

[54] **HYDROFOIL CAVITATION SENSING AND CONTROL APPARATUS**

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[58] Field of Search ..... 114/66.5 R, 66.5 H;  
115/11, 14; 340/5 R, 8 R; 73/67;  
415/1, 27; 417/42

### [56] References Cited

#### UNITED STATES PATENTS

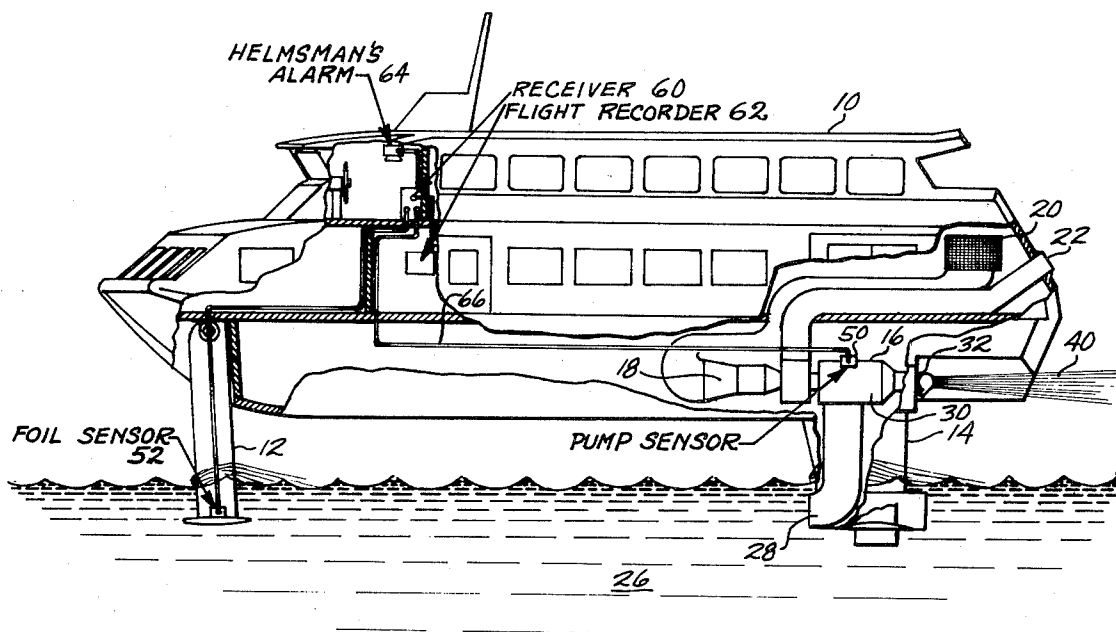
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|-----------|---------|---------------|------------|
| 3,149,602 | 9/1964  | Vogt .....    | 114/66.5 H |
| 3,443,797 | 5/1969  | Branson ..... | 73/67      |
| 3,704,442 | 11/1972 | Wright .....  | 340/5 R    |
| 3,757,288 | 9/1973  | Morin .....   | 340/5 R    |

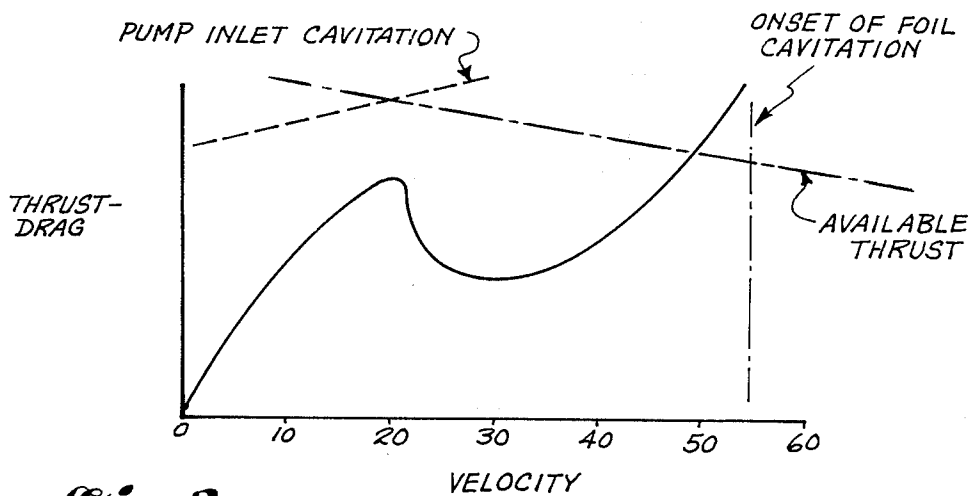
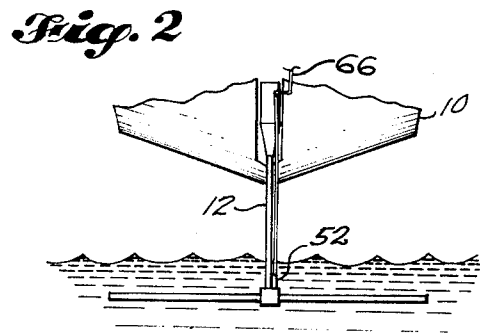
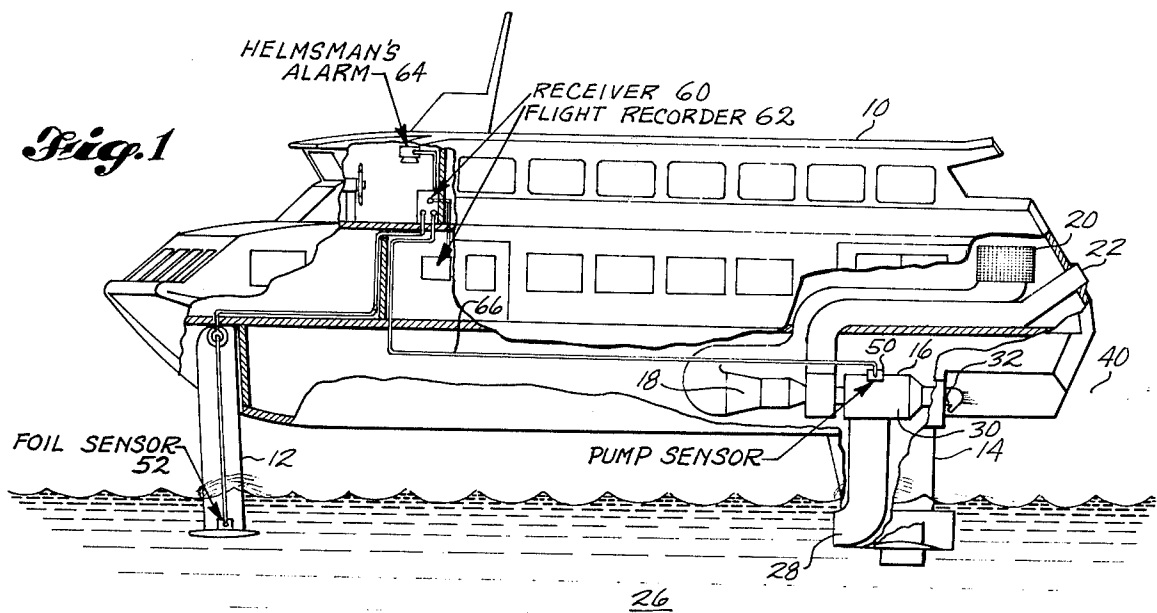
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### [57] ABSTRACT

A cavitation detection and control system for controlling the movement of a hydrofoil within a safe, cavitation-free, acceleration and speed region. The system utilizes transducers, associated with the hydrofoil propulsion apparatus and associated with the foil/strut apparatus, for sensing the onset and duration of cavitation in the liquid working medium adjacent to or within these apparatus and a receiver for converting the sensed cavitation data into a signal. An alarm device is responsive to that signal so that the helmsman can reduce the thrust for operating the hydrofoil movement within a cavitation-free region. A data storing device is connected to the receivers output for retaining occurrence of the onset and duration of cavitation.

7 Claims, 3 Drawing Figures





## HYDROFOIL CAVITATION SENSING AND CONTROL APPARATUS

### BACKGROUND OF THE INVENTION

#### a. Field of the Invention

This invention relates to preventing damage caused by cavitation to a hydrofoil boat during its travel, in the region, from neutral or hull-borne to its maximum designed foil-borne speed and, more particularly, to a system for providing and retaining control to its propulsion operation when cavitation is sensed during hydrofoil boat acceleration and speed.

#### b. Description of the Prior Art

A system for sensing, controlling and retaining cavitation occurrence information during the movement of a hydrofoil boat has never been developed before because there was no need for it in the prior art.

In the past, many hydrofoils, most of the surface piercing foil, have been built; however, never on a large production basis and never as sophisticated, complicated and as expensive as of today's submerged foil type.

Accordingly, when one purchases such an article from a manufacturer, the buyer requires guaranties of failureless operation and the manufacturer refuses such guaranty in case of misuse of operation.

The present invention relates to a system that provides for proper operation of hydrofoil boat by the operator and can also provide data to the manufacturer that the hydrofoil has been properly operated by the operator.

A state-of-the-art search did not uncover any patents in which transducers were used to detect cavitation in the region of movement, thrust and speed, of a hydrofoil, and also there seems to be no literature available referring and/or describing cavitation prevention control and recording systems for hydrofoil boats.

The only patents of interest mentioned were:

U.S. Pat. No. 3,618,006 by C. P. Wright, relating to sonar systems for hydrofoil, and various patents relating to underwater flow noise, speed and cavitation per se without application to hydrofoils, respectively, such as: U.S. Pat. No. 3,229,509 by R. A. Darby; U.S. Pat. No. 3,336,801 by B. L. Snively, and U.S. Pat. No. 3,525,977 by C. L. Darner.

Of particular interest to this invention is U.S. Pat. No. 3,757,288 which teaches an electronic circuitry and its operation for filtering out cavitation noise from ambient noise or signals.

### SUMMARY OF THE INVENTION

Basically, a hydrofoil boat is designed for travelling at higher speeds than a conventional boat. Obviously, the higher speed is obtained by reducing the hull drag through the water by the use of hydrodynamic foils mounted on struts. The foils produce lift and the boat flies above the water level on the submerged foils or wings, thus the hydrofoil is more or less a boat and airplane combination. As a result of the combined technologies of hydro- and aero-dynamics, a hydrofoil boat becomes an expensive, complex and highly intricate precision apparatus. Accordingly, it is very essential to protect the operation of the hydrofoil against the various causes of damage that may occur. One major and hard-to-control damage, which results in failures, is due

to the effect of cavitation in the water or transport medium.

In general, cavitation is a well known phenomenon and may be defined as the formation of bubbles of gas or vapor in a liquid due to localized low pressure areas caused by relative motion of a liquid and a solid. The bubbles normally contain desorbed gases as well as vaporized liquid. Nucleation of a bubble is generally believed to occur at a microscopic discontinuity in the liquid continuum. The discontinuity may be caused by stable micro-bubbles, solid particles, particle bubble combinations, nonmiscible micro droplets or active sites on solid bounding surfaces.

The bubble nucleus, therefore, is regarded as a weak spot in the liquid where rupture will occur under stress. Unless there is gas in solution in the liquid, cavitation cannot occur above the liquid's bubble point, which is the vapor pressure of the liquid at the temperature in question. Bubbles can be formed, however, when the fluid is at or below its bubble point pressure. As the bubbles later reach a point of higher pressure, a violent collapse occurs, thereby producing shock waves which can be severe enough to damage the mechanical members in contact with the fluid.

Cavitation damage is most often characterized by physical alteration of the surface contacted by the shock waves produced by the collapsing bubbles. Such alteration can range from subtle deformation of the surface geometry to serious erosion of the material.

Typical situations where the unwanted cavitation occurs in a hydrofoil is during its acceleration phase when hull-borne and at the foil-borne maximum designed speeds.

In the present invention it can thus be visualized to affix acoustic transducers to the system so as to provide continuous monitoring of the energy response of a particular system on the hydrofoil. For example, they could be affixed to the pump housing, the duct wall, etc., of a waterjet propulsion system; to the foils, or struts or elsewhere on the foil/strut system, etc. By simple electrical/electronic processing, (Such as per U.S. Pat. No. 3,757,288) the signal that any transducer gets when cavitation begins anywhere within the waterjet propulsion system or on the foil/struts, can be used to activate a warning light at the control station so that the operator can take action to stop the cavitation. When the cavitation stops, the signal will again be low enough so that the warning light will go out. In addition, the signal can be connected to a monitor which can be set to count any time that the signal remains present beyond a certain length of time. This monitor can be used to establish that cavitation was present and that action may not have been properly taken by an operator to eliminate it. This would be very useful to builders of equipment, owners, etc., to determine that equipment was being operated properly, that warranties were not being violated, etc. Since propulsion system cavitation will normally occur during take-off (or at low speed) and foil/strut cavitation at high speed, there may not be any need to provide more than one warning light, or audible warning signal, although it is simple to provide multiple warning and counting methods in order to establish which system is specifically involved in the cavitation. Generally, the helmsman or operator response to the warning is the same in any case, reduce acceleration if taking off, or reduce speed, either hullborne or

foilborne, by reducing the power until the warning goes off.

It is therefore an object of the present invention to provide for a system which prevents the damage resulting from cavitation development to the propulsion and lifting support means of a hydrofoil.

It is another object of the present invention to provide a system for sensing and warning of the presence of cavitation so that improper operation may be changed to proper operation of a moving hydrofoil.

It is an important object of the present invention to provide for a system which automatically warns the operator of cavitation development and records onset and duration thereof.

In general, the present invention relates to a system for informing of cavitation during the thrust and speed control operation of a hydrofoil boat, employing liquid propulsion means and strut/foil support means, by using transducers arranged with the liquid propulsion means and transducers arranged with the strut/foil means.

Additional objects, features and advantages will become evident from the following description taken in conjunction with the accompanying drawings.

#### DESCRIPTION OF THE DRAWINGS

FIG. 1 is a side view of a hydrofoil vessel with cut-away portions at fore and aft.

FIG. 2 is a front view of a strut-foil arrangement with cavitation sensor transducer means installed.

FIG. 3 is a diagram exemplifying the hydrofoil vessel drag during take-off and at foilborne high speed.

#### OPERATION OF THE INVENTION

The drawings diagrammatically illustrate by way of example, not by way of limitation, a preferred form of the invention. FIG. 1 discloses a typical hydrofoil boat 10 in which the invention may be utilized. The hydrofoil boat 10 is shown in its foilborne mode of travel and is supported on a forward strut/foil means 12 and rear or aft struts/foil means 14. The boat 10 is provided with a liquid or water jet propulsion system 16 which comprises a jet engine 18 with an air intake 20 and an exhaust 22. The jet engine 18 drives a pump 30. Water 26 is guided and pumped through the intake 28 located in the aft strut 14 and is pumped by the pump 30 towards the exit steering nozzles 32. The high-powered liquid or water jet 40 will propel the boat 10 from hullborne, through foil take-off, to a high foilborne speed. During the mode of movement from neutral to high speed, the pump 30 will pump water at a certain pump velocity and a slow movement of the boat will follow. However, a too-high pump velocity may cause cavitation onset as approximately illustrated in FIG. 3 by the dashed line called "pump inlet cavitation." In order to sense that cavitation, a transducer 50 is installed as shown on the pump housing 30; however, it should be realized that the location of the transducer 50 or the number of transducers 50 used can be varied and depend on requirements, tests and actual reduction to practice. The transducer 50 is similar to a hydrophone or microphone and is a conventional apparatus for receiving sounds over a predetermined spectrum which converts the received sounds to an electric signal. The submerged mounting is likewise accomplished as the mountings of sound receiving apparatus as is disclosed in the prior art by U.S. Pat. Nos. 1,960,240 by Clement,

2,410,806 and 2,434,666 by Mason. There is also a transducer 52 located at the forward strut 12 at the strut/foil intersection for sensing cavitation at high speed, which occurs as illustrated at approximately 54 knots by the straight vertical line plotted in FIG. 3 and called "Onset of Foil Cavitation." Here again it should be emphasized that the location of the transducer on the forward strut for sensing cavitation at high speed is purely shown for the purpose of illustration only and is not intended to define the scope of the invention. Thus it may be desirable to use several transducers at the forward or aft struts or foils 14 and at various locations.

Referring again to FIG. 1, the transducers 50 and 52 are connected to a receiver 60 by conduits or electrical cables 66. The receiver 60 is electrically connected to a flight recorder 62 and to a visual and/or sound tape warning means 64.

During operation of the hydrofoil, the warning means 64 will indicate that too much power is applied and reduction thereof will avoid the operation in the cavitation region. When the speed is high at foilborne operations, the cavitation may develop at approximately 54 knots because, as explained hereinbefore, various parameters such as the temperature, the chemical elements in the water, etc., influence the development of cavitation. Thereafter, as soon as the speed limit or the onset of cavitation is sensed, the warning means 64 will response and tell the operator to reduce power. In the case that the operation is on automatic flight control, the system, when hooked up with the propulsion power means (not shown), will automatically reset its power somewhat as soon as the sensed cavitation onset is experienced. In the meantime, when a certain voyage is made, the various onsets and duration of cavitation occasions can be read from the tape of the flight recorder 62 so that if any damage has occurred to the hydrofoil boat 10 during that voyage, struts, foil or propulsion means, it can be determined if such was due to misuse or faulty operation involving cavitation.

In general, it should be stated that cavitation noise in water occurs at frequencies above the 2 to 3 kilo-hertz and therefore the transducers used will be operable in a frequency range compatible therewith. Of course, a fixed frequency cannot be given since it will be different in each situation. For example, blade pitch, foil curvature, size of instrumentation, angle of attack, water composition and temperature, etc., have all some influence. However, these variables are all known to the persons skilled in the art and are easily determined in each situation for each particular boat so that transducers in the approximate proper frequency range with the required sensitivity will be chosen. Furthermore, the mounting of transducers in the surfaces adjacent the water flow is also well within the knowledge of the art and therefore further discussion is deemed unnecessary.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

Now, therefor, I claim:

1. System for detecting the occurrence of cavitation during the start to maximum speed of the thrust and

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speed operation of a hydrofoil boat employing liquid propulsion means and strut/foil means, comprising in combination:

- a. first transducer means associated with said liquid propulsion means for detecting cavitation noise in said liquid of said propulsion means and for converting said cavitation noise into a first signal;
- b. second transducer means associated with said hydrofoil/strut means for detecting cavitation noise about said hydrofoil/strut system ambient liquid medium and converting said cavitation noise into a second signal;
- c. receiving means for sensing the presence of said first and said second signals, and for generating an output signal, and
- d. means connected to said receiving means and responsive to said output signal for imparting a warning to an operator of said hydrofoil boat signifying the presence of said first and said second signals.

2. A system as claimed in claim 1 wherein said first transducer means is mounted in said liquid propulsion means associated pumping system, and wherein said second transducer means is mounted to said strut/foil structural intersection.

3. A system as claimed in claim 2 wherein said means connected to said receiving means includes an alarm device to tell an associated helmsman to reduce said thrust and speed control operation.

4. A system as claimed in claim 3 wherein said means

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connected to said receiving means includes a recording device for retaining the output of said receiving means.

5. An apparatus for informing of cavitation development during acceleration and speed control operation of a hydrofoil boat with strut/foil means employing waterjet propulsion apparatus comprising in combination:

- a. first transducer means associated with said waterjet propulsion apparatus for detecting and converting cavitation into a first signal;
- b. second transducer means associated with said hydrofoil boat strut/foil means for detecting and converting cavitation into a second signal;
- c. receiving means electrically connected to said first and second transducer means and adapted to sense said first and second signals at a predetermined level, and for generating an output signal, and
- d. means connected to said receiving means and responsive to said output signal for imparting a warning to an operator of said hydrofoil boat signifying the presence of said first and said second signals.

6. An apparatus as claimed in claim 5 wherein said first transducer means is mounted at said waterjet propulsion apparatus associated pumping means and wherein said second transducer means is mounted at said strut/foil structural intersection.

7. An apparatus as claimed in claim 5 wherein said means connected to said receiving means includes a recording device.

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