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Attorney Docket No. 300170

A RECOVERY SYSTEM FOR UNMANNED UNDERWATER VEHICLES

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] None.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention is an improvement to existing and future capture mechanisms and a method of use that employs the use of water jets and a Bernoulli Effect to stabilize an unmanned underwater vehicle and to simplify recovery efforts of the underwater vehicle from a surface vessel.

(2) Description of the Prior Art

[0004] The automated launch and recovery of unmanned vehicles in general and unmanned underwater vehicles in particular is an ongoing issue. The automated recovery of unmanned underwater vehicles is a more difficult problem than the automated launch of unmanned underwater vehicle

[0005] In the prior art shown in **FIG. 1**, a ball **10** in a vertical air jet 20 is shown where the ball remains at the center or centerline of the air jet because of the velocity profile of the air jet. The velocity profile is defined as the velocity of the jet as a function of the distance from the jet centerline. The range of pressure varies. See Equation [**1**] and [**2**]

$$p_a \leq p \leq p_a - \frac{1}{2}\rho u^2 \quad \textbf{[1]}$$

$$p_a = 10^5 + \rho g z; \quad \textbf{[2]}$$

where p_a is the ambient pressure in Pascals;

$\rho = 1024$ kg/m^3 is the density of water;

$g = 9.81$ m/s^2;

u is the velocity in meters/second; and

z is the depth in meters.

[0006] The flow rate for the air jet **20** is a design parameter. Typically, the flow rate can range from 0 to 5 meters per second. The velocity is highest (and the pressure is lowest) at the center of the air jet **20** as a result of the Bernoulli effect. The Bernoulli effect is a consequence of the Bernoulli equation which is valid along any point on a streamline – See Equation [**3**].

$$\frac{u^2}{2} + gz + \frac{p}{\rho} = constant \quad \textbf{[3]}$$

[0007] If and as described further, the air jets **20** are typically horizontal, "z" does not change along a streamline, so

$$p = p_a - \frac{1}{2}\rho u^2 \qquad \textbf{[4]}$$

[0008] An interpretation of Equations **[2]** and **[3]** is that the pressure in the air jet **20** is always lower than the ambient pressure surrounding the air jet, so that an object in the air jet will always be pushed by the higher ambient pressure toward the middle of the jet, effectively stabilizing the object.

[0009] As shown in prior art **FIG. 2**, if the ball **10** moves laterally to an outer boundary of the air jet **20**, the ball will be moved back toward the center of the air jet by ambient pressure in adjacent regions. The surrounding pressure is one atmosphere (10^5 Pascals) at sea level. At a depth "z", the surrounding pressure is $10^5 + pgz$.

[0010] Based on the utility of the air jets with the Bernoulli effect, there is a need for controlling the recovery of an unmanned underwater vehicle using a technology similar to that of the air jets.

SUMMARY OF THE INVENTION

[0011] Accordingly, it is a general purpose and primary object of the present invention to provide a capture mechanism and method of use that employs the Bernoulli Effect to stabilize an unmanned underwater vehicle as the vehicle is automatically recovered.

[0012] To attain the object of the present invention, a capture mechanism uses water jets flowing in a horizontal direction and acting similar to prior art vertical air jets to move an unmanned underwater vehicle toward a centerline region of the water jets. The water jets remedy the effect of wave forces on the unmanned underwater vehicle by moving the vehicle back to the centerline region.

[0013] The Bernoulli Effect is implemented with the water jet directed at the unmanned underwater vehicle as part of a capture mechanism. The unmanned underwater vehicle transits into the capture mechanism and can be guided by a homing device. Water jets can also be used with a wide variety of known capture mechanisms.

BRIEF DESCRIPTION OF THE DRAWINGS

[0014] Other objects, features and advantages of the present invention will be better understood by means of a detailed description of the drawings that illustrate the principals of the present invention in which:

[0015] **FIG. 1** depicts a prior art example of the dynamics of an object in which the object is centered in a vertical air jet due to a low pressure region along a centerline a result of the Bernoulli effect;

[0016] **FIG. 2** depicts a prior art example of the dynamics of an object in which the object is displaced to outer boundaries of a vertical air jet; and

[0017] **FIG. 3** depicts an unmanned underwater vehicle transiting into a capture mechanism of the present invention with the underwater vehicle being stabilized by water jets of the capture mechanism.

DETAILED DESCRIPTION OF THE INVENTION

[0018] As shown in **FIG. 3,** the present invention uses water jets **100** flowing in a horizontal direction but the water jets act in a way similar to the prior art air jets of **FIG. 1** and **FIG. 2** to move an unmanned underwater vehicle **200** toward a centerline region of the water jets. The unmanned underwater vehicle **200** can be displaced by wave forces during vehicle recovery efforts but the water jets **100** remedy the effect of the wave forces by moving the underwater vehicle back to the centerline region.

[0019] The Bernoulli effect is implemented with the water jets **100** directed at the unmanned underwater vehicle **200** as part of the capture mechanism **300.** As one water jet **100** or a plurality of the water jets align the unmanned underwater vehicle **200** toward the centerline of the water jets; the underwater vehicle stabilizes.

[0020] In the absence of the water jets **100,** the dynamics of the underwater vehicle **200** can be dominated by wave forces. Wave forces cannot be easily predicted and can be strong enough to require a significantly larger handling system and significantly more complex control methods to accommodate such forces. As noted, the water jets **100** cause the underwater vehicle **200** to stay in the center of the water jets which minimizes the effect of wave forces.

[0021] In the figure, the unmanned underwater vehicle **200** transits into a known cone capture mechanism **400** and can be guided by a homing device **402** to clamps **404**, with the clamping mechanism and homing device attached to a ship hull **500**. The water jets 100 then stabilize the underwater vehicle **200**. The water jets **100** can also be used with a wide variety of other capture mechanisms such as those disclosed in United States Patent No. 6,600,695 or a telescopic arm in United States Patent No. 6,770,475.

[0022] Water jets **100** positioned on the sides are more effective for stabilizing the unmanned underwater vehicle **200** as the vehicle approaches the capture mechanism **400**. Water jets **100** in the center are more effective for stabilizing the underwater vehicle **200** as the vehicle is entering the capture mechanism **400**.

[0023] A cross-section of the flow profile of each water jet **100** has a diameter that relates to a length scale associated with a lateral dimension of the unmanned underwater vehicle **200**. The typical diameter of an unmanned underwater vehicle is twelve inches. In addition, the centerline velocity of the water jets

100 should be sufficiently high that a pressure difference (relative to the ambient pressure of the surrounding environment) will be large relative to the lateral pressures associated with wave motions. These parameters would vary as a function of the sea state, the ship handling system, the capture mechanism and the design of the capture mechanism **400.**

[0024] The water jets **100** will increase drag on the unmanned underwater vehicle **200.** This increased drag will increase the axial force (along the longitudinal axis of the underwater vehicle)required to recover the underwater vehicle **200.** However, the axial force is largely, a constant and known force. The design tradeoff for a handling system will involve increasing the power of the underwater vehicle **200** during recovery (due to the increased drag) rather than increasing the size of the handling system to accommodate the larger lateral motions due to wave forces.

[0025] It has been determined experimentally by Equation **[5]** that turbulent jets have a velocity profile "u" that is well modeled by a Gaussian function:

$$u(x,r,\sigma) = u_{max} e^{-\frac{r^2}{2\sigma^2}} \qquad [5]$$

[0026] Here "x" is the length coordinate along the centerline of the water jets **100,** "r" is the radial distance from the centerline, "u_{max}" is the maximum speed (i.e., at the centerline), and "σ" is the standard deviation associated with the velocity profile. It has also been determined that the velocity along the centerline decreases linearly with distance as defined by Equation **[5]**. These parameters can be used to model UUV recovery systems with stabilizing jets for the purposes of performing tradeoff or comparative effect studies.

[0027] The present invention provides a system and method of use to stabilize unmanned underwater vehicles in order to facilitate recovery (both automated and manned) by reducing the forces that handling systems must accommodate and to reduce lateral motion. These less stressful forces on the handling systems can lead to smaller and more simplified control systems.

[0028] It will be understood that many additional changes in the details, materials, steps and arrangement of parts, which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

[0029] The foregoing description of the preferred embodiments of the invention has been presented for purposes of illustration and description only. It is not intended to be exhaustive nor to limit the invention to the precise form disclosed; and obviously many modifications and variations are possible in light of the above teaching. Such modifications and variations that may be apparent to a person skilled in the art are intended to be included within the scope of this invention as defined by the accompanying claims.

A RECOVERY SYSTEM FOR UNMANNED UNDERWATER VEHICLES

ABSTRACT OF THE DISCLOSURE

A capture mechanism is provided that employs water jets flowing in a horizontal direction to move an unmanned underwater vehicle toward a centerline region of the water jets. The Bernoulli effect is implemented with the water jets directed at the underwater vehicle. As the water jets align the vehicle toward the centerline of the water jets; the vehicle stabilizes. The underwater vehicle transits into the capture mechanism and can be guided by a homing device.

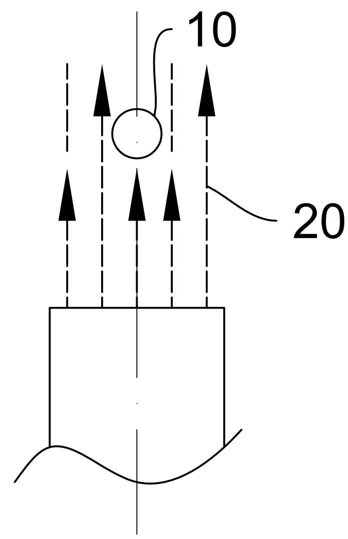

FIG. 1

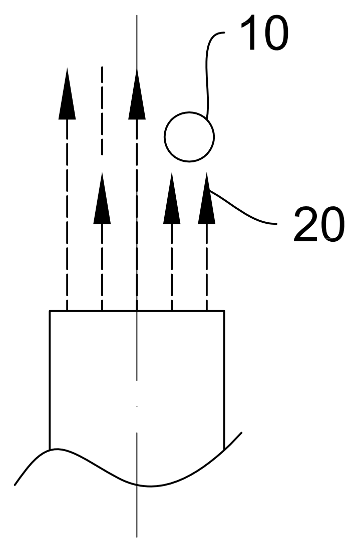

FIG. 2

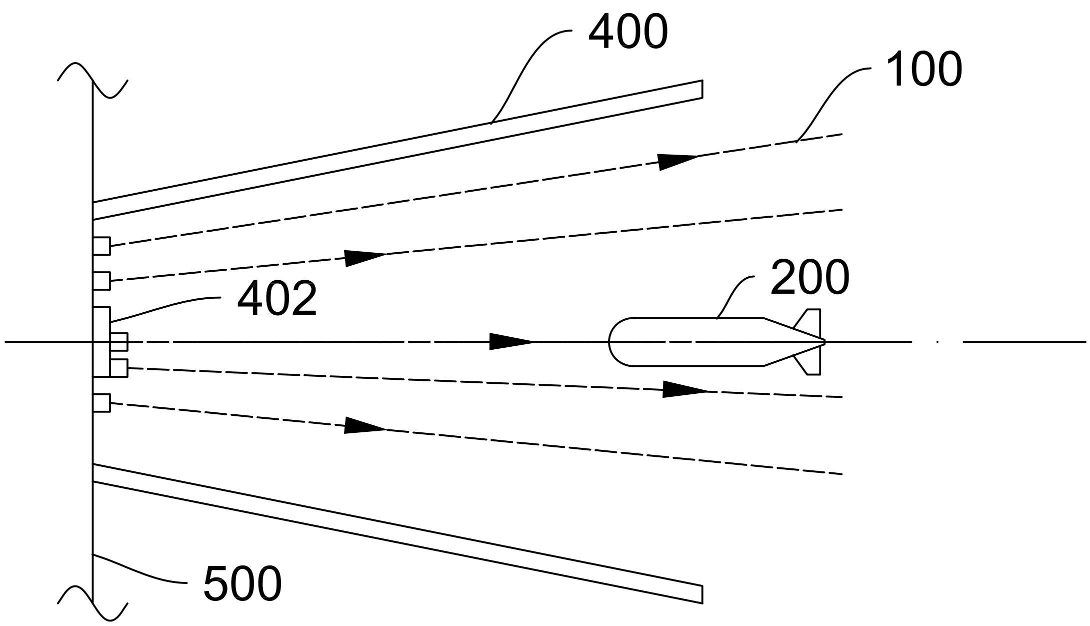

FIG. 3