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Attorney Docket No. 98257

PROPELLED TOW BODY

STATEMENT OF GOVERNMENT INTEREST

[0001] This application claims the benefit of United States Provisional Patent Application Serial No. 60/963,202, filed on July 18, 2007 and entitled "Propelled Tow Body" by the inventor, Anthony A. Ruffa.

STATEMENT OF GOVERNMENT INTEREST

[0002] 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.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates to a tow body with a propulsion component. The tow body is capable of forward thrust by the propulsion component thereby allowing the use of a compact and lightweight handling system for the tow body.

(2) Description of the Prior Art

[0004] It is known in the art that conventional design principles require a heavy tow cable a heavy tow body or a depressor tow body to achieve a required depth. A 1.6 inch diameter cable is an example of a "heavy" tow cable in that it weighs more than 2 pounds per foot in air or water thereby requiring a winch diameter exceeding four feet.

[0005] A depressor tow body is an upside-down wing that produces force in a downward direction to achieve a depth. Depressor wings are typically large (more than four feet across); thereby complicating handling requirements.

[0006] To illustrate the effects of the use of a tow cable, the following catenary equations describe a steady state configuration for a tow cable.

[0007] The catenary equations (See **Table 1** for symbol definitions are:

$$\frac{dT}{ds} = -\rho_0 (\sigma - 1) \pi a^2 g \sin\phi - \rho_0 v^2 \pi a C_T \cos\phi$$

$$T\frac{d\phi}{ds} = \rho_0 (\sigma - 1) \pi a^2 g \cos\phi + \rho_0 a v^2 \left[C_D \sin\phi + \pi C_N\right]\sin\phi;$$

$$\frac{dx}{ds} = \cos\phi; \text{ and} \qquad (1)$$

$$\frac{dy}{ds} = -\sin\phi .$$

TABLE 1

Parameter	Description
a	Radius of tow cable
ρ_0	Density of sea water (1025 Kg/m^3)
g	Gravitational acceleration (9.81 m/s^2)
v	Tow speed
C_T	Tangential drag coefficient (0.0025)
C_N	Drag co-efficient 0.75C_T
C_D	Normal drag coefficient (1.4)
σ	Specific gravity of tow cable
L	Length of tow cable
T	Tension of tow cable
ϕ	Incidence angle of tow cable
x	x-coordinate (positive along the direction of the flow
y	y-coordinate (positive in the downward direction)
s	Cable scope (distance along the cable measure from the aft end

[0008] The uncertainty associated with modeling a towed system is dominated by that of the drag coefficients. This modeling can lead to depth variations up to ten percent (measured drag data typically has a lot of scatter). In other words, if a drag measurement is made multiple times, the results will not always match. This disparity is generally due to the nonlinear nature of fluid mechanics that can magnify small differences in test conditions.

[0009] Small changes in speed and angle of the tow cable can lead to significant changes in drag, resulting in a chaotic system. Vortex shedding does not always occur. However, when vortex shedding occurs would be when the wake is altered, and the drag on the cable can increase by a factor of two.

[0010] A high-fidelity model usually makes a build-test-build process unnecessary; therefore, modeling can sufficiently explore the tradeoff space. A high-fidelity model has high accuracy, both in the absolute sense (i.e. small errors in predicted forces and displacements), and in the relative sense (i.e. accurately predicting tends due to design changes, allowing the tradeoff space to fully explored). As such, a system designed from a catenary model is considered (as a practical manner) identical to a system that would be built and tested (except for approximately ten percent uncertainty in depth). Dynamic cable behavior is more difficult to simulate and may require some testing.

[0011] In critical angle tow, the cable catenary is virtually a straight line (except for a small region near the aft end of the tow body having a nonzero curvature). When there is a concentrated force at the aft end of the tow cable, the extent of the curvature increases.

[0012] A towed system in two dimensions is described by four equations and four unknowns (T, ϕ, x, y). Steady state towed systems form an initial value problem, requiring initial conditions for each variable at the aft end. The following test cases are useful to check sign conventions and other errors.

[0013] **Test Case 1: Zero tow speed.** In Test Case 1, the tow cable hangs vertically, so that $\phi = \pi / 2$. The equations reduce to:

$$\frac{dT}{ds} - \rho\, 0\, (\sigma - 1)\, \pi\, a^2 g = 0$$

$$\frac{d\phi}{ds} = 0;$$

$$\frac{dx}{ds} = 0; \text{ and} \qquad (2)$$

$$\frac{dy}{ds} = -1.$$

[0014] In Test Case 1, the tension at any point equals the weight of the cable below.

[0015] **Test Case 2: Neutrally buoyant cable.** In Test Case 2, the cable tows horizontally when $\phi = 0$. The equations reduce to:

$$\frac{dT}{ds} - \rho_0 v^2 \pi a^2 C_T = 0$$

$$\frac{d\phi}{ds} = 0;$$

$$\frac{dx}{ds} = 1; \text{ and} \qquad (3)$$

$$\frac{dy}{ds} = 0.$$

[0016] In Test Case 2, the drag at any point equals the accumulated drag of the tow cable behind the point.

[0017] In a working example, consider a tow body (e.g. a countermeasure) towed from a one inch diameter steel cable at five knots. The critical angle would be approximately 18 degrees and the tow body would achieve a depth of 100 meters (m) with a cable scope of 340 meters (m) and a cable tension of 100 pounds (lbs).

[0018] Based on the drag calculations and the working example, a propellable tow body would be a significant improvement in the art and would have significant benefits over known tow systems. However, a propellable tow body cannot have a nose tow (front end tow attachment point) because propulsion of the tow body would cause tow cable compression. Therefore, an alternate propelled tow body arrangement is needed.

SUMMARY OF THE INVENTION

[0019] Accordingly, it is a general purpose and primary object of the present invention to provide a propellable tow body.

[0020] It is a further object of the present invention to provide a propellable tow body which achieves depth requirements with a shortened or lighter tow cable compared to achieving depth requirements with those tow cables typically used with tow bodies.

[0021] It is a still further object of the present invention to provide a propellable tow body which allows the use of a compact and lightweight handling system.

[0022] In order to attain the objects described above, a propellable tow body with a "top" tow attachment point is provided. A tow cable would be secured at the attachment point and along with the attachment point positioned nominally at a nonzero angle relative to the direction of thrust. The thrust is achieved by an operating propulsion component of the tow body with the result of forward thrust without a cable compression because the tow cable pivots about the tow point, increasing an angle relative to the thrust direction as thrust is increased.

This effect eliminates the possibility of cable compression, which could lead to mechanical failure.

[0023] The tow body is also capable of accepting electric power for an electric propulsion motor within the body. The electric propulsion motor provides the power for the propeller or other propulsion equipment. Alternatively, the power for the electric motor could be provided by a tow cable or a power storage capability within the tow body.

[0024] The addition of forward thrust by the propulsion components of the tow body decreases cable scope (i.e., the cable length) and the required winch volume for storing the long length of cable.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein like reference numerals and symbols designate identical or corresponding parts throughout the several views and wherein:

[0026] **FIG. 1** depicts a tow body of the present invention in which the tow body has a tow attachment point;

[0027] **FIG. 2** depicts the propellable towed body of the present invention in arrangement with a support ship;

[0028] **FIG. 3** is a depiction of a steady state shape of a one inch tow cable with a horsepower of thrust at five knots; and

[0029] **FIG. 4** depicts a graph showing the depth of the tow body as a function of thrust.

DETAILED DESCRIPTION OF THE INVENTION

[0030] In **FIG. 1**, a propellable tow body **10** with a "top" tow attachment point **12** is shown. The attachment point **12** may be any securing mechanism known to those ordinarily skilled in the art. Importantly, the attachment point **12** allows a tow cable **100** to be secured nominally at a nonzero angle relative to the direction of thrust of the propellable tow body **10**. The tow cable pivots about the tow point, increasing is angle relative to the thrust direction as thrust is increased. This effect eliminates the possibility of cable compression, which could lead to mechanical failure.

[0031] When the tow body **10** is powered for propulsion by an electric motor **16** (commercially-available motors would be suitable) and under propulsion by a propulsion component **18** (i.e., propeller blades), forward thrust is achieved without compression of the tow cable **100**. The addition of forward thrust of the tow body **10** decreases cable scope and the required volume for storing the tow cable **100** on a winch **110** on a ship **120** (See **FIG. 2**).

[0032] Under power, the tow cable **100** takes the shape of a bow (due to the normal drag on the tow cable and the tow body **10**) with the propelled tow body directly below the ship **120**. **FIG. 3** (having units of meters on both axes) shows that the tow cable takes the shape of a bow (due to the normal drag). In this figure, the tow body is oriented directly under the ship. There is no other way to achieve this much depth at speed with such a short tow cable. In practice, there are cases where the depth at a given speed achievable by conventional means is limited, and the use of forward thrust is the only way to overcome such limitations.

[0033] The tow cable **100** could also provide power from a power source (not shown) for the electric motor **16** or could supply the power directly to the propulsion component **18**.

[0034] To further illustrate the advantages of the invention, the propellable tow body **10** would increase the depth to 165 meters when the forward thrust is 900 lbs at 5 knots (8.4 ft/sec). This translates to approximately 13.7 horse power (900 lbs x 8.4 ft/sec divided by 550 ft/lbs.

[0035] Power conductors, typically required for operation of the electric motor **16**, can fit in a one-inch diameter tow cable with sufficient spare volume for conductors supporting other components (e.g., sensors). When the tow body **10** transmits significant acoustic power, additional power conductors would be required. In such an instance, coaxial cables or non-twisted conductor pairs can be used to minimize volume use within the tow cable **100**.

[0036] Additionally or alternatively, power storage in the tow body **10** can support use of the propulsion component **18**. The diameter of the tow cable **100** cannot be made too small and simultaneously achieve depth at speed, since the weight of the tow cable varies with the area and the drag varies with the diameter. [Note: This is only true without a propelled tow body, because the depth is achieved with weight or downward thrust. With a propelled tow body, the depth at speed can be achieved with any cable diameter.]

[0037] In relation to the working example in the "Description of the Prior Art" section, a non-propelled system would increase the scope of the tow cable **100** from 340 meters to 570 meters to achieve the same depth. In other words, addition of forward thrust decreases cable scope (and therefore the required winch volume) by 40 percent. Thrust increases the tension to 292 lbs; however, the tension of the non-propelled system would increase to 160 lbs when considering the cable scope. No approach known in the art can increase depth this much with such a small impact on size and weight.

[0038] Important advantages of the present invention are reduced handling system size, strength rating requirements and weight. The tow body **10** also enables use of legacy handling systems that are too small for conventional towing, or for use from unmanned surface vehicles having comparatively small handling systems.

[0039] 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.

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PROPELLED TOW BODY

ABSTRACT OF THE DISCLOSURE

A tow body is provided with an attachment point to connect to a tow cable. The attachment point is positioned nominally at a nonzero angle relative to the length of the tow body. Propulsion components of the body generate thrust. The body is capable of accepting electric power for a propulsion motor within the body. The motor provides the power for the propeller or other propulsion equipment. The power for the motor can also provided by a tow cable. The addition of forward thrust by the propeller decreases cable scope (the need for long lengths of cable) and required winch volume for storing the cable.

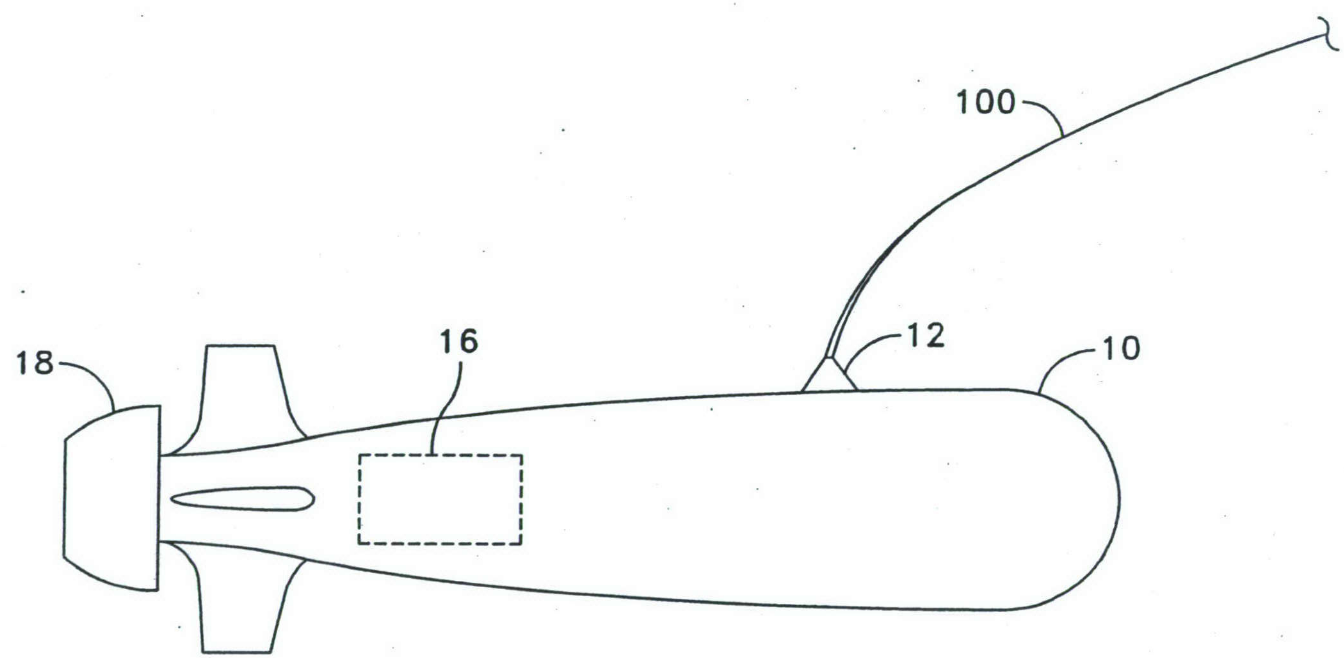

FIG. 1

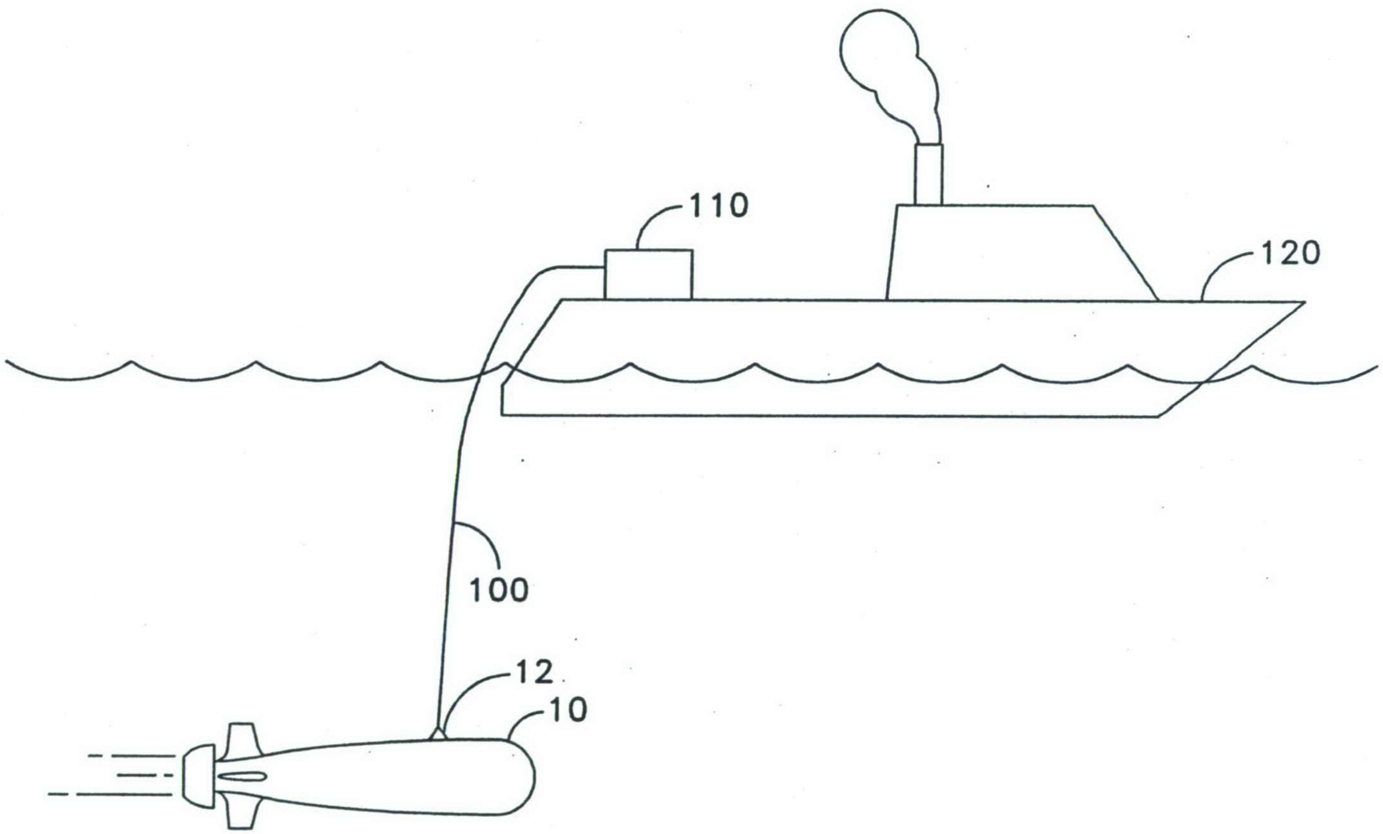

FIG. 2

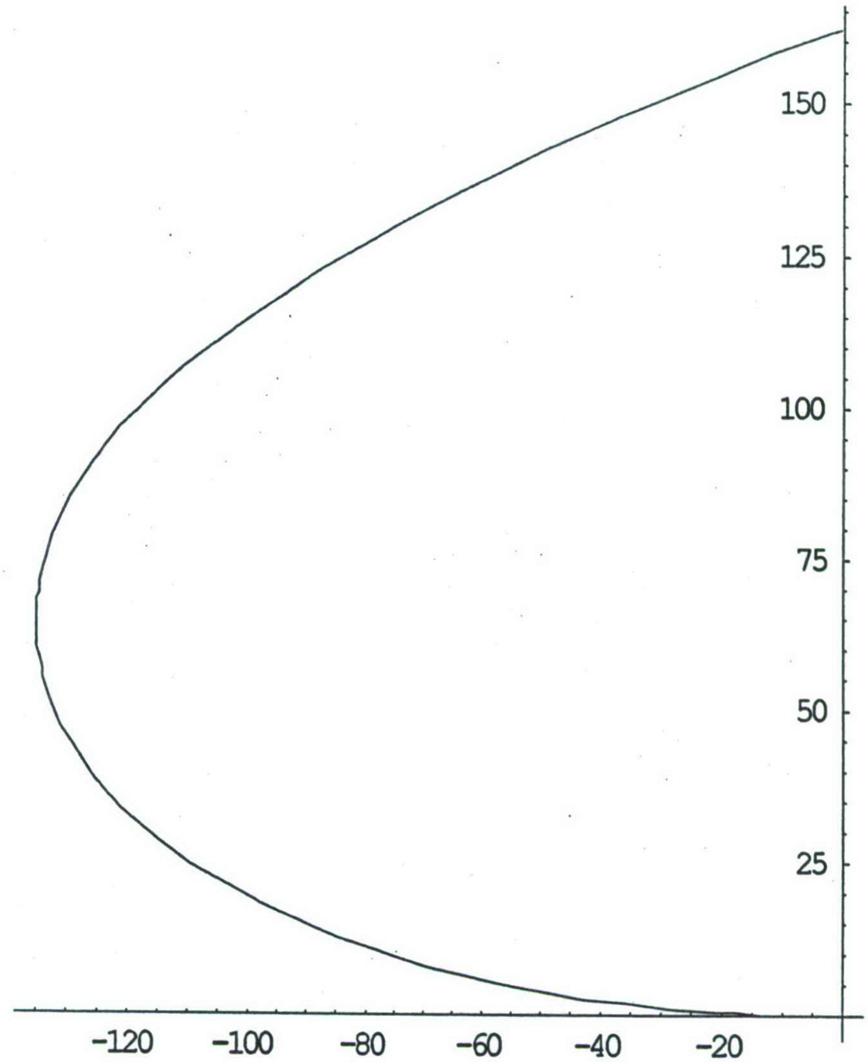

FIG. 3

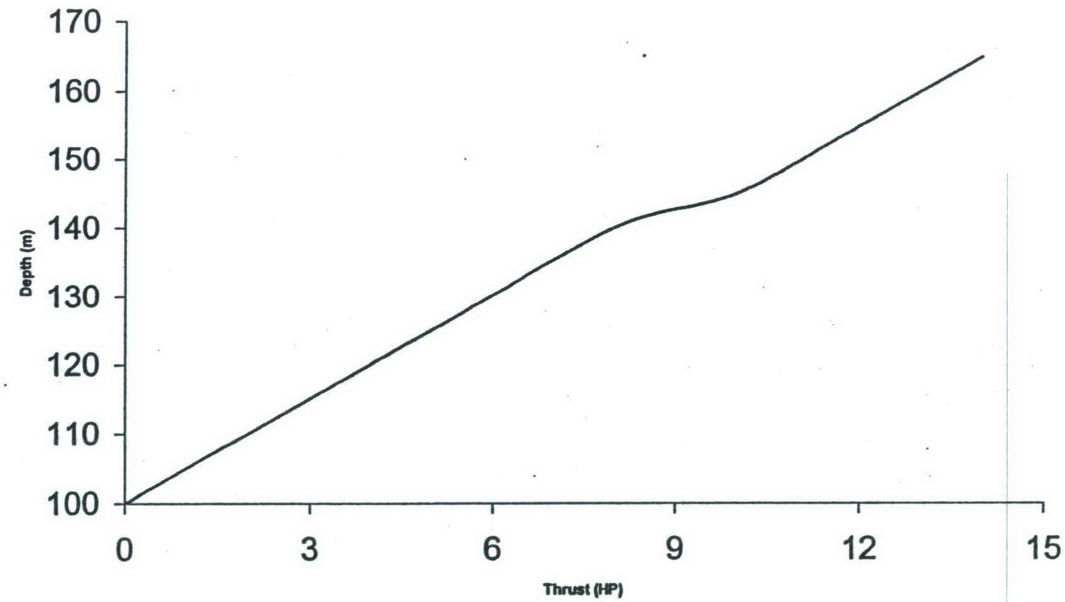

FIG. 4