

HIGH SPEED HYBRID MARINE VESSEL

Present invention generally relates to marine vessels and particularly a high-aspect-ratio hydrofoil assisted high speed hybrid hull featuring a main hull and two or more
5 sidehulls.

General.

Among modern high speed vessels, the catamarans have over the latter years gained a dominating market position over monohulls, particularly of size less than 100 meters.
10 This type of vessel is characterized by its simplicity of operation, high stability and relatively high speed- and seakeeping capabilities, particularly in the speed regime of 30-35 knots. The marked, however, seems to continue putting higher demands to speed performance, and several catamarans making 45 knots, and exceptionally above 50 knots, have today become a reality. Seakeeping performance have also become a major
15 issue in modern high speed marine transportation. These demands have resulted in larger propulsion power installations and the introduction of active motion damping systems, like small T-foils located in the bow region and trim-tabs located aft, for improvement of ride comfort. The introduction of T-foils, which basically are non permanent lift generating devices, however, is associated by a notable drag that reduces
20 the speed with approximately 2-3 knots on a 40-45 knots catamaran.

Parallel with the increased speed demands on certain routes, most fast ferry operators are still reluctant to join this trend of development because of the associated sky-rocking fuel consumption. It is very likely that the catamaran technology, initially commercially
25 developed during the early seventies, today have reached its optimum stage of development from a hydrodynamic point of view. Further reduction of drag is severely limited by the fact that the major drag component is related to hydrodynamic skin friction. To overcome this, either wetted surface area has to be reduced, or the skin friction has to be reduced by application of new technology, like air lubrication.

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Recognizing the lack of proven means to solve these technological challenges, it indicates that the catamaran concept, as we know it today, is no longer particularly suited to fully comply with the future marked needs in all respects. This view is supported by the increased attention concerning environmental issues paid by the public and
35 authorities, which is likely to force through the development of novel concepts that performs better in this respect.

In the early nineties, this led among others, to a temporary renaissance of the well-known hydrofoil principle, in order to reduce the frictional forces between the water and the hull. A variation of the catamaran concept with a foil system that lifts both hulls out of the water was introduced, as described in Norwegian patent no. 175199 and various
5 US patents. Apart from the advantages related to speed- and seakeeping capabilities, this technology, however, was associated with a few draw-backs, such as increased investment costs and weight sensitivity problems, which to a considerably degree have limited this particular type of vessel's physical size and pay-load capacity, which ultimately resulted in lack of commercial acceptance.

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Within the environment of naval research, as well as the high speed ferry business generally, one can today observe a clear trend towards designing and model scale testing of various novel designs. Among several trend-braking designs, certain variant of the trimaran concept appears to be a potential interesting compromise of the near future.

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Prior art.

A variant belonging to this category is described in US patent no. 5503100. However, this particular invention seems to be impaired by a number of impracticable and partly un-functional attributes that is likely to render the invention of little or no use
20 concerning requirements connected to high speed vessels generally. Among others, this concerns the underwater hull shape and the arrangement of the propulsion system, which are likely to result in major hull frictional- and form resistance, large draft and excessive overall weight.

The invention.

The present novel design in a preferred version, is a variant of the well-known trimaran design that has gained increased reputation within the sail-boat environment due to its high speed- and seakeeping capabilities. As known, the trimaran design consists of three hull elements, including a long and narrow center hull and a pair of shorter outrigger
30 hulls or side hulls, integrated to the underside of a transverse bridging structure located midship or aft. However, this design is yet not brought into use in the high speed ferry marked. A variation of this design is described in various patents, like US 4348972, 5178085, 5529009, WO 93/07046, 94/20359, 97/10988, EP455605 and JP 63130492.

As known, the so-called Froude's number, expressed by the formulae;

$$Fn = v/\sqrt{g*L}$$

- 5 where, v = speed (m/s), g = gravitational acceleration, L = water line length (m)

plays an important role on a vessel hydrodynamic resistance. On a traditional trimaran featuring fully submerged sidehulls, this tends to operate in a planing regime when the length is short and the speed is sufficiently high. The relatively large side hull
10 submergence which generally characterize these trimarans due to stability requirements, i.e. a sufficiently high positive GM-value, leads to risk of substantial increased resistance at higher Froude numbers.

The present invention is an improved variation of the above mentioned trimaran form
15 and concerns a hybrid marine vessel that operates in two distinctly different modes, namely a hydrostatic stable low speed mode, featuring a positive GM-value with at least three submerged hull elements, including a deep slender main hull and at least a pair of slender and shallow support hulls, which in the following is referred to as side hulls, being integrated to the vessel via a stiff deck construction connecting the side hulls to
20 the main hull, and a partly lifted, hydrostatic unstable high speed mode featuring a negative GM-value, with only the slender main hull partly submerged and the side hulls above the waterline, the transition from the one mode to the other being augmented by the use of integrated hydrodynamic lift-generating, roll stabilizing and pitch controlling wings, or hydrofoils, the vessel being characterized by a combination of following:

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- that the main hull itself is of hydrostatic unstable type, with a negative GM-value, featuring a large water line length in relation to the water line width, and a large main deck width in relation to the water line width;
 - that the aft part of the main hull below its wet deck level has a transverse section
30 as shown on fig. 4a-d, eventually a combination of these;
 - that the forward part of the main hull below its main deck level has a V-, U- or Y- shaped transverse section as shown on fig. 4e-m, over a major portion of its length;
 - that the support hulls have a depth that is substantially less than the depth of the
35 main hull, eventually of adjustable height, and located aft or close to the vessels midship point looking in the speed direction, and symmetrically about its center line;

- that at least one primary hydrodynamic wing or hydrofoil is arranged between the main hull and the sidehulls, integrated to these through vertical struts, eventually also to the in-between-laying wet deck construction through at least one vertical strut, symmetrically arranged on each side of the vessel's center line; and
 - that the main hull, preferably on larger vessels, is equipped with a quick water scooping ballast system of a self controlling type, eventually with means of controlling filling and draining
- 10 In a preferred version, the vessel is equipped with a fully submerged lift generating and roll stabilizing high-aspect-ratio primary hydrofoil located underneath and between the main hull and the sidehulls, close to the vessels longitudinal center of gravity, LCG, and fixed to the main hull, to the in-between-laying wet deck construction and the sidehulls, and a secondary hydrodynamic lift generating and pitch controlling wing or hydrofoil
- 15 located aft or forward, eventually both places, and fixed to the main hull, eventually also to the in-between-laying wet deck construction, depending on the transverse extent of the foil.

In an other preferred version, particularly suited for vessels larger than 100 m, the vessel

20 is equipped with two primary lift generating, roll stabilizing and pitch controlling high-aspect-ratio hydrofoils. Since vessels of this size normally will have full load displacement well in excess of 1000 metric tons, it may be desirable with respect to optimizing overall drag that the foil width is increased beyond the normal width of the vessel in order to provide a lift-to-displacement ratio in the range of 50% at 40 - 45

25 knots speed. Such an arrangement is shown in figure 8. Here, parts of the deck construction is extended transversely beyond the normal width of the vessel in order to facilitate support for the outer struts of the foils. These bridge constructions may also facilitate mooring- as well as embarkation and disembarkation stations.

30 Increasing the lift by increasing the foil width will generally result in multiple drag benefits; reduced hull drag due to less draft and wetted hull area, and overall reduced foil drag due to reduced strut submergence and increased aspect ratio of the foil itself. Even if the foil system from an isolated point of view will result in increased weight due to the foil system and the required structural reinforcements, drag calculations indicate

35 that there is indeed a considerable drag reduction potential at speeds above 35 knots compared to catamarans and monohulls of similar size and payload capacity. In addition, such tandem foil arrangement will provide exceptionally high seakeeping

capability due to high degree of active and passive damping of heave-, pitch- and roll motions. As known, the combination of high speed-to-power ratio and seakeeping has so far been very difficult to achieve, whilst it is of paramount importance to most fast ferry operators.

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For larger versions, like in excess of 200 m, even three primary lift generating foils may be feasible. In such a case their approximate location should be aft, forward and midship. However, if the longitudinal distance between the foils are not big enough, the down-wash effect of the forward foil will create increased resistance on the tracking
10 foil, so the ultimate benefit should be carefully considered.

The particular transverse shape of the main hull, specially on larger vessels, is advantageous compared to traditional catamarans with respect to utilization of the internal hull volume below the main deck, as well as reduction of shell area and
15 structural hull weight. Compared to catamarans of similar overall size and payload capacity, a reduction of shell area in the range of 20-30% can be obtained, including the sidehulls. Normally this will result in a structural weight reduction of the same order.

Best mode.

20 The high speed hybrid marine vessel according to present invention is equipped with hydrodynamic lift-generating, roll stabilizing and pitch controlling wings or hydrofoils, and operates in two distinctly different modes, namely a hydrostatic stable low speed mode, featuring a positive GM-value with at least three submerged hull elements, and a hydrostatic unstable high speed mode, featuring a negative GM-value with only one
25 submerged hull element, consisting of

- a main hull featuring an integrated stiff deck construction, that in the transverse direction protrudes beyond the width of the main hull and where the lower edge of said deck construction, defined as the wet deck lays above the water line when
30 the vessel is at rest on a intact water line, and at an increasing height above the water line when the vessel's forward speed is substantially increased,
- said main hull has a relation between the largest frame width at a random height above the water line and the largest frame width at a water line that represent any
35 intact condition of at least 2,

- said main hull has a relation between the largest water line length and the largest water line width at any upright floating intact condition of at least 6,
- the forward part of said main hull has a V-, U- or Y- shaped transverse section below the main deck level, eventually a combination of these,
- the aft part of said main hull has a V-, U- or Y- shaped transverse section below the wet deck level, eventually a combination of these,
- said main hull is provided with side hulls integrated below the wet deck, featuring a depth that is substantially less than the depth of the main hull such that when the vessel has a speed corresponding to 40-70% of the maximum speed the bottom of said side hulls are above the water line and that said side hulls are located aft or across the vessels midship point viewed in the speed direction, and parallel or at a minor inboard angle to the vessel's center line, located symmetrically about said center line on both sides,
- said wet deck that is at least extending from the upper- and foremost part of the bow of the side hulls to the aft edge or transom of the main hull, features in the longitudinal direction an arc shape with the endpoints located at a higher level than any point elsewhere along the arc, or is in its entirety, or parts thereof, parallel to the main deck, with parts that are in an angle to the main deck, preferably with the fore- and aft ends at a higher level than a plane in between, eventually with a combination of an arc shaped middle part and angular oriented fore- and aft parts,
- said wet deck is in the transverse section parallel or at an angular position to the main deck, such that a point on the outer line that is farther away from the vessel's center line, lies on a level closer to the main deck level,
- said sidehull has wedged bow shape in the horizontal plane and a butt-shaped aft part featuring an area in the horizontal plane that is constant in the vertical direction, or increasing due to the in- and / or outboard sides being vertical or sloped, viewed in a transverse section,

- said sidehull is located such that the position of its transom, when located aft of the vessel's midship point viewed in the speed direction, lies aft of the transom of the main hull,
- 5 - said sidehull has a combined buoyancy at light ship condition and when the vessel is at rest, that amounts to less than 20% of the vessels total light ship buoyancy,
- on larger size vessels, said sidehull can be arranged one forward of the other so
10 that one is located aft of the longitudinal center of gravity and the other is located forward of said point, both located at the same transverse distance to the main hull center line, or the forward sidehull is located at a less distance to said center line, each pair of sidehulls being symmetrically arranged about said center line.

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In a preferred embodiment, said hybrid marine vessel further includes an arrangement consisting of a fully submerged primary hydrodynamic wing or hydrofoil with a chord line (CL), defined as the longitudinal distance between the leading- and following edge of the transverse located hydrofoil profile, and being submerged in relation to the water
20 line at random forward speed at a depth at least corresponding to 50% of the chord line (CL), where the hydrofoil extends in the transverse direction of at least 50% of the distance between the center lines of the main hull and the sidehulls, and where said hydrofoil is located close to the vessel's longitudinal center of gravity, fixed to the main hull, the wet deck and the sidehulls, eventually parts of the wet deck or deck
25 construction extending transversely beyond the sidehulls, or to some of these structural elements, dependent on the transverse length of the hydrofoil, by means of struts, that transfer the hydrodynamic lift to the vessel, and where it is provided at least one remotely controllable flap integrated to the aft part of the hydrofoil on each side of the vessel's center line, that provide the required hydrodynamic stability by executing a
30 controllable transverse righting momentum about the vessels centerline when the vessel moves forward at higher speed and the sidehulls are partly submerged or located entirely above the waterline.

In a further preferred embodiment, said hybrid marine vessel includes an arrangement
35 consisting of a fully submerged secondary hydrodynamic wing or hydrofoil extending in the transverse direction less than 50% of the distance between the center lines of the main hull and the sidehulls, and where said hydrofoil is located forward or aft on the

main hull, eventually both places, fixed to said hull and / or the wet deck, dependent on the transverse length of the hydrofoil as well as the longitudinal position, by means of at least one strut pr. hydrofoil, that transfer the hydrodynamic force, normally an upwards directed force, to the vessel, and where it is provided at least one remotely controllable flap pr. hydrofoil, integrated to the aft part of said foil, that provide the required trim regulating momentum about the vessels longitudinal pivoting center when the vessel moves forward at higher speed.

10 Figures.

The present invention will be explained further by reference to the enclosed figures, where:

- 15 - figure 1 shows the hybrid marine vessel according to the invention, viewed from the side;
- figure 2 shows the vessel according to figure 1, a midship transverse section through the primary hydrofoil, indicating the main hull, wet deck and sidehulls;
- figure 3 shows an aft-ship transverse section, indicating the water line (WL-1) at high speed mode, the water line (WL-2) at low speed mode, and vertical center of gravity (VCG) and the metacentric point (M) at low speed mode and at high speed mode (M1).
- 20 - figure 4a-4d shows optional transverse section of the aft part of the main hull below the wet deck level
- figure 4e-4m shows optional transverse section of the forward part of the main hull below the main deck level
- 25 - figure 5 shows a vessel according to the invention in a aft view, indicating the adjustable sidehulls
- figure 6 shows details in a transverse section of the height adjustable sidehulls on a vessel according to the invention, indicating the operating principle
- 30 - figure 7a-7g illustrates the operating principle of the water ballast system
- figure 8 illustrates the plan of a larger vessel with two sets of primary hydrofoils and two sets of sidehulls
- figure 9 shows a transverse section through the vessel equipped with a surface piercing primary hydrofoil;
- 35 - figure 10 shows plan of a fully submerged primary hydrofoil, indicating leading- and following edge, chord length (CL) and controllable flaps;

Figure 1 shows the hybrid marine vessel (1) with main hull (2) with sidehulls (3). Below the vessel, the primary hydrofoil (4) system and vertical struts (11), as well as the secondary hydrofoil (5) system, are shown.

- 5 As described, an arrangement consisting of a primary hydrodynamic wing (4), or hydrofoil, is located between the main hull (2) and the sidehulls (3), which provide a major hydrodynamic lift force, that results in reduced draft and decreased wetted hull surface, while it simultaneously provide dynamic stability through a surface piercing hydrofoils system (6), as shown on figure 9, or preferably a fully submerged foil system
- 10 supported by vertical struts (11) as shown on figure 2, featuring a fully controllable hydrofoil section, or preferably controllable flaps (27) integrated along the following edge (29) of said foil surface (4). At a speed of 45 knots, the hydrodynamic lift generated by the foil system can attain values corresponding to 50-75 % of the full load displacement of a 45 m vessel, depending on the size of the foil and the displacement.
- 15 As an effect of this, the craft will be lifted sufficiently up in the water so that the side hulls clear the water line.

This gives the craft a major advantage concerning hydrodynamic drag compared to a traditional catamaran that eventually is lifted correspondingly. The reason for this is that

20 the submerged shell area of the main hull of the present vessel is initially relatively less, basically due to the hull shape, and secondary, the effects of the mentioned structural weight reduction. Furthermore, the wetted area of a submerged single hull of any particular shape will be less than two hulls of same shape, even if the total displacement is the same. The mathematical difference in wetted surface of a submerged body of

25 square shape at a given displacement is approximately 27 % less than that of two similar shaped bodies of the same displacement. The corresponding reduction for bodies of triangular shape is approximately 29 %. In other words, a major reduction of hydrodynamic hull friction can be obtained by the present novel design.

30 This fact contributes, together with the effects from the foil generated lift, to a reduction of wetted surface on a 45 m vessel in the range of 50-70 % compared to catamarans of similar size and displacement. Hence, it leads to a major reduction of skin frictional resistance, which render the concept exceptionally well suited as high speed transportation platform.

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Modern hydrofoil systems featuring a high aspect ratio, as is the case for the present invention, have particularly high lift to drag ratio, L/D . Compared to the corresponding

ratio for a catamaran at higher Froude-numbers, namely the displacement to drag ratio, D/D , such a foil system can typically be in excess of 60% more efficient, including resistance from struts and pods. In addition to the effects of reduced wetted surface area of the same order, this gives the present invention superior resistance characteristics
5 compared to catamarans and monohulls.

To exemplify this, at a Froude-number of 1,0, corresponding to 35 knots and a water line length of 34 m, drag and power calculations shows that a vessel according to present invention has 15-20 % lower power requirement than a typical catamaran of same size
10 and deadweight. At 45 knots, however, the power requirement is 40-65 % lower, depending on the actual lift fraction of the foil system.

The lift generated by the hydrofoil system, combined with the trim momentum, makes it possible to decrease the vessel's draft such that the bottom of the sidehulls comes above
15 the water line at a given forward speed, as shown on figure 1-3. On a 40 m length vessel with a beam of 14 m, and a full load displacement of approximately 200 metrical tons, this will typically take place at around 20-25 knots, depending on actual deadweight. At this condition, and at higher speed, just the narrow lower part of the main hull and the hydrofoil system are submerged. At increasing speed the clearance between the
20 waterline and the bottom of the sidehulls will increase, and will typically be above 1 m at 45 knot.

Contrary to traditional catamarans, that is characterized by a high metacentric height that results in high hydrostatic stability, or roll stiffness, the vessel according to present
25 invention initially has lower hydrostatic stability at small angles of inclination when at rest in the water. With increased speed and lift generated by the hydrofoil system, the hydrostatic stability becomes further reduced. When the speed and lift is high enough, and the sidehulls clear the waterline, the vessel according to present invention will enter a completely hydrostatic unstable condition. Such a condition is characterized by a
30 negative metacentric height, GM, which generally is defined as the vertical distance between a vessel's vertical center of gravity, VCG, and an imaginary metacentric point (M) on a vertical line through the vessel's centerline. At small angles of inclination said vertical line will be crossing itself at a given point, normally above the VCG. The larger the distance the metacentric point is located above VCG, the higher hydrostatic stability.
35 An unstable vessel is therefore generally associated with a low, or negative GM value, meaning the metacentric point is below VCG.

This can be illustrated more practically by considering the fact that the relation between the water line length and width of the main hull, L/B is high at the same time as the vessels vertical center of gravity, VCG also is high. To exemplify the condition, as shown on figure 3, the VCG (G) will for the said 40 m vessel at a such condition be located approximately 2,7 m above the waterline. The maximum waterline length of the main hull is approximately 37 m, and the width at that waterline is approximately 3.7 m. Keeping in mind that the whole vessels weight of approximately 200 metric tons is centered at the VCG (G), it has obviously no stability at all under this condition, and will isolated viewed unconditionally capsize, unless the required righting momentum is provided hydrodynamically by the foil system and / or in combination with the hydrostatic effect from the side hulls. The corresponding location of the metacentric point for such a condition is illustrated by the point M2.

Figure 4 shows, as above indicated, various main hull forms that are examples of labile or hydrostatic unstable hull forms.

First line of hull forms shown on figure 4, indicated a-d, shows four possible hull shapes of the aft part of the main hull below the wet deck level. To the right, the various referenced levels are indicated, namely; water line (WL-1), wet deck (8) level and main deck (7) level.

The remaining variants of figure 4, e-m, shows possible hull shapes of the forward part of the main hull below the main deck level. As indicated, it may consist of the principally distinguished V-, U- or Y-shapes, or combinations of these.

The dynamic stability operating principle applied to the hybrid marine vessel according to the present invention, is basically similar to those applied on modern jet-fighter planes. As known, these type of planes are aerodynamically unstable, and can not be manually controlled as opposed to the conventional stable planes that can be controlled by the pilot. Therefore they are controlled by computers in a principally identical way as the vessel according to present invention. Needless to say, they are statically stable when supported by the wheels on the ground, similar to the present hybrid vessel when at rest or at low speed. A more down to the earth example is the bicycle, which also is statically unstable and can not be balanced without a righting momentum being applied to it.

A static unstable condition is very advantageous with respect to achieving high ride comfort by utilizing an active dynamic stabilization effect provided by the controllable flaps on the hydrofoil. The externally excitation forces represented by the wave impacts on the hull is naturally much less for a hull according to present invention characterized by a negative GM-value, as opposed to a traditional catamaran vessel characterized by a high positive GM-value. This is particularly the case in beam waves that cause roll motions. In effect this results in that the vessel according to the present invention will exert limited or no roll motions dependent on the wave height, while the said catamaran have no ways to avoid this, even if equipped with a hydrofoil system of same capability.

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Since only the main hull is submerged in the water, an this typically feature a considerably less water plane area than a catamaran or a traditional monohull, also the vertical heave movements are reduced. These are further reduced due to the combination of passive and active heave damping of the relatively large primary hydrofoil located near the LCG, or slightly forward of said point, as indicated on figure 1.

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Under a normal service condition where the speed typically will be 40-45 knots, the craft will have a dynamic stability margin against roll excited by side waves that at least can be compared to the so-called foil-catamarans that is lifted completely above the water. This is so because the sidehulls have considerably less displacement compared to said foil-catamarans. With respect to the pitch movements, the aft or forward located secondary hydrofoil, or trim foil, located on the main hull will generate a major pitch damping effect. This renders the vessel according to the present invention unique seakeeping capabilities.

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When designing such a vessel, due attention has to be paid to features like the depth and buoyancy of the main hull, side hulls, location of VCG, LCG and the lift center of the foils. To arrive at an vessel that is optimized from an performance point of view, requires a delicate balance and compromise between these factors.

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An important criterion is to obtain a sufficient high clearance between the waterline and the bottom of the sidehulls during all phases of high speed operation. This is so in order to reduce the wave impact in larger sea states and minimize the drag that otherwise will tend to create directional instability and potential speed loss. On the other hand the stability requirements requires the sidehulls to be deep enough to provide hydrostatic stability. This requirement tends to work detrimental to the first mentioned criterion.

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A feasible solution to this dilemma is to introduce a self-priming and evacuating water ballast tank in the bottom of the main hull, as described in the following, that in effect will reduce the depth and the displacement requirement of the sidehulls, since the vessel get a larger draft when the tank is filled at rest and low speed. This arrangement is not necessarily required for vessels of smaller size vessels, like in the 30-50 m range. For larger sizes, say in the range of 70 m upwards, the displacement will be of such an order that even a pair of large hydrofoils is unlikely to provide sufficient lift, at say 25 knots, to make the sidehulls clear the waterline. Therefore vessels of increasing size are likely to have increased benefit of such a system. An alternative to this arrangement will be adoption of sidehulls that are adjustable in height, as will be described in the following. Alternatively a combination of these means.

When the vessel moves forward at lower speed, or is at rest in the water, the lift force from the foil system is reduced or canceled. Thus, the draft will increase and both sidehulls (3) will be submerged as indicated by the water line (WL-2) on figure 1 and 3. The sidehulls will thus provide the required hydrostatic stability.

A method to render this possible, is to make the relation between the vessel's longitudinal center of buoyancy and the longitudinal center of gravity, without any significant lift from the hydrofoils (4,5), such that the forces acting in above mentioned centers, are in balance at a given aft trim that provides sufficient submergence of the sidehulls, and thus provide the required static stability. A potential draw-back by this method is that the vessel may get a relatively large aft trim.

A way to adjust the draft of the sidehulls is indicated on figure 5 and 6. The adjustment of the side hulls (3) may principally take place in any technical feasible way, for example by means of suitable support element (21) that is forced out of its normal stored compartment (22) by means of injecting fluid into a piston device that forces the said element downwards until it is sufficiently displaced in the water, as indicated on figure 5. In this way a hydrostatic unstable hull can be made stable, and the support elements can under any desired condition be redrawn so that it no longer is in contact with the water.

Contrary, the sidehulls are kept in lower position at a given depth or displacement when the vessel moves forward at a lower speed, or is at rest in the water. When the speed increases and the hydrofoil system provide the required dynamic stability, the sidehulls are temporary lifted such that a desired clearance to the water line is obtained. Such an

arrangement may be provided by support elements (21) that is connected to the above located wet-deck (8) by means of a plurality of pneumatic or hydraulic actuators (23) located between these (8, 21), in addition to an air sealed flexible membrane (24) fastened to said adjustable elements and the above located wet-deck. The actuators (23) may be connected to a common or individual pressure accumulator provided with the required permanent pressure, such that it keep the actuators and the adjustable elements in a permanent lower position, retained by the flexible membrane (24) that completely surrounds said elements and the internally located actuators. Lifting of the support elements is provided by applying a negative pressure to the internal volume (22) within the flexible membrane by use of electrically driven vacuum pumps. Thereby the relatively large internal area will execute a sufficient vertical lift force that exceeds the opposing vertical forces generated by the pressurized hydraulic or pneumatic actuators (23), so that said actuators becomes compressed, which results in that the support elements temporarily will be lifted to an upper position. The electrical vacuum pumps can be started manually from the bridge, while the controller signal that disengages the said pumps may be provided by the vessel's permanent electronic feed-back system, as for example the speed log and roll indicator. This will secure that the vacuum pumps automatically will be disengaged at a certain condition or situation, for example a given maximum roll angle or a minimum speed. The support elements will then automatically be lowered back into normal displaced position.

The draw-back connected to this method is that it is relatively complicated and cost demanding. For smaller size vessel, like 30-60 m, it will result in relatively large increase of weight. For larger size vessel, however, this is not necessarily the case, since it may actually reduce the weight, depending on the overall size and the actual level of the wet-deck above the waterline. The advantage is that it makes it possible to reduce the draft of the sidehulls when the vessel is operating in the high speed mode, which in effect will reduce the chances of sidehull interference with waves. Compared to the water ballast method, which will be described in the following, it will reduce maximum draft as well as resistance at low speed, since the increased displacement at lower speeds is avoided.

An other method is that the vessel is equipped with a separate water ballast tank (15) as shown on figure 1 and 7, structurally integrated into the bottom of the main hull (2), and located a distance forward of the vessel's transom, preferably aft of the longitudinal center of gravity, LCG. At the aft part of the tank a suitable formed opening (16) is located, at a given distance aft of a vertical step (17) in the bottom plating. When the

craft is at rest, and with a forward speed which is below a given value, the water will enter into the tank, as illustrated on figure 7b. The maximum speed at which this takes place is given by the longitudinal length of the opening (16) and the vertical distance between the forward located step (17) and the aft located toe (18), as well as the static pressure-head of the water. When the speed is above this value, the water flow will separate at the vertical step (17). At increased speed the direction of the water flow will move more towards the horizontal plane, until it at a given speed no longer will hit the toe on the inclined aft part of the opening, but pass underneath this, as illustrated on figure 7 a. Under this condition the ballast tank will no longer be scooping water, but gradually being drained due to the so-called ejector principle, until it is completely empty. At a given lower speeds, the water flow will again hit the toe, become separated and scooped into the tank until it is filled. The tank is equipped with an air pipe (25) for ventilation to the atmosphere in order to avoid internal vacuuming and pressurizing of the tank.

Above described procedure requires a condition with a certain degree of idealization, where the static pressure head, given by the draft of the vessel, is approximately constant. This, of course, is naturally not always the case since it is influenced by the vessel load condition, trim, foil generated lift and waves. To cure this problem, a controllable wedged shoe (19) can be installed at the aft part of the opening, as indicated on figure 7 d. This is hinged at a point (27) at the aft part so that its angular position freely can be regulated up and down. The bottom of the shoe is preferably shaped such that it has an arc shape in the longitudinal direction. The toe of the shoe is wedge-formed to easily allow separation of the water flow. While the vessel is at rest, or moves forward below a given speed value, the shoe will be tilting downwards in the vertical plane as illustrated by the dashed lines on figure 7 d, such that the toe of the shoe protrudes sufficiently deep in relation to the lower edge of the step (17) in order to secure that the shoe is scooping water. Depending of the vertical position of the toe in relation to the said lower edge of the step, the angle of the hinged shoe will at a given speed be changed by it self when the water flow no longer hits the toe. At this point the water scooping ceases, and the tank is gradually being drained. Under this condition the shoe will be planing on the surface of the water flow due to the planing forces and the vertical momentum about the hinge of the shoe, as long as this is freely supported. As long as the speed is above a given value, the angle of the shoe will regulate itself and adapt to the minor variations of the surface of the water flow, which are influenced by trim and waves, without the toe touching the water plane. When the forward speed again is reduced below a certain value, the water flow will hit the toe, become separated and

get scooped into the tank. By connecting a remotely controlled hydraulic cylinder to the shoe, one can to a greater degree control its angular position and thus fill and drain the tank more independent of the vessel's speed (v).

- 5 An alternative to above described shoe device, is the arrangement shown in figure 7 f-g. Here the hinged shoe is removed and replaced by a permanent toe, as first described.. However, a hinged plate (20) is arranged in front of the opening. A remotely operated actuator device (26) being controlled from the bridge, is attached to the plate so that it can be tilted vertically about its forward located hinge (27). When the plate is at its
- 10 lower position, the water flow will separate at the aft edge of the plate, and pass underneath the toe dependent of the forward speed and the tilting angle of the plate. When the plate is tilted slightly upwards, the water flow will adhere to the plate, depending on the tilting angle and forward speed (v), and being led into the tank. This method is safer and more advantageous from an operational point of view, compared to
- 15 the above described shoe alternative. Like the remotely controlled shoe alternative, the priming and draining of the tank can be controlled more independently of the vessels speed and trim, but the latter alternative is likely to be less exposed to operation damage. Dependent of the volume of the tank and its longitudinal position, the above described quick water ballast system can be used to give the sidehulls the required
- 20 degree of submergence, which means that the vessel will get a rapid transition form dynamic to static stability. Naturally also the transition can be aided by use of the trim foil This method is advantageous due to its operational simplicity.

P a t e n t C l a i m s

1.

High speed hybrid marine vessel (1) with hydrodynamic lift-generating, roll stabilizing and pitch controlling wings (4, 5) or hydrofoils, that operates in two distinctly different modes, namely a hydrostatic stable low speed mode, featuring a positive GM-value with at least three submerged hull elements (2, 3), and a hydrostatic unstable high speed mode, featuring a negative GM-value with only one submerged hull element (2), characterized by that

- it consists of a main hull (2) featuring an integrated stiff deck construction, that in the transverse direction protrudes beyond the width of the main hull (2) and where the lower surface of said deck construction, defined as the wet deck (8) lays above the water line (WL-2) when the vessel is at rest at an intact condition, and at an increasing height above the water line when the vessel's forward speed is substantially increased,
- said main hull (2) has a relation between the largest frame width at a random height above the water line and the largest frame width at a water line (WL-1, WL-2) that represent any intact condition of at least 2,
- said main hull (2) has a relation between the largest water line length and the largest water line width at any upright floating intact condition of at least 6,
- the forward part of said main hull (2) has a V-, U- or Y- shaped transverse section below the main deck (7) level, eventually a combination of these,
- the aft part of said main hull (2) has a V-, U- or Y- shaped transverse section below the wet deck (8) level, eventually a combination of these,
- said main hull (2) is provided with sidehulls (3) integrated below the wet deck (8), featuring a depth that is substantially less than the depth of the main hull such that when the vessel has a speed corresponding to 40-70% of the maximum speed the bottom (12) of said sidehulls are above the water line (WL-1),

- said sidehulls (3) are located such that the major portion of said sidehulls are positioned aft of the vessels midship point viewed in the speed direction, or that said sidehulls are positioned approximately midship,
- 5 - said sidehulls (3) are located such that they are parallel to the vessel's longitudinal center line (9), or at a minor inboard angle, such that the longitudinal center line (10) of said sidehulls are closer to the main hull's center line (9) at the transom than the bow, and that said sidehulls are located symmetrically about the main hull's center line (9) on both sides,
- 10 - said wet deck (8) is at least extending from the upper- and foremost part of the bow (30) of the sidehulls to the transom (14) of the main hull (2), and features in the longitudinal direction an arc shape with the endpoints (30, 31) located at an higher level than any point elsewhere along the arc, or is in it's
15 entirety, or parts there off , parallel to the main deck (7), or with parts that are in an angle to the main deck, preferably with the fore end (30) and aft end (31) at a higher level than a plane in between, eventually with a combination of an arc shaped middle part and angular oriented fore- and aft parts,
- 20 - said wet deck (8) is in the transverse direction horizontal or in an angular position, such that a point (32) on the outer line that is farther away form the vessel's vertical center line (9), lies on a higher level, or at the same level, as a point (33) located closer to said center line,
- 25 - said sidehulls (3) have wedged bow shape in the horizontal plane and a butt-shaped transom (13), when positioned aft of the vessel's midship point viewed in the speed direction, featuring an area in the horizontal plane that is increasing in the vertical direction, due the vertically inclined bow and that the inboard sides (35) and / or outboard sides (34) being sloped, viewed in a transverse section,
- 30 - said sidehull (3) are located such that the position of the transom (13), when located aft of the vessel's midship point viewed in the speed direction, lies aft of the transom (14) of the main hull,
- 35 - said sidehull (3) have a combined buoyancy at light ship condition and when the vessel is at rest, that corresponds to less than 20% of the vessels total light ship buoyancy,

- on larger size vessels, said sidehull (3) can be arranged one forward of the other so that one is located aft of the longitudinal center of gravity (LCG) and the other is located forward of said point, both located at the same transverse distance to the main hull center line (9), or the forward sidehull is located at a less distance to said center line, each pair of sidehulls being symmetrically arranged about said center line.

2.

- 10 High speed hybrid marine vessel (1) according to claim 1, characterized by an arrangement consisting of a fully submerged primary hydrodynamic wing (4) or hydrofoil with a chord line (CL), defined as the longitudinal distance between the leading edge (28) and following edge (29) of the transverse located hydrofoil, and being submerged in relation to the water line (WL-1, WL-2) at random forward speed at a
- 15 depth at least corresponding to 50% of the chord line (CL), where the hydrofoil extends in the transverse direction of at least 50% of the distance between the center line (9) of the main hull and the center line (10) of the sidehulls, and where said hydrofoil is located close to the vessel's longitudinal center of gravity (LCG), fixed to the main hull (2), the wet deck (8) and the sidehulls (3), eventually parts of the wet deck or deck
- 20 construction extending transversely beyond the sidehulls, or to some of these structural elements, dependent on the transverse length of the hydrofoil, by means of struts (11), that transfer the hydrodynamic lift force to the vessel, and where it is provided at least one remotely controllable flap (27) integrated to the aft part of the hydrofoil (4) on each side of the vessel's center line, that provide the required hydrodynamic stability by
- 25 executing a controllable transverse righting momentum about the vessel's centerline (9) when the vessel moves forward at higher speed and the sidehulls are partly submerged or located entirely above the waterline.

3.

- 30 High speed hybrid marine vessel (1) according to claim 1 and 2, characterized by an arrangement consisting of at least one fully submerged secondary hydrodynamic wing (5) or hydrofoil extending in the transverse direction less than 50% of the distance between the center line (9) of the main hull and the center line (10) the sidehulls, and where said hydrofoil is located forward or aft on the main hull, eventually both places,
- 35 fixed to said hull and / or the wet deck (8), dependent on the transverse length of the hydrofoil as well as the longitudinal position, by means of at least one strut (11) pr. hydrofoil that transfer the hydrodynamic force to the vessel, normally an upwards

directed force, and where at least one remotely controllable flap (27) pr. hydrofoil is integrated to the aft part of said foil, that provide the required trim regulating momentum about the vessels longitudinal pivoting center when the vessel moves forward at higher speed.

5

4.

High speed hybrid marine vessel (1) according to claim 1 and 2, characterized by an arrangement consisting of two or more fully submerged primary hydrodynamic wings (4) as described in claim 2, where one hydrofoil is located substantially forward of the vessel's longitudinal center of gravity (LCG), and one hydrofoil is located substantially
10 aft of said point, fixed to the main hull (2), the wet deck (8), the sidehulls (3), eventually parts of the deck construction extending transversely beyond the sidehulls, or to some of these structural elements, dependent on the longitudinal position and transverse extension of the foil, by means of struts (11).

15

5.

High speed hybrid marine vessel (1) according to any of above claims 1-4, characterized by an arrangement consisting of one or several hydrodynamic self-stabilizing surface piercing wings (6) or hydrofoils located and fixed to the vessel as described in any of
20 the claim 2-4 by means of vertical and / or inclined struts (11).

6.

High speed hybrid marine vessel (1) according to any of above claims 1-5, characterized by the hydrodynamic lift fraction generated by the hydrofoils at maximum speed are at
25 least 20 % of the vessel's total displacement.

7.

High speed hybrid marine vessel (1) according to any of above claims 1-6, characterized by the sidehulls (3) consisting of structurally integrated, or independent fastened,
30 elements located below the wet deck (8) and made of a stiff construction material, alternatively a flexible shock absorbing elastomeric material, all over it's length or over a major portion of it's length.

8.

35 High speed hybrid marine vessel (1) according to any of above claims 1-7, characterized by the sidehulls consists of support elements (21) that are adjustable in the height all over its length, or over a major portion of its length

9.

High speed marine vessel (1) according to any of above claims 1-8, characterized by the main hull (2) being equipped with one, or a plurality of, water ballast tanks (15) for quick draining and priming of water by means of (16, 17, 18, 25).

10.

High speed marine vessel (1) according to any of above claims 1-9, characterized by a water ballast tank (15) being integrated in the submerged part of the main hull (2) featuring a permanent opening (16) in the bottom of said hull, positioned forward of the transom (14) of the main hull, for utilizing the effect of the surrounding water's static pressure head and / or dynamic pressure head for quick priming of the tank when the vessel is at rest or moving forward, and utilizing the effect of the dynamic pressure head of the water flow passing below the opening to drain the water ballast at a forward speed, by means of a vertical step (17) in the bottom plating and a structurally integrated wedged toe (18) at the aft part of the opening, alternatively a self-regulating and remotely controlled separate hinged shoe (19) located in the aft part of the opening, or a remotely controlled plate (20) located in the forward part of the opening and hinged at point (27) behind the vertical step.