/each sail, in other embodiments, more or fewer pairs may be provided.

20 In use, one or more of the sails or sail assemblies are mounted on the deck of a ship. The sails/sail assemblies could be provided aligned with the centreline of the vessel, offset from the centreline (ie towards the starboard or port side), or a combination of those. A control system is provided to allow control of each leading and/or trailing portion of each sail. A feedback system using load
25 sensors incorporated with the or each spar could be used to control the angular position of each leading and trailing portion, together with the rotational position of the spar. Feedback using information from other sensors, and indeed other types of sensors could be used in addition or alternatively. The control system, which comprises a data processor provided with executable
30 instructions, processes signals from the sensors and is arranged to output control signals to each of the leading and trailing edge portions, as well as control signals for the rotational position of the spar, using feedback

information from the sensors. In this way control of the sail(s) can largely be controlled automatically. It will be appreciated, however, that the control system allows for manual intervention as and when required. In that regard, control may be from the bridge of the vessel, and from a second control point
5 next to the (or each) sail/sail assembly.

Reference is made to Figure 5 which shows a cargo vessel 100 which is provided with four sails 1 along the centreline of the vessel, and to Figure 11, which shows a vessel 200.

10

Because each of the leading and trailing portions is controllable individually, the configuration of each sail can be tailored to maximise the available wind conditions (as indicated by the onboard sensors), and thereby maximise the propulsive power provided by the sail(s). In certain circumstance, however, the
15 sails may need to be configured to minimise the propulsive power, for example when the vessel needs to reduced or substantially no motive power.

With sails at each end of the ship, advantageously it will be possible to steer the ship on long passages and help reduce the rudder drag which is
20 considerable on large vessels. Additionally, in port the sails could advantageously be utilised as thrusters for manoeuvring and at sea they will help greatly stabilising the dynamic roll of the ship.

The control system for multiple wings ensures the safe operation of such a
25 powerful device. With such power which can be harnessed from the sails, the required fuel consumption can advantageously be significantly reduced. Figure 12 shows various power curves for two of the sail assemblies 30 (which allows for 30% losses from aero test data).

30 It is envisaged that multiple sails/sail assemblies will be fitted to a ship and positioned to minimise disturbance for loading and off-loading operations.

Advantageously, the sails are robust, tall and high aspect ratio and should not impede most overhead cranes.

5 Due to the high displacement of a commercial ship the righting moment that will resist the heeling force will be very large and a stable five degree heel due to the wings should be a maximum. This is clearly going to depend on each ship, case by case. The reality is the bigger the ship the better this system works.

10 Due to this being an auxiliary power supply the ship will always be making approximately 13 knots (standard commercial speed). There will always be side force produced by the hull moving through the water at approximately thirteen knots and hence the side force of the wings should have little effect.

15 The sail being rigid is advantageously extremely predictable and is largely self balancing, the forces to control it will be very low. The control system will be fail-safe, ie the wings automatically line up with the wind. If built in steel and powered by hydraulic motors this will be much more appealing to the shipping industry as these are well understood and very reliable technologies.

20 In an alternative embodiment, the trailing portion of each pair is rigidly fixed to the spar, and the leading portion is mounted for controlled angular movement relative to the trailing edge. By virtue of the spar being rotatable about itself, the angular position of the fixed portion relative to the longitudinal axis of the
25 spar can be altered in a controlled fashion.

In an embodiment, the outer surfaces of the sail/sails may be provided with solar panels, from which the power sourced can be used to drive the angularly controllable portions.

In another embodiment, the bearings which mount the spar are both provided above deck, by way of a spigot or socket housing. It will be appreciated that more than two bearings may be provided.

- 5 The spar bearings for the above embodiments are self-aligning, with a tube connecting them for watertight integrity, and to allow self-alignment when the sail/sail assembly is lifted into position.

The above embodiments include failsafe mechanisms which will weather cock,
10 and the actuatable leading/trailing portions comprise hydraulic or electrical lead screw actuators which will release and allow the portions to naturally find a neutral position.

Preferably, the or each spar is accessible at all heights thereof to allow
15 maintenance or survey by an operator. This is achieved by providing man-sized openings and access ways to/within the spar/s.

CLAIMS

- 2013282975 08 Sep 2017
- 5 1. An aerofoil sail assembly for providing motive power to a waterborne cargo vessel comprising at least two aerofoil sails, each sail comprising a leading aerofoil portion and a trailing aerofoil portion, and the aerofoil sail assembly comprising a single spar which supports the aerofoil sails, at least one of the aerofoil portions rotatably positionable, and the aerofoil sail assembly comprising a controller to control individually the angular position of at least one of the aerofoil portions relative to the spar, and the spar rotationally positionable about its longitudinal axis, and wherein the leading portion is longer than the trailing portion in a transverse direction when viewed in plan, and a gap is provided between the leading portion and the trailing portion, and wherein the aerofoil sail assembly comprises at least two of the aerofoil sails provided in a side-by-side spaced apart relationship.
- 10
- 15 2. An aerofoil sail assembly as claimed in claim 1 in which the controller performs automated control of the at least one aerofoil portion and the spar.
- 20 3. An aerofoil sail assembly as claimed in claim 2 in which the controller uses feedback signals from one or more sensors incorporated, associated with or related to the aerofoil sail in order to determine a suitable control signal.
- 25 4. An aerofoil sail assembly as claimed in any preceding claim in which one of the aerofoil portions is rigid with the spar, and the other aerofoil portion is rotatably positionable relative to the spar.
5. An aerofoil sail assembly as claimed in any one of claims 1 to 3 in which both of the aerofoil portions are pivotably positionable relative to the spar.
- 30 6. An aerofoil sail assembly as claimed in any one of the preceding claims in which when aligned, the leading portion and the trailing portion form an aerofoil profile.

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7. An aerofoil sail assembly as claimed in any one of claims 1 to 5 in which each portion is of aerofoil shape when viewed in plan.
- 5 8. An aerofoil sail assembly as claimed in claim 7 in which the at least one rotatably positionable aerofoil portion is rotatably connected to an aerofoil portion that is rigid with the spar.
9. An aerofoil sail assembly as claimed in any one of the preceding claims
10 which comprises multiple sets of leading portions and trailing portions, each set of a leading portion and a trailing portion arranged one above the other.
10. An aerofoil sail assembly as claimed in claim 9 in which each set of a
15 leading portion and a trailing portion is at substantially the same vertical position.
11. An aerofoil sail assembly as claimed in claim 9 in which each of the trailing portions and the leading portions comprises a leading flap and a trailing flap.
20
12. An aerofoil sail assembly as claimed in any one of the preceding claims in which at least one of the leading and trailing portions is pivotable through around sixty degrees.
- 25 13. An aerofoil sail assembly as claimed in any one of the preceding claims in which at least one of the leading and trailing portions is driveable on a curved track.
14. An aerofoil sail assembly as claimed in any preceding claim in which
30 each of the leading and trailing portions is pivotable by way of toothed gear arrangements.

15. An aerofoil sail assembly as claimed in claim 14 in which each of toothed gear arrangements comprises a rack and pinion.

16. An aerofoil sail assembly as claimed in any one of the preceding claims in which a centre of effort of the aerofoil sail is located anterior of a centreline of the spar.

17. An aerofoil sail assembly as claimed in any one of the preceding claims in which an internal volume of the spar is sized so as to allow an operative access thereto.

18. An aerofoil sail assembly as claimed in claim 17 in which the spar is sized so as to allow an operative access within the spar for a major portion of the length of the spar.

19. An aerofoil sail assembly as claimed in any one of the preceding claims in which the aerofoil sail is a substantially rigid structure.

20. An aerofoil sail assembly as claimed in any one of the preceding claims in which the spar supports the aerofoil portions.

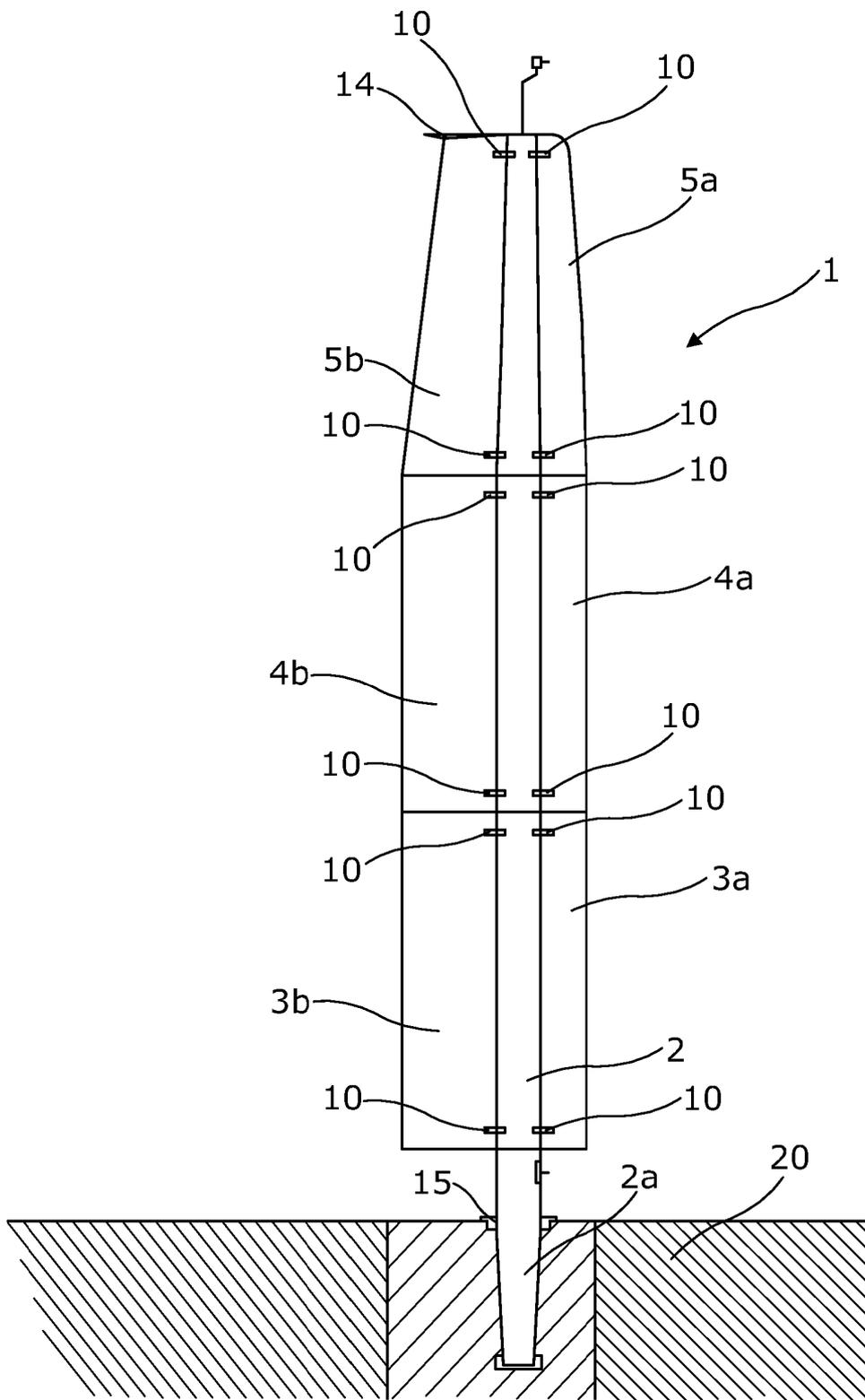


Figure 1

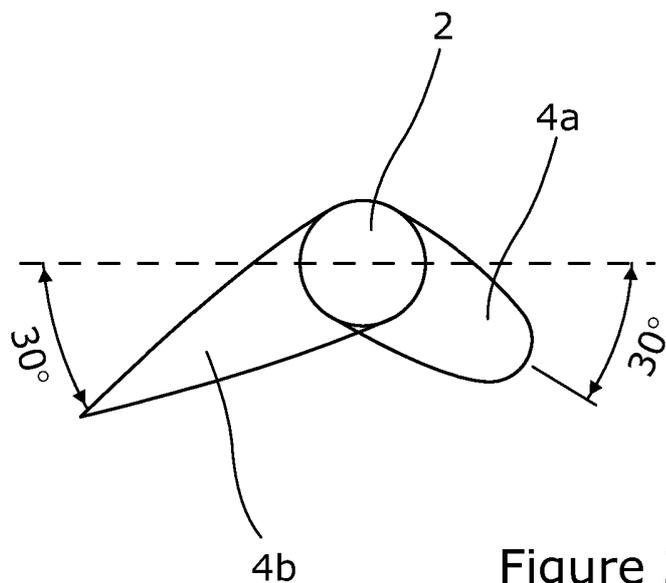


Figure 2

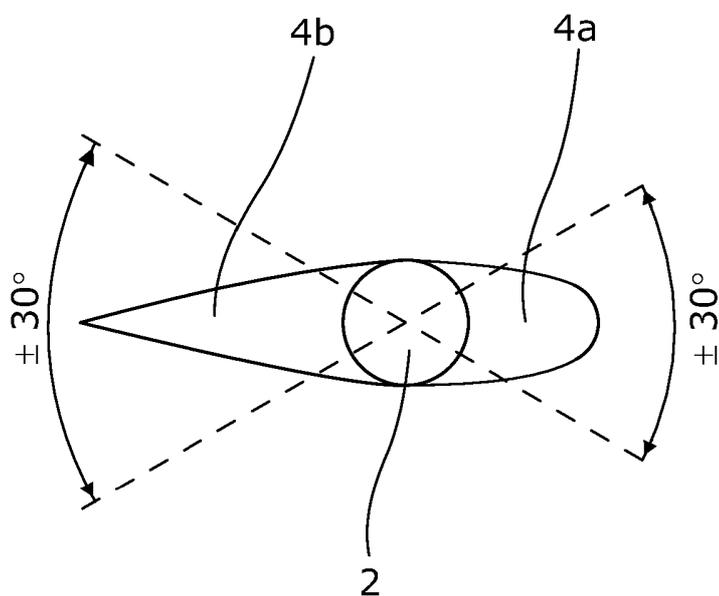


Figure 3

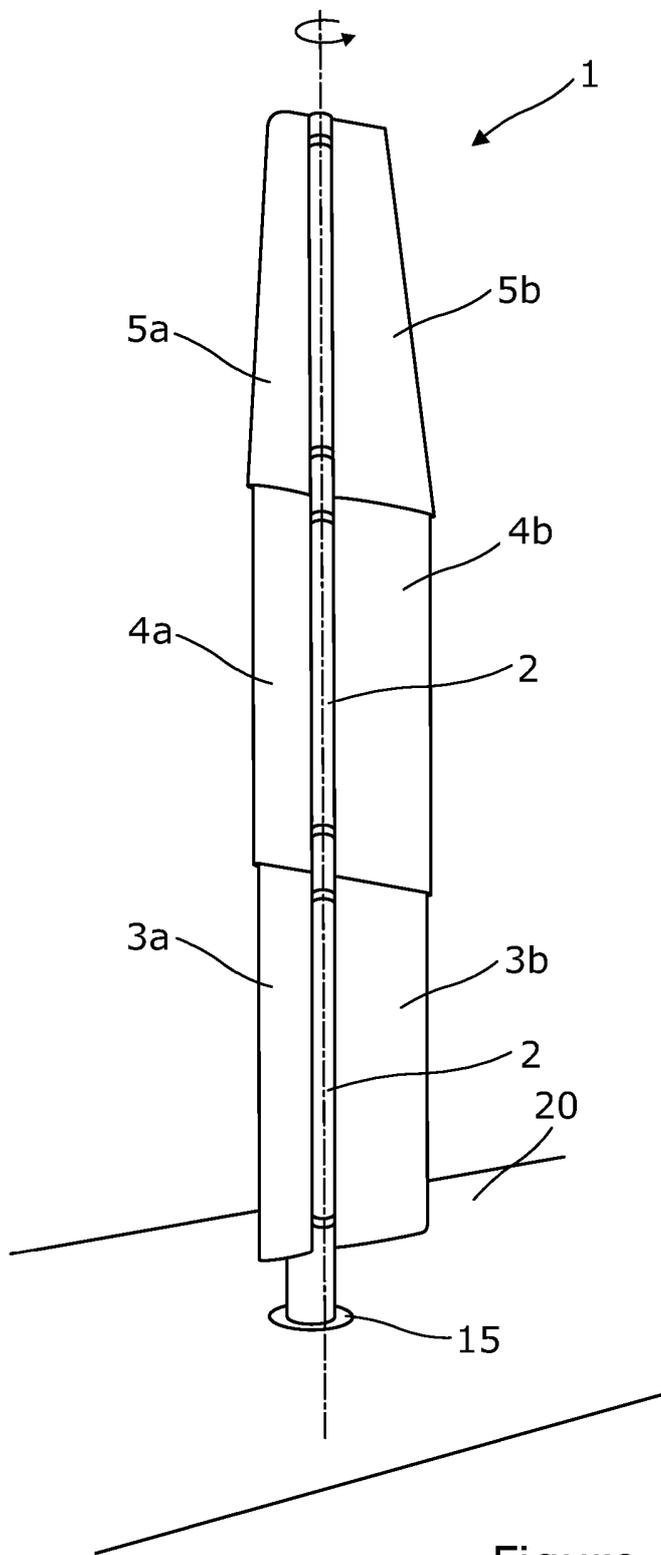


Figure 4

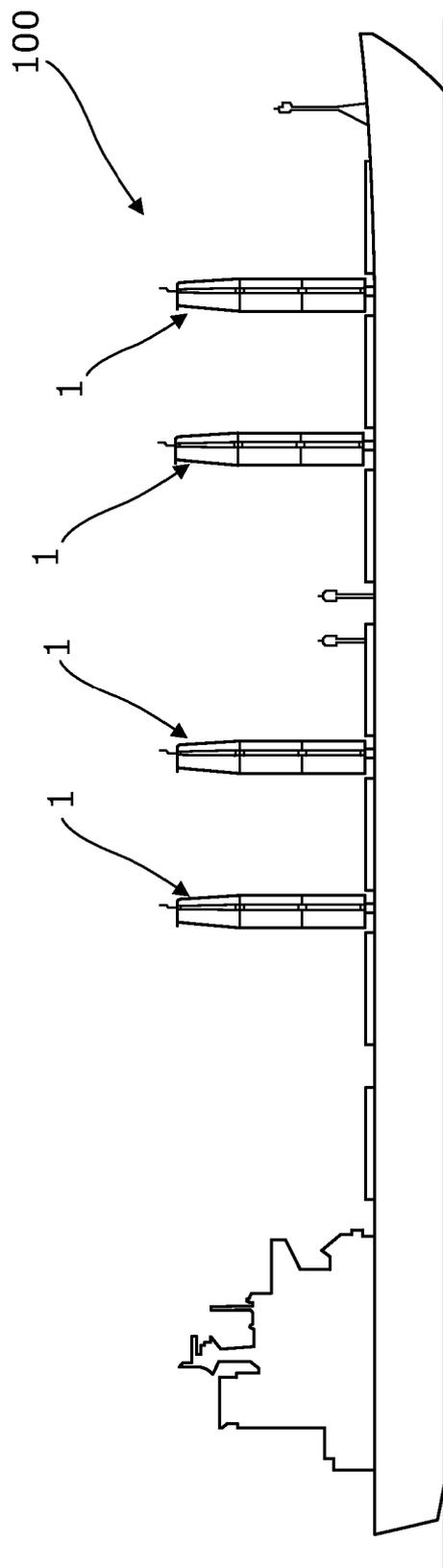


Figure 5

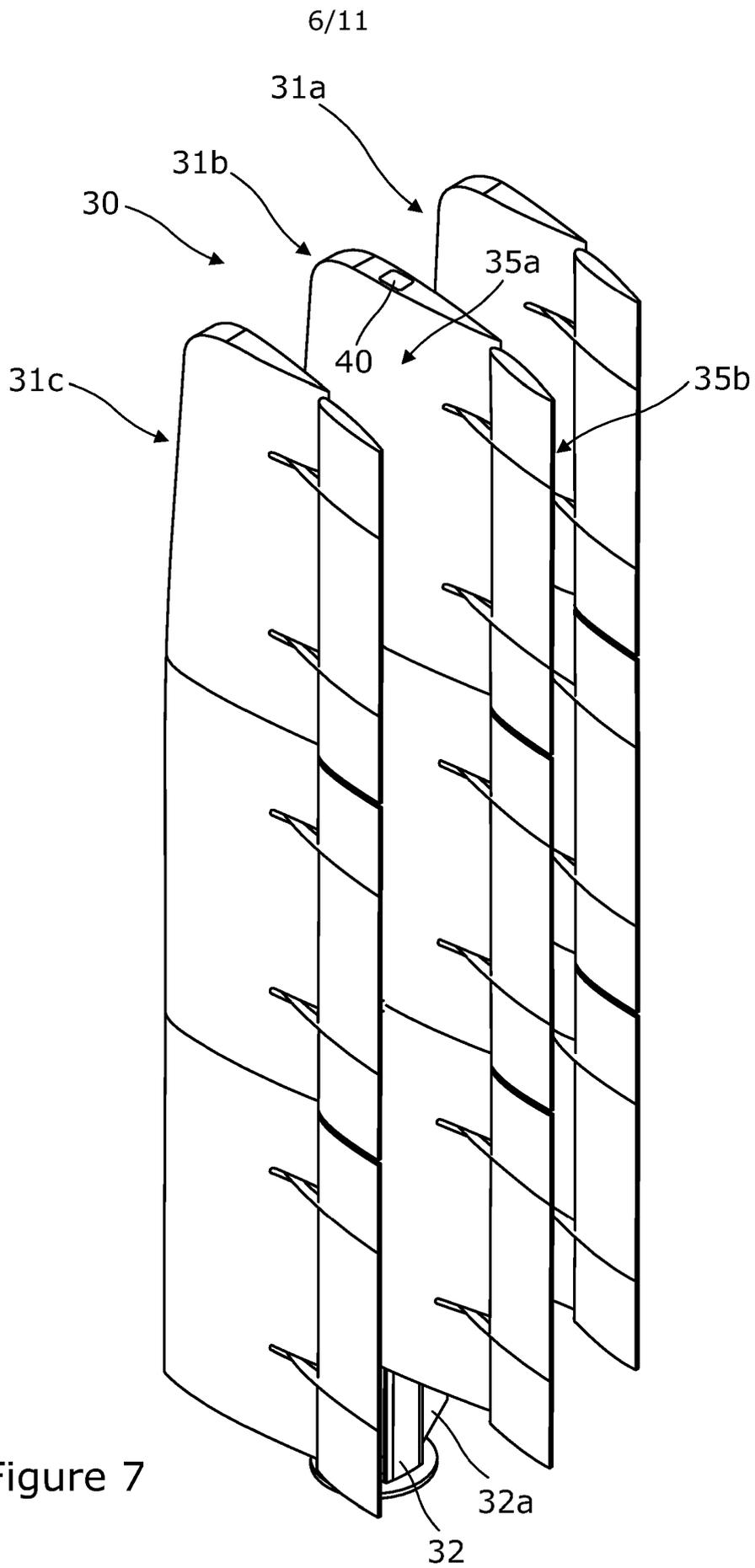


Figure 7

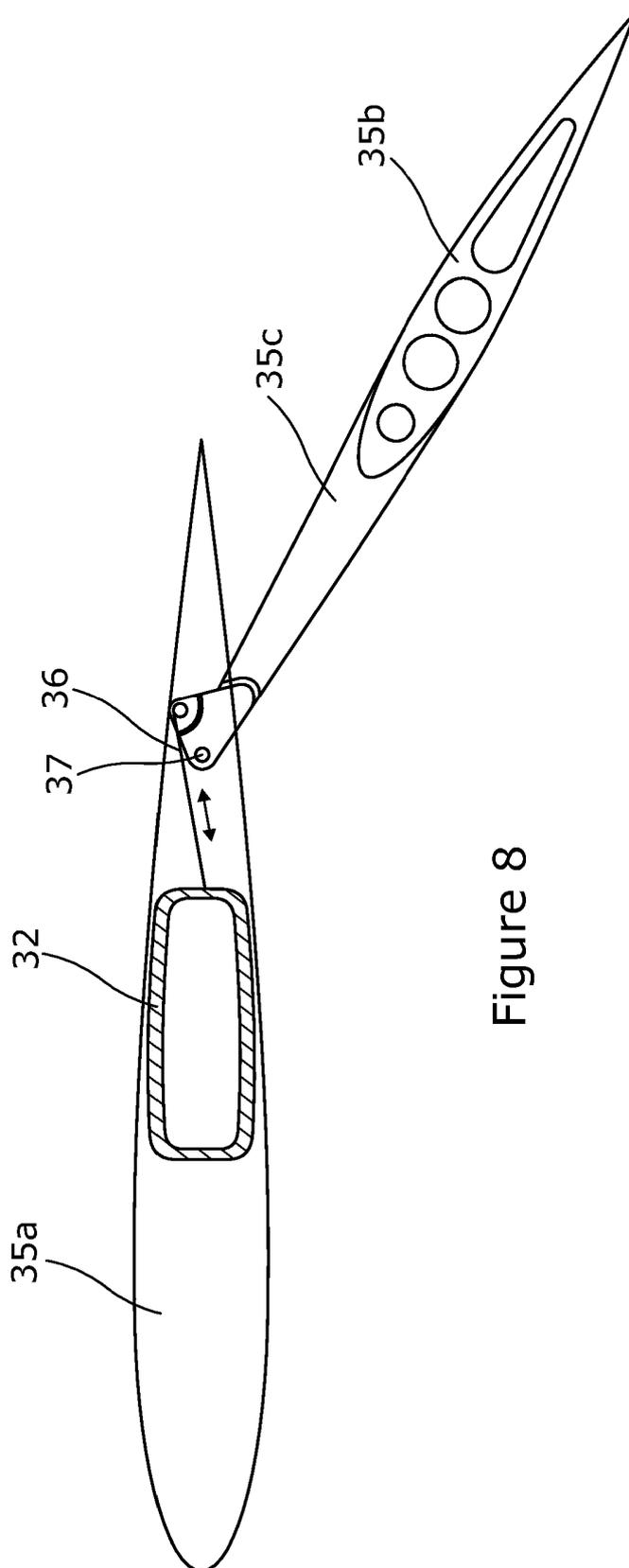


Figure 8

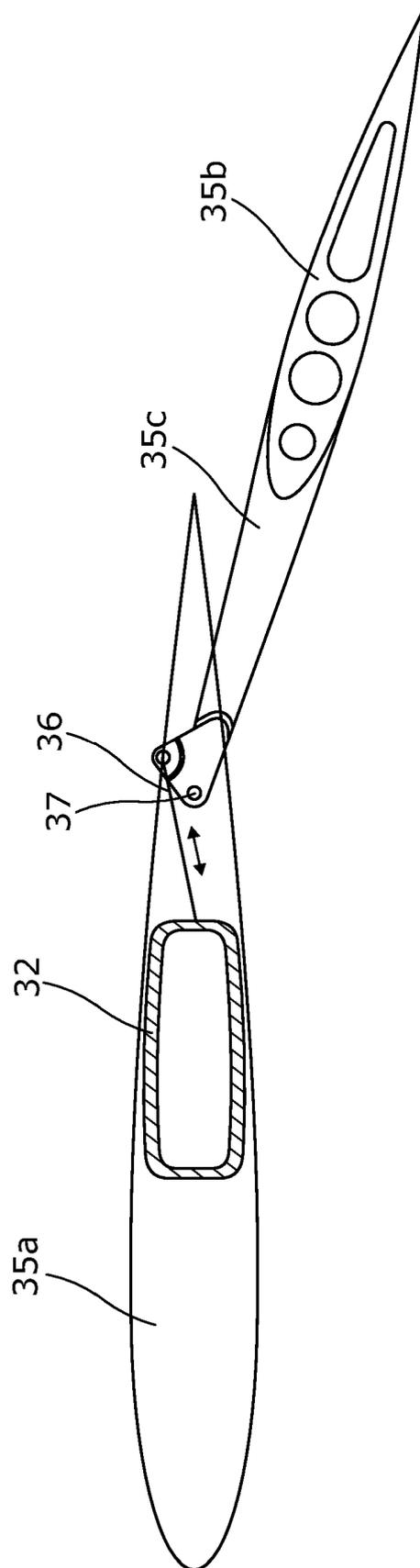


Figure 9

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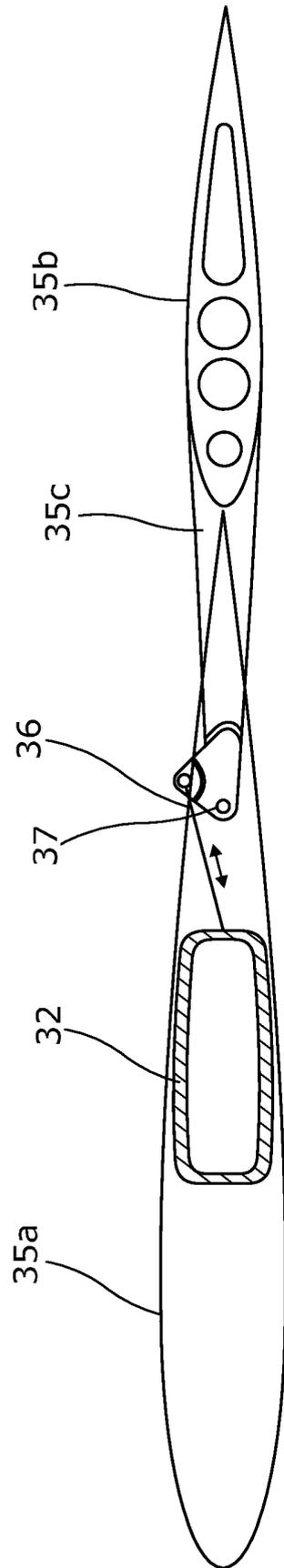


Figure 10

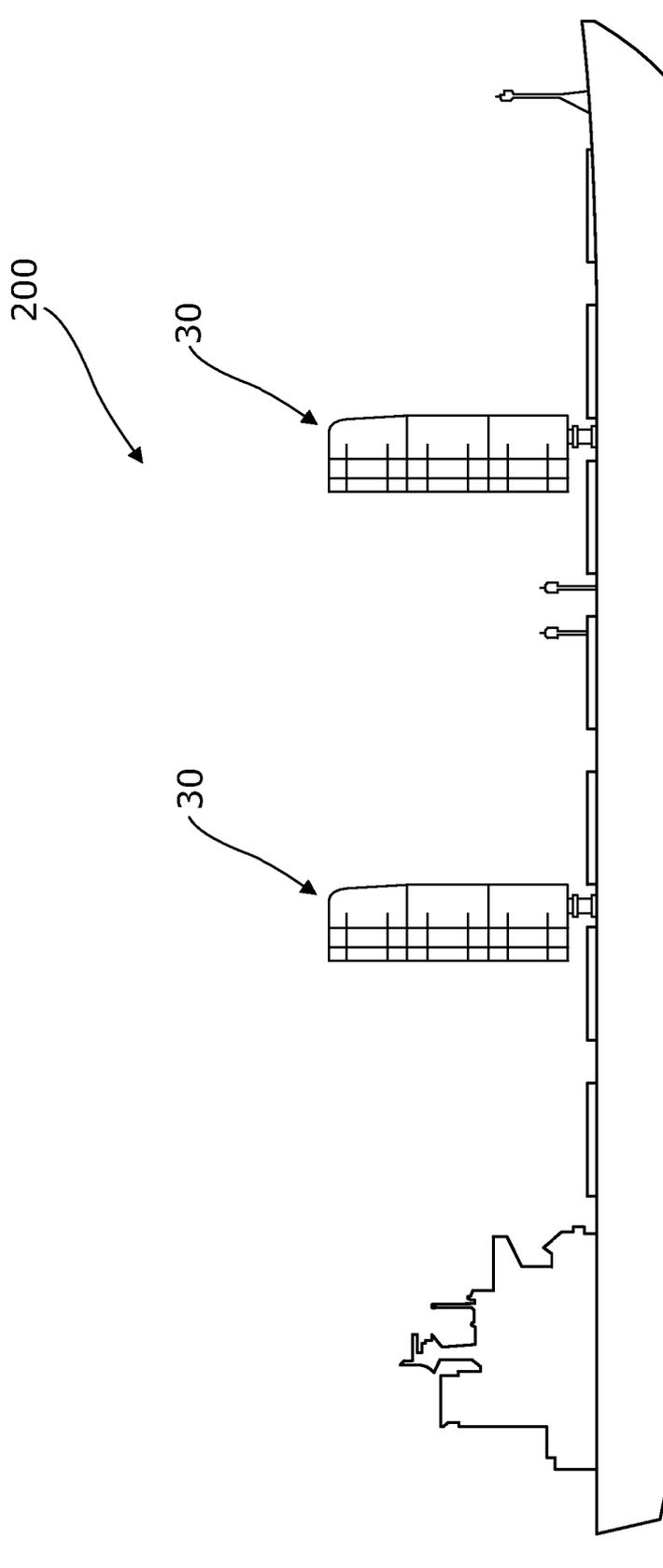
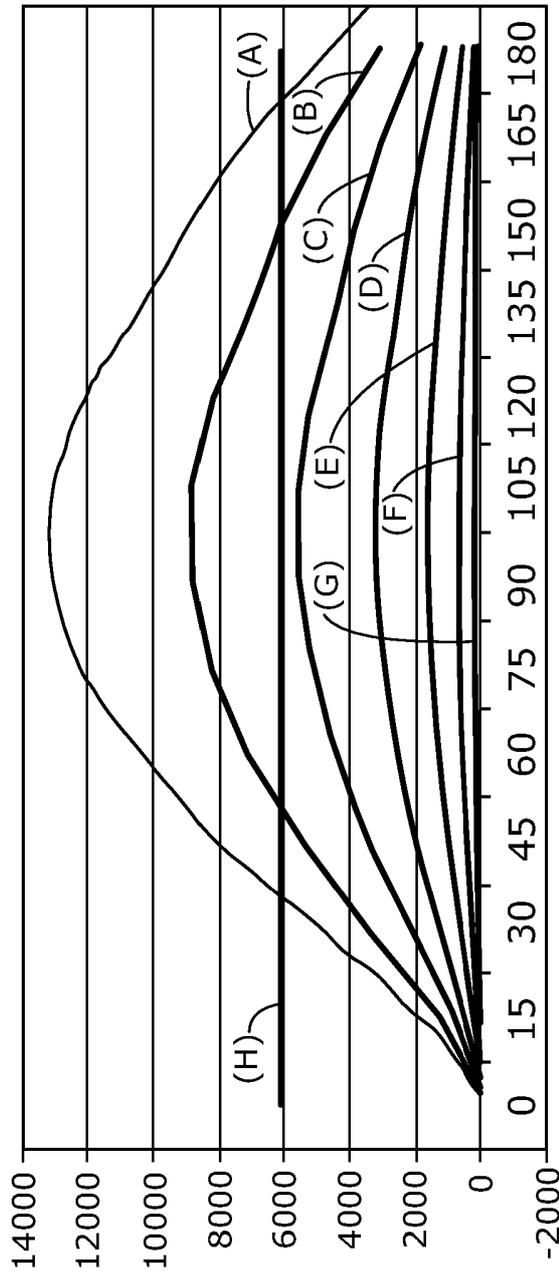


Figure 11

- 74000 DWT SHIP
Total Power (H)
- 10 Knot Apparent
Wind Speed (G)
- 15 Knot Apparent
Wing Speed (F)
- 20 Knot Apparent
Wind Speed (E)
- 25 Knot Apparent
Wind Speed (D)
- 30 Knot Apparent
Wind Speed (C)
- 35 Knot Apparent
Wind Speed (B)
- 40 Knot Apparent
Wind Speed (A)



Apparent Wind Angle

Figure 12