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SELF-ACTUATING, FOLDABLE OBSTACLE SYSTEM ON HYDRAULIC LIFTING BODIES

BACKGROUND OF THE INVENTION

5 The invention relates generally to hydraulic lifting bodies such as the blades of marine propellers, hydro-turbines, pumps, fins, or rudders of ships, and the like. More specifically the invention provides apparatus and methods for preventing or reducing cavitation noise and erosion on such lifting bodies.

10 Cavitation on the surface of a hydraulic lifting body causes noise and erosion of that surface. These are caused by the formation and collapse of bubbles adjacent to the surface due to pressure changes as the fluid flows over the lifting body. The situation is most severe when unsteady sheet cavitation and a bubble cloud (cloud cavitation) occur on the surface of the
15 hydraulic lifting body under operating conditions. The bubble cloud may contain thousands of tiny bubbles. These bubbles' collapse often causes significant broad-band noise and surface erosion.

 A re-entrant jet over the surface of the lifting body causes periodic shedding of such a bubble cloud under a thick sheet cavity. The re-entrant
20 jet travels forward over the surface of the body at a speed on the order of the inflow of fluid over the body. A re-entrant jet rushing from the end of

the unsteady sheet cavity to the leading edge of the lifting body triggers the sheet cavity's collapse. As a result, the sheet cavity is cut off in the vicinity of its leading edge. The cut off portion of the sheet cavity then moves downstream as a cluster of bubbles called a cloud cavity or bubble cloud.

Cloud cavitation can be controlled by obstacles on the surface of the lifting body. Such obstacles can reduce or eliminate noise and surface erosion. When cavitation is not occurring, though, these obstacles cause an undesirable increase in foil drag and the efficiency of the lifting body is thereby reduced. Thus, if one or more obstacles are provided on the lifting body, under cavitation conditions the noise and erosion as well as drag can be reduced. When the cavitation conditions are removed, though, the continued presence of the obstacle or obstacles increases drag and reduces the effectiveness of the lifting body. Such obstacles should be removed, therefore, whenever cavitation is not occurring.

It is difficult to determine, though, just when a lifting body such as a propeller or a hydro-turbine blade might experience cavitation. It is thus quite difficult to determine when the obstacle is helpful to reduce cavitation noise and erosion, and when it should be removed for greater efficiency. It is difficult, too, to determine where on the lifting body's surface the re-entrant jet will pass by. Obstacles provided in locations on the lifting body where the re-entrant jet does not appear are of little or no use. Even if one could predict cavitation conditions correctly, obstacles on the lifting body

will still disturb fluid flow over the lifting body under conditions that do not cause cavitation. Many lifting bodies such as propeller blades or hydro-turbine blades are rotated at very high speeds, moreover, and it is very difficult to install servo-control devices or the like to control the
5 **presence**, and removal of obstacles for such lifting bodies under operating conditions. Furthermore, sensors are required on the lifting body to provide information about when and where cavitation is occurring

A need exists, therefore, for improved apparatus and methods for providing removable obstacles selectively on hydraulic lifting bodies under
10 cavitation conditions. Such apparatus should be simple, inexpensive, and effective in operation. The apparatus should provide obstacles placed appropriately on the lifting body surface under cavitation conditions. Those obstacles should then be removed from the surface when cavitation is not in effect. The invention provides these and other advantages, as will be
15 appreciated more fully in connection with the explanation below

SUMMARY OF THE INVENTION

In accordance with the invention, a foldable obstacle device is provided for blocking a re-entrant jet produced by unsteady sheet cavitation
20 on a hydraulic lifting body. The foldable obstacle device is mounted at a surface of the body and is movable between a closed position at the surface of the body and an open position extending outwardly from the body. The

foldable obstacle device is lifted from the closed position and moved into the open position by the occurrence of the re-entrant jet, to block the re-entrant jet and reduce or prevent cloud cavitation. The foldable obstacle device may comprise a plate which is pivotally mounted adjacent the surface of the body at one edge thereof. The obstacle device may be substantially perpendicular to the surface of the body and mounted so that it cannot be moved beyond such orientation, when in the open position. The foldable obstacle device may have one or more feather-like flaps mounted thereon so as to extend from an edge thereof opposite the pivoting edge. The re-entrant jet blows up the feather-like flaps with an initial driving force. The torque caused by the initial driving force forces open the obstacle device. Once partially open, the re-entrant jet also exerts force on the obstacle device. The torques caused by force on the obstacle device and the initial driving force further open the device to the fully opened position.

The hydraulic lifting body may have a plurality of the foldable obstacle devices, which devices may be mounted at different locations on the surface of the body or may be mounted along a common axis. In either event, each obstacle device is movable between the closed and opened positions independently of the other obstacle devices.

The hydraulic lifting body has leading and trailing edges and a chord length. In accordance with the invention, the obstacle device is located at a distance of 35-50% of the chord length from the leading edge of the body,

and preferably at a distance of approximately 37% of the chord length from the leading edge of the body, for optimum results. Additionally, it is preferred that the obstacle device have a height when in the open position which is at least 12-20 % of the chord length. Preferably, the obstacle device has a height which is greater than the thickness of the re-entrant jet and less than the thickness of the sheet cavity, for optimum results.

A preferred arrangement for mounting a plurality of the obstacle devices along a common axis on the body utilizes an elongated groove in a first one of the opposite surfaces of the body. The groove extends laterally along a portion of the body at a location intermediate the opposite leading and trailing edges. A plurality of generally cylindrical hubs are rotatably disposed, end-to-end, within the elongated groove, and each has a shaft extending from a first end thereof and a hole in an opposite second end thereof for receiving the shaft of an adjacent hub. Each of the hubs has a different one of a plurality of plates mounted thereon to form the obstacle devices. Rotation of each of the hubs within the elongated groove moves the plate which is mounted thereon between a closed position in which an external surface of the plate is generally continuous with the surface of the body and an open position in which the plate is generally perpendicular to the surface of the body. The groove provides a clearance fit for each of the hubs therein so as to prevent movement of the plates beyond the open positions thereof.

In such arrangements according to the invention, the obstacle devices or plates are closed by fluid flow over the surface of the body from the leading edge, for low drag in the case of non-cavitation. However, in the case of cavitation, the re-entrant jet which flows from the end of the unsteady sheet cavity toward the leading edge of the body creates lifting forces which move the obstacle plates into the open positions, thereby blocking the re-entrant jet and preventing or substantially reducing the noise and surface erosion that might otherwise result.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a perspective view of a hydraulic lifting body having a plurality of foldable obstacle devices in accordance with the invention, with the obstacle devices being shown in enlarged fashion relative to the body for clarity of illustration.

Fig. 2 is a broken-apart, perspective view, partly in cross-section, of portions of the body of Fig. 1, illustrating one arrangement for movably installing the obstacle devices.

Fig. 3 is a cross-sectional view of the body of Fig. 1 illustrating the manner in which a re-entrant jet produces an initial driving force to rotate the obstacle devices toward an open position and thereby block the re-entrant jet.

Fig. 4 is a perspective view, partly in cross-section, of the body of Fig. 1, showing three of the foldable obstacle devices in the open position so as to block the re-entrant jet

Fig. 5 is a perspective view, partly in cross-section, of the body of Fig. 1, illustrating the manner in which some but not all of the foldable obstacle devices may be opened depending on the location of the re-entrant jet on the lifting body

DESCRIPTION OF THE PREFERRED EMBODIMENT

When fluid flow over the surface of a hydraulic lifting body is not cavitated there is no re-entrant jet. When the hydraulic lifting body operates under certain operating conditions, however, the unsteady sheet cavity and the cloud cavity can appear on the surface of the body. The cloud cavitation is caused by a re-entrant jet, which moves upstream (toward the leading edge of the body) from the end of the unsteady sheet cavity. When the re-entrant jet reaches a location near the leading edge, it cuts the sheet cavity off. The cut off part of the sheet cavity then moves downstream as a cluster of bubbles called a cloud cavity or a bubble cloud. The bubble cloud may contain thousands of tiny bubbles, whose collapse can cause broadband noise and erosion on the surface of the hydraulic lifting body. After the cut-off, the small sheet cavity on the leading edge will grow again and gradually reach its maximum length. The re-entrant jet will re-form and move again

from the end of the unsteady sheet cavity upstream toward the leading edge of the body. This process can repeat indefinitely, or until conditions conducive to cavitation no longer exist.

As described in detail below, the present invention provides a hydraulic lifting body with a self-actuating, foldable obstacle system. The system includes a plurality of foldable obstacles or plates that rotate outwardly from the surface of the body to block the re-entrant jet if and when it occurs, thereby preventing or substantially reducing noise and surface erosion. The obstacle devices are designed so that when the re-entrant jet flow moves forward over the body (which occurs at a flow velocity of roughly the same order as that of the inflow velocity) over the body, feather-like flaps on the obstacle devices are lifted up from the surface of the body. The lifting force acting on the feather-like flaps from the re-entrant jet acts as an initial driving force. Torque produced by this initial driving force opens the obstacle devices or plates. As soon as an obstacle device is partially open and thus projecting out from the surface of the body, the re-entrant jet can then exert a force on the obstacle device itself. Torque applied both to the obstacle device and the feather-like flap act to further open the obstacle device until the device is fully opened and the plane of the obstacle device becomes approximately normal to the surface of the lifting body. The re-entrant jet is blocked by the obstacle device and cannot move further forward. The re-entrant jet cannot reach a location

near the leading edge of the body, and thus will not cut off the sheet cavity at that position. As a result, cloud cavitation is suppressed or extensively reduced. Noise caused by the cloud cavity is similarly reduced and blade surface erosion largely eliminated.

5 If the operating conditions for the hydraulic lifting body then change so that they are no longer favorable for cavitation, the force of the fluid flowing in the usual way from the leading edge of the body toward the trailing edge closes the foldable obstacle device so that the obstacle device does not disturb the fluid flow unnecessarily.

10 Fig. 1 shows a hydraulic lifting body 10 which extends laterally between an outer end 12, and which has a leading edge 14 and a trailing edge 16. The body 10 has an upper surface 18 and an opposite lower surface 20. The upper surface 18 has curvature equal to or greater than that of the lower surface 20, and is thus generally the low-pressure or
 15 suction side of the body 10, if the angle of attack α is positive for a symmetric configuration, or if $\alpha > \alpha_0$ for a non-symmetric (cambered) configuration, where α_0 is the angle of attack for zero lifting force and is negative for a non-symmetric configuration and zero for a symmetric configuration. The body 10 may be, e.g., a blade of a marine propeller, a
 20 hydro-turbine, or a pump, a fin or rudder of a ship, or another hydraulic lifting body. The body 10 moves through a fluid to create the desired lifting

action Under normal conditions, the fluid passes over the body 10 from the leading edge 14 to the trailing edge 16

This embodiment includes a self-actuating, foldable obstacle system 22 on the upper surface 18 of the body 10. The system 22 includes a plurality of foldable obstacle devices or plates 24 mounted in the upper surface 18 of the body 10. Each of the plates 24 has a plurality of feather-like flaps 26 extending in a rearward direction from a trailing edge of the plate 24. In the embodiment of Fig. 1, the feather-like flaps 26 are generally semicircular in shape. In other embodiments, the feather-like flaps may be rectangular, square, trapezoidal, semi-elliptical, semi-circular, or of any other shape appropriate to the flaps' function as described herein

As can be seen in Fig. 2, the plates 24 are mounted to fold or pivot along a common axis extending in a lateral direction across the body 10. Opposite end covers 28 are mounted on the upper surface 18 of the body 10 to secure the obstacle system 22 with its plates 24 in place. Fasteners 30 secure the end covers 28 in place on the upper surface 18 of the body 10

Each of the plates 24 rotates independently of the other plates to open or close against the lifting body 10. In operation, fluid flows over the body 10 from the leading edge 14 to the trailing edge 16. When there is no cavitation, or when a sheet cavity is not severe enough to produce a re-entrant jet, the plates 24 remain in their closed or folded positions as shown in Fig. 1. The flow field on the surface 18 of the body 10 is not disturbed by

the plates 24 and the feather-like flaps 26, because the external surfaces of the plates 24 have a curvature like that of the upper surface 18 of the body 10, and the feather-like flaps 26 are flexible and very thin

The foldable obstacle devices or plates 24 are mounted on the body 10 so as to be disposed at the central portion of an area of possible cavitation along the lateral direction of the body 10 so as to achieve the best effect. Location of the plates 24 in this manner acts to extensively reduce cavitation noise, although an unsteady cavitation may extend over the entire low pressure surface of the body 10 in its lateral or span-wise direction. It is also desirable to mount the plates 24 at a central location on the body 10 because the thickness of the body 10 is large enough to accommodate the rotating apparatus for the plates 24.

The body 10 has a chord length between its leading and trailing edges 14 and 16. The positions of the plates 24 in the chord-wise direction are preferably at a distance of approximately 35%-50% of the chord length, measured from the leading edge 14. In particular, locating the plates 24 at 37% of the chord length from the leading edge 14 has been found to reduce the noise levels most effectively, although location of the plates 24 at other chord length distances can also reduce the noise level

Fig 2 shows an arrangement of the self-actuating, foldable obstacle system 22 in which the obstacle devices or plates 24 are mounted for independent rotation along a common axis extending along the body 10. An

elongated groove 32 is formed within the body 10, and is curved in cross-section so as to rotatably seat a plurality of generally cylindrical hubs 34. Each hub 34 has one of the plates 24 mounted thereon at a first or leading edge of the plate. An opposite trailing edge of each plate 24 has a plurality of the feather-like flaps 26 mounted thereon (not shown in Fig. 2). Each hub 34 has a shaft 36 extending from one end thereof and rotatably received within a hole 38 in an adjacent hub 34. A shaft 40 at the left end of the obstacle system 22 as viewed in Fig. 2 extends into a hole 38 in a left-most one of the hubs 34 to facilitate rotating motion of such hub. A right-most one of the hubs 34 as viewed in Fig. 2 has the shaft 36 thereof rotatably disposed within a hole 42 at a right-hand end of the elongated groove 32. The opposite covers 28 help to secure the arrangement of foldable obstacle devices or plates 24 within the body 10. Also, the groove 32 is configured so as to rotatably retain the hubs 34 therein and to define a rotational limit for each of the plates 24. As a result, each of the plates 24 is rotatable through an angle of approximately 90° between a closed position at the upper surface 18 of the body 10 and an open position in which the plate 24 extends outwardly so as to be substantially perpendicular to the upper surface 18 of the body 10.

Referring to Fig. 3, when an unsteady sheet cavity 44 is fully developed on the body 10, a re-entrant jet 46 appears. The pressure within the sheet cavity 44 is the saturated vapor pressure P_v , which is always

lower than the pressure of nearby fluid. The re-entrant jet 46 is comprised of running fluid. The jet 46 flows in a direction from the trailing edge 16 to the leading edge 14 of the body 10, and does so at a velocity on roughly the same order as that of the inflow. When the re-entrant jet 46 reaches the

5 feather-like flaps 26, the jet 46 blows the feather-like flaps 26 upward and produces a force F_0 on the feather-like flaps 26. The torque generated by the force F_0 causes some rotation of the plates 24. Once each plate 24 is partially opened so as to extend outwardly from the upper surface 18 of the body 10, the re-entrant jet 46 exerts a force on the plate itself. The torques

10 caused by the forces on the plate 24 and the initial driving force F_0 act to further open the plate 24 until it is fully opened and approximately normal or perpendicular to the upper surface 18 of the body 10. With the plate 24 opened in this fashion, the plate blocks the re-entrant jet 46 so that the jet 46 cannot move further forward to a location near the leading edge 14 and

15 cannot cut off the sheet cavity 44 near the leading edge. Accordingly, cloud cavitation is prevented or extensively reduced. The noise caused by a cloud cavity is reduced and surface erosion of the body 10 is largely eliminated.

Because the obstacle devices or plates 24 are foldable and rotate to the closed position in the case of non-cavitation, the heights of the plates 24

20 can be greater than in a case where fixed obstacles are provided on the surface of a body. As soon as the plates 24 disturb the flow of fluid from the leading edge 14 to the trailing edge 16 of the body 10, in the case of non-

cavitation, the force produced by the flow closes the plates 24. For this reason, the height of the plates 24 can be between the thickness of the re-entrant jet 46 and the thickness of the sheet cavity 44. Experimentation can be used to determine the ideal plate height. Alternatively, the thickness of the re-entrant jet 46 and the thickness of the sheet cavity 44 can be observed experimentally. A still further method of determining the optimum height of the plates 24 is to predict the thickness of the re-entrant jet 46 and the thickness of the sheet cavity 44 using numerical methods. It is preferred that the obstacle device have a height when in the open position which is at least 12-20 % of the lifting body's chord length, though this will depend somewhat upon the characteristics of a particular lifting body and the fluid through which it moves.

Fig. 4 depicts a condition in which all of the obstacle devices or plates 24 have been fully rotated to the open position. The re-entrant jet 46 lifts the feather-like flaps 26 to produce the initial driving force F_0 . The initial driving force combines with forces acting on the half-opened plates 24 to rotate the plates 24 to the fully open position, as shown in Fig. 4. The plates 24 cannot be rotated further, because the configuration of the elongated groove 32 prevents this. In the example of Fig. 4, all of the plates 24 are open because the re-entrant jet 46 extends across all of the positions where the plates 24 are located.

Fig 5 illustrates a condition in which some but not all of the obstacle devices or plates 24 are open. More specifically, two of the plates 24 are opened, but a third of the plates 24 remains closed. This is because the re-entrant jet 24 in this figure extends only across the positions of the first two
— 5 plates 24 and not to that of the third such plate. The plates 24 open and close independently of each other, and take their effect only where necessary

Self-actuating, foldable obstacle systems according to the invention can be designed to suit the particular surface of the hydraulic lifting body
10 with which they are mounted. Where a plurality of obstacle devices or plates are provided, they need not necessarily be of the same size, although a common size or shape can be chosen for simplicity. In the embodiment described herein, a plurality of the obstacle devices or plates 24 are mounted along a common axis. However, the obstacle devices or plates can
15 be mounted in different locations on the body 10 for rotation about different axes if desired. Also, the shafts 36 and the holes 38 can be hemispherical or otherwise curved in shape in order to mount the plates on a hydraulic lifting body that may be skewed, twisted or raked.

The close clearance fit between the hubs 34 and the walls of the
20 elongated groove 32 constrains the motion of the hubs 34 in the radial direction relative to the body 10 and allows the hubs 34 to rotate relative to the body 10 even without the shafts 36 and 40 and the holes 38 and 42

The clearance fits between the shafts 36 and 40 and the holes 38 and 42 make the system more reliable, however. Also, for certain applications it may be desirable to utilize bearings where the various shafts and holes are connected to facilitate the desired rotational movement

5 In Figs 1-5, the self-actuating, foldable obstacle system 22, with its obstacle devices or plates 24, is shown in enlarged fashion relative to the body 10 for clarity of illustration. In actual practice, the system 22 with its obstacle devices or plates 24 is usually substantially smaller relative to the body 10 than is indicated in the figures

10 The obstacle devices or plates 24 are preferably made of material that is light, hard, tough, and resistant to erosion and fatigue. ABS plastic is a suitable material for many applications. The feather-like flaps 26 can be made of a flexible material such as Teflon[®]

An exemplary embodiment of the invention has been described
15 herein for purposes of illustration. The invention is not limited to this embodiment, though, and numerous and diverse changes, modifications, or additions may be made by those of skill in the art without departing substantially from the inventions basic principles. The true scope of the invention should be determined, therefore, primarily by reference to the
20 appended claims, along with the full scope of equivalents to which those claims are legally entitled

CLAIMS

What is claimed is

1 A foldable obstacle device for blocking a re-entrant jet produced by unsteady sheet cavitation on a hydraulic lifting body, the foldable obstacle device being mounted at a surface of the body and being movable between a closed position at the surface of the body and an open
5 position away from the body, the foldable obstacle device being lifted from the closed position and moved into the open position by the occurrence of a re-entrant jet to block the re-entrant jet and reduce or prevent cloud cavitation

2 A foldable obstacle device according to claim 1, wherein the obstacle device is substantially perpendicular to the surface of the body when in the open position and is mounted so that it cannot be moved beyond the open position.

3 A foldable obstacle device according to claim 1, wherein the obstacle device comprises a plate-like device which is pivotally mounted adjacent the surface of the body

4 A foldable obstacle device according to claim 3, wherein the plate-like device is pivotally mounted at a first edge thereof and has a

plurality of feather-like flaps extending from a second edge thereof opposite the first edge

5 A hydraulic lifting body having a plurality of foldable obstacle devices according to claim 1, wherein the plurality of foldable obstacle devices being mounted at different locations on the surface of the body and each being movable between closed and open positions independently of
5 other ones of the plurality of foldable obstacles

6 A hydraulic lifting body according to claim 5, wherein the plurality of foldable obstacle devices are mounted for pivoting movement along a common axis

7 A hydraulic lifting body having a plate-like obstacle device pivotally mounted adjacent a surface of the hydraulic lifting body so as to be movable between a closed position in which the device is generally continuous with the surface of the body and an open position in which the
5 device extends outwardly from the surface of the body in response to a re-entrant jet at the surface of the body

8. A hydraulic lifting body according to claim 7, wherein the body has a chord length and a leading edge, and the obstacle device is located at a distance of 35-50% of the chord length from the leading edge of the body

9. A hydraulic lifting body according to claim 8, wherein the obstacle device is located at a distance of approximately 37% of the chord length from the leading edge of the body

10. A hydraulic lifting body according to claim 7, wherein the body has a chord length and the obstacle device extends upwardly from the surface of the body by a height which is at least 12-20% of the chord length.

11. A hydraulic lifting body according to claim 7, wherein a sheet cavity of a certain thickness forms at the surface of the body when cloud cavitation occurs at the surface providing a re-entrant jet of a certain thickness at the surface of the body, and the obstacle device extends outwardly from the surface of the body and has a height which is greater than the thickness of the re-entrant jet and less than the thickness of the sheet cavity

12 A hydraulic lifting body according to claim 7, wherein the
obstacle device is pivotally mounted at a first edge thereof adjacent the
surface of the lifting body and extends to an opposite second edge thereof so
as to be generally continuous with the surface when in the closed position,
5 and further including at least one feather-like flap extending from the —
second edge of the device so as to be generally continuous with the surface
when in the closed position.

13. A hydraulic lifting body according to claim 12, wherein each of
the feather-like flaps is has a shape selected from the group consisting of
rectangular, square, trapezoidal, semi-elliptic, semi-circular

14. A hydraulic lifting body according to claim 7, wherein the body
has a plurality of the plate-like obstacle devices mounted adjacent a surface
of the hydraulic lifting body and each being movable independently of the
other obstacle devices.

15 A hydraulic lifting body extending laterally between opposite
leading and trailing edges and having opposite surfaces, the body
comprising an elongated groove in a first one of the opposite surfaces
extending laterally along a portion of the body at a location intermediate
5 the opposite leading and trailing edges, a plurality of generally cylindrical

hubs rotatably disposed, end-to-end, within the elongated groove and each having a shaft extending from a first end thereof and a hole at an opposite second end thereof for receiving the shaft of an adjacent hub, each of the hubs having one of a plurality of plates mounted thereon, rotation of each of
10 the hubs within the elongated groove moving the plate mounted thereon between a closed position in which an external surface of the plate is generally continuous with the first one of the opposite surfaces of the body and an open position in which the plate is generally perpendicular to the first one of the opposite surfaces of the body.

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16 A hydraulic lifting body according to claim 15, wherein each shaft is rotatable within the hole of an adjacent hub in which it is received so that each plate may pivot between the closed and open positions thereof independent of the other plates

17 A hydraulic lifting body according to claim 15, wherein the groove provides a clearance fit of each of the hubs therein which prevents movement of the plates beyond the open positions thereof

18 A hydraulic lifting body according to claim 15, wherein each of the plates has at least one feather like flap extending from an outer edge thereof opposite the hub on which the plate is mounted, the flap being

generally continuous with the first one of the opposite surfaces of the body
5 when the plate is in the closed position

19 A hydraulic lifting body according to claim 15, further including a pair of covers secured on the first one of the opposite surfaces of the body at opposite ends of the plurality of hubs to rotatably secure the plurality of hubs within the groove

20 A hydraulic lifting body which is subject to formation of a cloud cavity on a surface thereof if a re-entrant jet is produced, apparatus for minimizing or preventing formation of a cloud cavity comprising means responsive to production of a re-entrant jet for blocking the re-entrant jet
5 from moving forward on the surface of the body, and means responsive to the absence of a re-entrant jet for allowing unblocked fluid flow over the surface of the body

21 A hydraulic lifting body in accordance with claim 20, wherein the body has a leading edge and an opposite trailing edge, fluid flow normally occurs over the surface of the body from the leading edge to the trailing edge, and a re-entrant jet, when produced, flows over the surface of
5 the body from an end of an unsteady sheet cavity in a direction toward the leading edge

22 A movable obstacle for installation on a hydraulic lifting body,
the foldable obstacle comprising:

a blocking plate portion;

a hub at one end of the blocking plate portion; and

5 mounting structure for mounting the hub to the lifting body so that
the blocking plate portion is movable between a first position in which it is
closed against the hydraulic lifting body and a second position in which it is
opened away from the hydraulic lifting body;

wherein the hub is mounted to the mounting structure so that a re-
10 entrant jet flowing over the lifting body applies a force to the movable
obstacle and wherein the force of the re-entrant jet urges the blocking plate
portion to its opened position.

23 The movable obstacle of claim 22, wherein the blocking plate
portion is substantially perpendicular to a surface of the lifting body when
the blocking plate is in its opened position.

24 The movable obstacle of claim 22, and further comprising at
least one feather-like flap mounted on the blocking plate portion at an end
opposite the hub

25 A hydraulic lifting body having at least one movable obstacle
according to claim 1 installed on the lifting body

26 The hydraulic lifting body of claim 25, wherein a plurality of
the movable obstacles are installed on the lifting bodies

27. A fluid lifting body comprising:

a fluid lifting body surface; and

a movable obstacle comprising

a blocking portion; and

5 mounting structure for mounting the movable obstacle

on the lifting body so that the blocking plate portion is

movable between a first position in which blocking plate

portion is closed against the fluid lifting body surface and a

second position in which the blocking plate portion is opened

10 away from the fluid lifting body surface;

wherein the movable obstacle is mounted on the lifting body so that a

re-entrant jet flowing over the lifting body applies a force to the movable
obstacle;

wherein the force of the re-entrant jet urges the blocking plate to its

15 opened position, and

wherein the blocking structure in the opened position interferes with the flow of the re-entrant jet over the lifting body surface

28 The fluid lifting body of claim 27, wherein the lifting body has a chord length and a leading edge, and wherein the movable obstacle is mounted on the lifting body at a distance of 35-50% of the chord length from the leading edge of the lifting body.

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29. The fluid lifting body of claim 28, wherein the movable obstacle is mounted on the lifting body at a distance of approximately 37% of the chord length from the leading edge of the lifting body.

30. The fluid lifting body of claim 27, wherein the lifting body has a chord length, and wherein the movable obstacle in the opened position extends upward from the lifting body surface to a height of at least about 1.2% of the chord length

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31 The fluid lifting body of claim 30, wherein the movable obstacle in the opened position extends upward from the lifting body surface to a height of between 1.2% and 2.0% of the chord length

32 The fluid lifting body of claim 27, wherein a sheet cavity having a sheet cavity thickness and a re-entrant jet having a re-entrant jet thickness form over the fluid lifting body surface under cloud cavitation conditions, and wherein the blocking portion extends outward from the fluid
5 lifting body surface to a height that is greater than the re-entrant jet thickness and less than the sheet cavity thickness.

33 The fluid lifting body of claim 27, wherein the movable obstacle is mounted at a first end thereof adjacent the fluid lifting body surface and extends to an opposite second thereof so as to be generally continuous with the fluid lifting body surface when the movable obstacle is
5 in the closed position

34 The fluid lifting body of claim 33, and further comprising at least one feather-like flap extending from the second edge of the movable obstacle so as to be generally continuous with the fluid lifting body surface when the movable obstacle is in the closed position.

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35. The fluid lifting body of claim 27, wherein the fluid lifting body includes a plurality of the movable obstacles, and wherein the movable obstacles are movable independently of one another

36 A method for reducing fluid cavitation over a fluid lifting body,
the method comprising

flowing fluid over a flow surface of the lifting body, wherein flowing
the fluid over the flow surface forms a re-entrant jet over the flow surface;

5 interposing a movable blocking structure into the re-entrant jet to
interfere with flow of the re-entrant jet over the flow surface

37. The method of claim 36, wherein the lifting body has a chord
length and a leading edge, and wherein the movable blocking structure is
located at a distance of 35-50% of the chord length from the leading edge of
the body

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38 The method of claim 37, wherein the movable blocking
structure is located at a distance of approximately 37% of the chord length
from the leading edge of the body.

39. The method of claim 36, wherein the lifting body has a chord
length, and wherein interposing the movable blocking structure into the re-
entrant jet includes extending the blocking structure away from the flow
surface to a distance that is at least 12% of the chord length.

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40 The method of claim 36, wherein a sheet cavity having a sheet cavity thickness is formed over the flow surface,

wherein the re-entrant jet has a re-entrant jet thickness; and

wherein interposing the movable blocking structure into the re-
5 entrant jet includes extending the blocking structure away from the flow surface to a distance between the re-entrant jet thickness and the sheet cavity thickness.

41 The method of claim 36, wherein interposing the movable blocking structure into the re-entrant jet includes pivoting the movable blocking structure at a first edge that is toward a leading edge of the lifting body to extend a second edge that is toward a trailing edge of the lifting
5 body away from the flow surface.

42 The method of claim 36, wherein interposing the movable blocking structure into the re-entrant jet includes

locating the movable blocking structure at a position in which the re-entrant jet is directed against a feather-like flap to apply a force to the
5 feather-like flap that urges the movable blocking structure toward an opened position; and

interposing the blocking structure into the re-entrant jet in a configuration in which the re-entrant jet urges the blocking structure more fully toward the opened position

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43. The method of claim 36, and further comprising positioning the movable blocking structure in a configuration in which the flowing fluid is directed against the movable blocking structure in a direction that urges the movable blocking structure to move from an opened position to a closed position

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44. The method of claim 36, wherein interposing a movable blocking structure into the re-entrant jet includes interposing a plurality of movable blocking structures into the re-entrant jet, wherein the plurality of movable blocking structures are urged into the re-entrant jet by a force applied by the re-entrant jet; and

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wherein the movable blocking structures are movable into the re-entrant jet independently of one another