Jan. 16, 1962 H. P. EICHENBERGER 3,016,865

METHOD AND APPARATUS FOR REDUCING DRAG

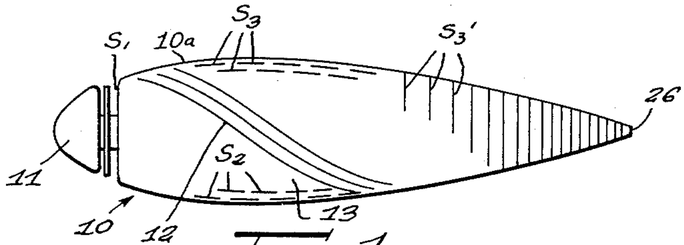


Fig. 1

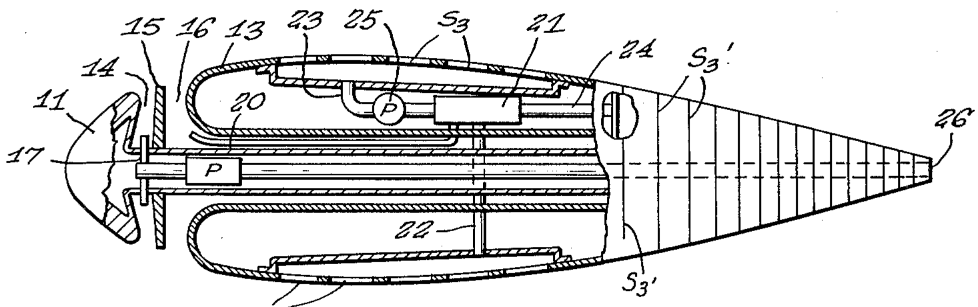


Fig. 1a

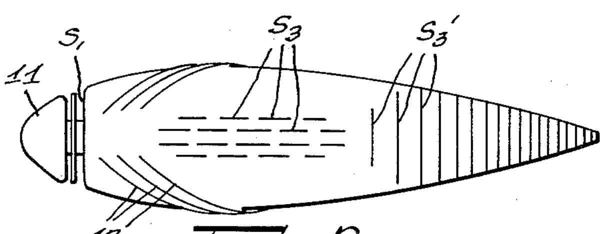
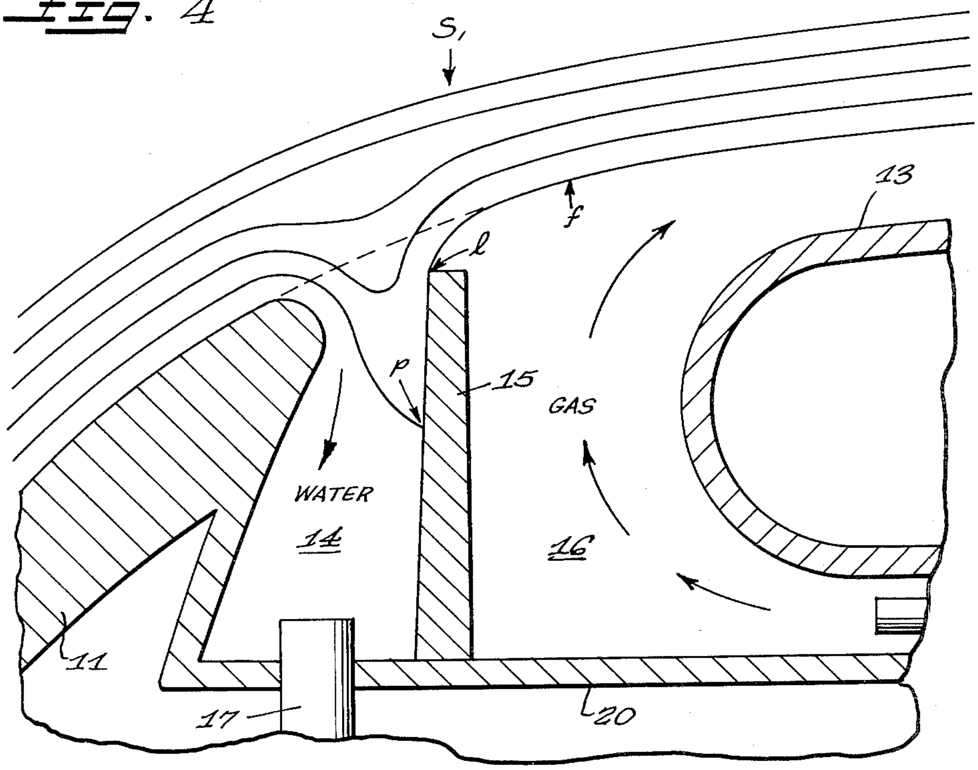


Fig. 2

FIG. 4



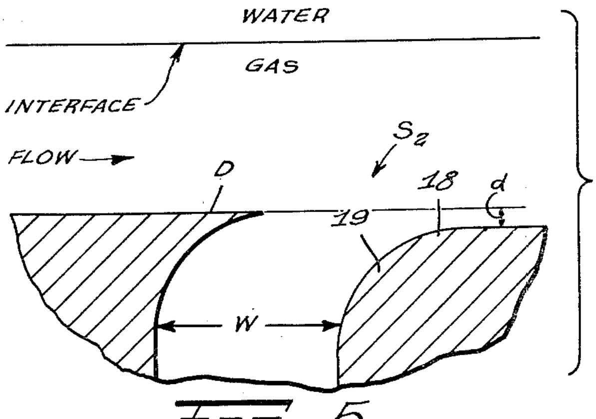


FIG. 5

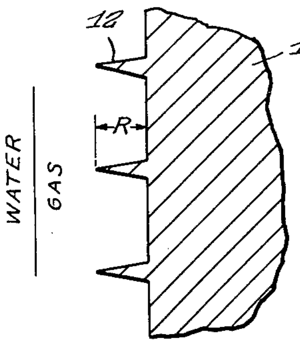


FIG. 6

Inventor
Hans P. Eichenberger

By Hill, Sherman, Meroni, Gross & Simpson Attys

Jan. 16, 1962 H. P. EICHENBERGER 3,016,865

METHOD AND APPARATUS FOR REDUCING DRAG ON SUBMERGED VEHICLES

Filed May 21, 1959 3 Sheets-Sheet 3

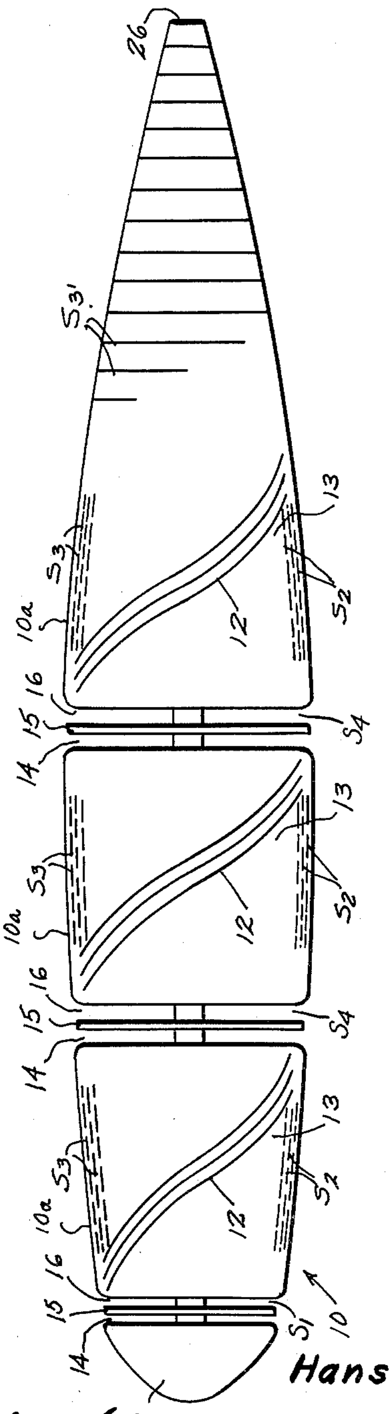


FIG. 7

INVENTOR.
Hans P. Eichenberger

BY

Hill, Sherman, Meroni, Gross & Simpson

ATTORNEYS

United States Patent Office

3,016,865

Patented Jan. 16, 1962

1

3,016,865

METHOD AND APPARATUS FOR REDUCING DRAG ON SUBMERGED VEHICLES

Hans P. Eichenberger, Cleveland, Ohio, assignor to Thompson Ramo Wooldridge Inc., Cleveland, Ohio, a corporation of Ohio

Filed May 21, 1959, Ser. No. 814,809

8 Claims. (Cl. 114—67)

This invention relates to a method and apparatus for reducing the drag of bodies or vehicles such as a torpedo or a submarine or the like submerged in a liquid such as water. More particularly, the invention relates to a method and apparatus for providing a many-fold reduction of such drag by stabilization of a laminar water

2

not break up into bubbles. The thickness of the gas film can be controlled or maintained by continually injecting gas and by removing a part of the existing gas layer through porous walls or slots. The stability of the gas-water interface can be improved also by the reduction of shear stress on this interface. One device for achieving such shear reduction is the provision of deflecting ridges or fins to deflect a portion of the gas film at an angle to the direction of the velocity of the body in a manner to be described in detail below.

It is a feature of the present invention to provide means for separating a body such as a torpedo or a submarine immersed in a liquid from that liquid by a gas film in such a fashion as to maintain the stability of a laminar liquid boundary layer and the stability of th

FIGURE 3 is a view looking upwardly at the bottom of the torpedo shown in FIGURE 1;

FIGURE 4 is a fragmentary sectional view on an enlarged scale showing detailed construction of a suitable means by which a gas film may be introduced onto the surface of the torpedo in such a fashion as to maintain a laminar water boundary;

FIGURE 5 is a fragmentary sectional view on an enlarged scale showing the cross-sectional structure of the blowing slots found on the bottom of the torpedo; and

FIGURE 6 is a fragmentary sectional view showing the cross-sectional structure of the gas deflecting ridges on the surface of the torpedo.

FIGURE 7 is a diagrammatic longitudinal sectional view (parts being shown in exaggerated size and not to scale for the sake of clarity) of an elongated vehicle constructed in accordance with the present invention.

As noted above, the present invention is directed to a method and apparatus for reducing the drag of a body such as a vehicle submerged in an ambient fluid by a factor of many times and in some instances as great as 100 times by stabilization of the laminar boundary layer of the fluid by a film of a fluid of substantially lower viscosity such as a gas. The stabilization of the laminar water boundary layer results also in the stabilization of the water-gas interface. The method of the present invention is more easily applied where the Reynolds number for the body or vehicle is small. In this sense, the Reynolds number for the body may be defined as being equal to the velocity of the body times the length of the body, the product being divided by the kinematic viscosity of the water or other fluid medium in which the body moves. It is thus apparent that the method is particularly suitable for application to torpedoes where this Reynolds number of the body is small.

There are essentially two conditions which are necessary to insure the stability of the water boundary layer and the gas interface therewith. The first of these conditions is that the streamlines forming the interface between

10*a* thereof. The purpose of this slot S1 is two-fold. First, it serves to remove all water boundary layer which has been created in the flow over the frontal nose surface and secondly it serves to introduce a gas film which flows backwardly over the surface of the rest of the torpedo to thereby isolate the rest of the torpedo from direct contact with the surrounding water. A typical configuration of the two adjacent annular channels suitable for accomplishing this purpose is shown in FIGURE 4 and will be discussed in detail below. This slot serves to remove all water boundary layer which has been created in the flow over the front nose and to introduce a gas film over the surface of the rest of the torpedo.

After this gas film has been introduced at S1, it has to be replenished by additional gas from slots S2 generally disposed on the bottom of the underwater body as seen by way of example in FIGURE 3. These blowing slots S2 may be arranged in various patterns but should have special geometric form (shown in detailed cross-section in FIGURE 5 and to be described below) such that they replenish the gas film thickness but provide a minimum of disturbance to the film. For instance, for a torpedo, the gas film must remain laminar and the flow in these blowing slots has, therefore, to be at a very low Reynolds number (based on the width W of the slot) such that the laminar flow of the gas film is not disturbed.

The underwater body 10 also has suction slots S3 on its top surface as shown in FIGURES 1 and 2. These suction slots remove gas from the film and are distributed in such a fashion as to keep the gas film thickness within specified limits. For instance, for a torpedo operating at normal speeds, the gas film height should be of the order of $\frac{1}{1000}$ foot.

Further back on the torpedo, more gas must be removed on the top than is introduced on the bottom. This begins to occur in the region where the water flow introduces a positive pressure gradient along the surface of the torpedo. Additional suction slots S3′ are provided and may be positioned to run perpendicular to the axis of gas interface is concave seen from the gas side. These conditions are achieved by the device shown in cross-section in FIGURE 4. The water in which the submerged body travels is shown flowing from left to right. This water flowing over the front nose portion **11** of the sur-

any event at least a sharp corner. The surface wall **18** to the right side (downstream in the gas flow) is slightly depressed by the amount or distance, *d* (FIGURE 5), and the corner **19** of slot **S2** leading to this surface is generously rounded as shown in FIGURE 5.

torpedo is terminated at its rearward end in the angularly disposed suction slots S3' to gradually merge with the water discharge portion 26. It will further be understood, however, that the drawings are intended to diagrammatically or schematically illustrate merely one type apparatus suitable for carrying out the method of the present invention and that in practice the necessary apparatus can be far more compactly arranged to leave room for the other conventional components (not shown) in the torpedo or submarine.

In accordance with the above disclosed method, it is possible, by stabilizing the water-gas interface on the body of a torpedo, to reduce the propulsive power required by the torpedo by a factor in the range to 10 to 100 times and at the same time to reduce the noise created by the torpedo by more than 100 fold. The major problem in obtaining these gains in performance is the stabilization of the laminar water boundary layer which is separated from the torpedo skin by the gas layer. If this interface is stable the above-noted desirable operating results can be achieved.

There are two reasons which tend to lead to instability of the water-gas interface and which must be overcome in practice. The first of these is the Taylor instability which is exemplified by the instability of a gas layer on the bottom of a glass of water. This is the phenomenon wherein the gas breaks up into bubbles which rise to the surface in the glass. Generally, this kind of instability occurs whenever the body force acts in the direction from the denser fluid (water) toward the less dense fluid (gas). This is not necessarily the case on the top of the torpedo (or submarine) provided the centrifugal force exceeds the gravity.

The second reason tending toward instability is of the same nature as the instability which leads from a laminar water boundary layer to a turbulent one. It is clearly a function of the water boundary layer velocity profile and the Reynolds number in the water. The water boundary layer Reynolds number, based for instance on the displacement thickness of the water boundary layer, becomes smaller when the shear stress is reduced which is exerted on the water by the gas film everything else being equal. On a typical torpedo, a gas film of $1/100''$ thickness produces a shear stress on the torpedo which is so small (about $1/100$ of the shear stress which would exist in a laminar water boundary layer for the same torpedo without gas film) that the water boundary layer has a chance not to break up before the end of the torpedo. More particularly, even though the gas-water interface may tend to become unstable, the amplification of the instability wave does not lead to sufficiently large amplitude before the end of the torpedo to form water droplets.

It might be speculated that it is easy to increase the gas film thickness to a value where the shear stress is reduced so that essentially no water boundary layer is created and, as a consequence of the resulting low boundary layer Reynolds number, the water-gas interface would be expected to be stable. This argument is essentially correct except that the increase of gas film thickness is limited by the magnitude of cross-flow shear stress which can be tolerated. Indeed, due to gravity or angle of attack a pressure gradient exists which produces a motion in the gas perpendicular to the water velocity. This gas flow, which occurs from the bottom of the torpedo to the top has to be counteracted by admitting additional gas on the bottom of the torpedo and removing gas by suction slots at the top of the torpedo such that the gas film thickness on the bottom and top of the torpedo remains essentially the same. To be sure, for a gas thickness of 0.01'' these quantities of gas added and removed for the control of the gas film thickness turn out to be extremely small. Nevertheless, this phenomenon sets a lower bound to the achievable values of longitudinal stresses acting on the gas-water interface because the cross-flow shear stresses increase with increasing thickness.

It must be emphasized that these shear stresses are already extremely small considering the drag which they produce, but their reduction by such means as the deflecting ridges discussed in detail above is of value because it is the stabilization of the gas-water interface to laminar flow which represents the central or basic problem involved in reducing drag on a submerged vehicle through the use of a lubricating fluid film.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

1. The method of reducing the drag on a vehicle immersed in a liquid comprising, introducing a circumfluous gas film between said vehicle and said liquid, withdrawing said gas from certain points on the surface of said vehicle, continuously repeating said introducing and withdrawing steps to maintain a gas film of predetermined thickness around a major portion of the surface of said vehicle to stabilize a laminar liquid boundary layer and the liquid-gas interface between said layer and said film, and deflecting a part of said gas film at an angle to the direction of the velocity of said vehicle to reduce the magnitude of the shear stresses acting on said gas-water interface.

2. A method of reducing the drag on a vehicular body immersed in water comprising the steps of removing a boundary layer of water which has flowed over the front portion of the surface of this body at a point near the front of said body, introducing a circumfluous gas film around said body at said point so as to maintain the water-gas interface in a concave shape as seen from the gas side, said gas film being introduced in such a fashion that the liquid accelerates from a stagnation point to the point where said film is introduced to form a free streamline, withdrawing a portion of said circumfluous gas film from rearward portions of the surface of said body to maintain the thickness of said film at a predetermined value to stabilize a laminar water boundary layer and the water-gas interface between said layer and said film, and deflecting a portion of said gas film around said body at an angle to the direction of the velocity of said body to reduce the shear stresses acting on said gas-water interface.

3. In a vehicle adapted to operate entirely immersed in water, drag reducing apparatus comprising, means positioned near the front of said vehicle to introduce a gas film around a major portion of the surface thereof, gas withdrawal means associated with said vehicle to maintain the thickness of said film at a predetermined value, and gas deflecting means on at least a portion of the surface of said vehicle to reduce the shear stress exerted on said water by said gas film to maintain a laminar water boundary layer adjacent said film.

4. In a vehicle adapted to be operated entirely immersed in water, drag reducing and noise insulating apparatus comprising, annular slot means extending around said vehicle near the forward portion thereof, said slot means having at least one channel connected to a source of gas to introduce a circumfluous gas film around a major portion of the surface of said vehicle, additional gas introducing means positioned along the bottom surface of said vehicle, gas withdrawal means associated with said vehicle to maintain the thickness of said film at a predetermined value, and gas deflecting ridge means on the surface of said vehicle, said ridge means having a height less than said predetermined thickness of said gas film and being positioned to deflect said gas to reduce the shear stress exerted by said gas on said water to maintain a laminar water boundary layer adjacent said gas film.

5. In a vehicle adapted to operate entirely immersed in water, drag reducing and noise insulating apparatus comprising, annular slot means extending around said vehicle near the front end thereof, said slot means comprising first and second annular channels separated by

an annular knife edge, said first channel being positioned forwardly of said knife edge and being connected to means for withdrawing the water boundary layer flowing over the front portion of the surface of said vehicle, said second annular channel being positioned rearwardly of said annular knife edge and being connected to means to supply gas to be introduced onto the surface of a major portion of said vehicle rearwardly of said annular slot, and gas withdrawal means positioned rearwardly of said annular slot to maintain said gas supplied through said slot in a film of predetermined thickness around the surface of said vehicle.

6. In a vehicle adapted to be operated entirely im-

immersed in liquid comprising the steps of removing a boundary layer of liquid which has flowed over a portion of the surface of the body, introducing a circumfluous gas film around said body adjacent the region of removal of the boundary layer of liquid from the body so as to maintain a liquid gas interface in a concave shape seen from the gas side, said gas film being introduced in such a fashion that the liquid accelerates from a stagnation point to the point where said film is introduced, and withdrawing a portion of said circumfluous gas film from portions of the surface of said body spaced rearwardly from the region of introduction of the gas film around said body to maintain the thickness of said gas film at