Oct. 17, 1967 G. J. GOODRICH ET AL 3,347,199

ROLL STABILIZERS

Filed Jan. 28, 1966 5 Sheets-Sheet 1

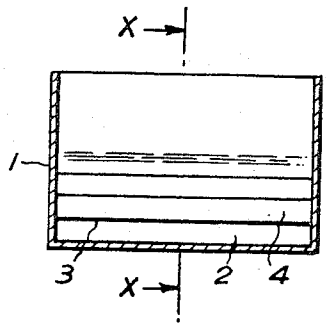


Fig. 1a.

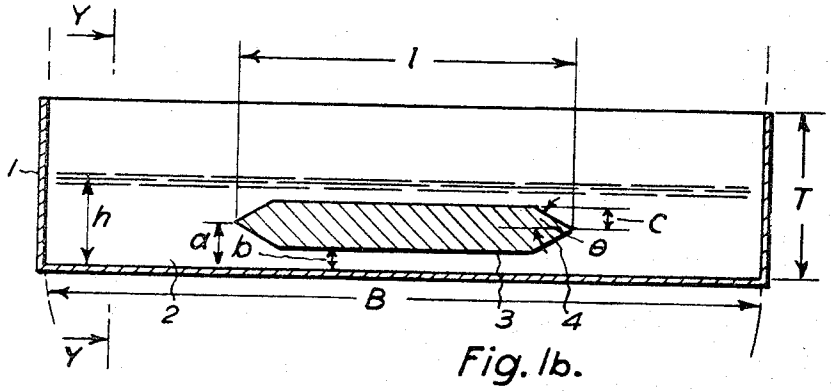


Fig. 1b.

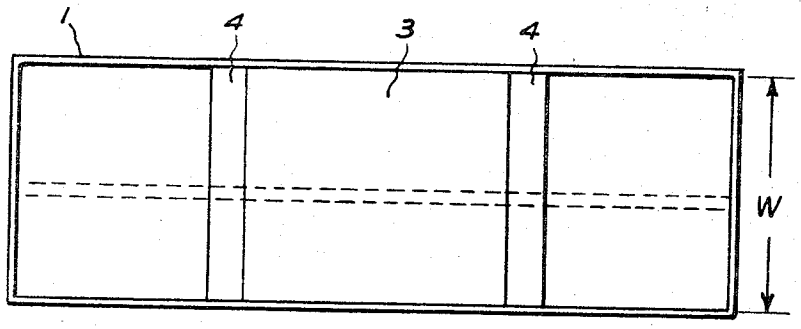


Fig. 1c.

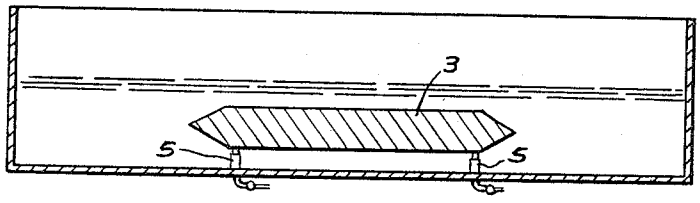


Fig. 1d.

INVENTORS
G. J. GOODRICH
R. A. WILLIAMS
BY
Cameron, Kerkam & Sutton
ATTORNEYS

Oct. 17, 1967 G. J. GOODRICH ET AL 3,347,199

ROLL STABILIZERS

Filed Jan. 28, 1966 5 Sheets-Sheet 2

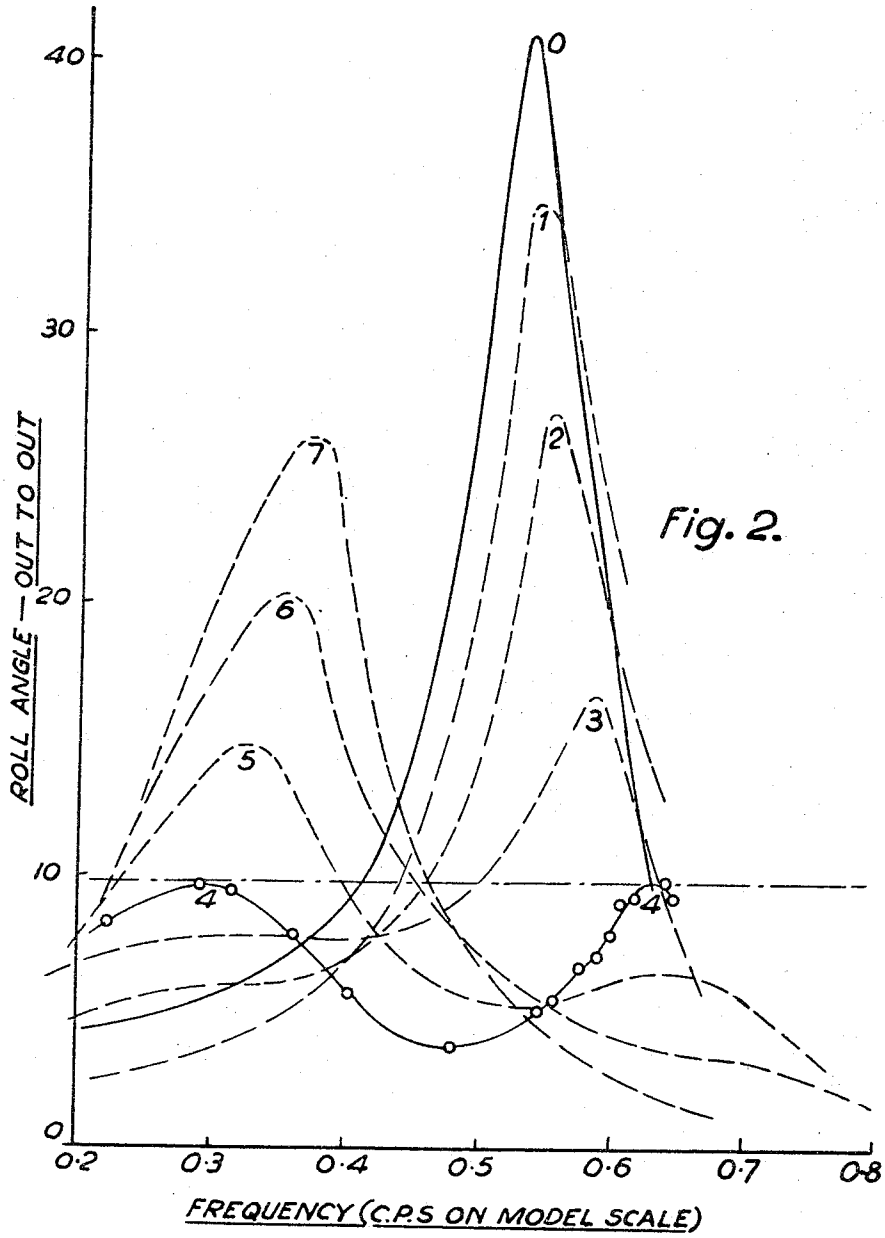


Fig. 2.

INVENTORS
G. J. GOODRICH
R. A. WILLIAMS
BY
Cameron, Kerkam & Sutton
ATTORNEYS

Oct. 17, 1967 G. J. GOODRICH ET AL 3,347,199

ROLL STABILIZERS

Filed Jan. 28, 1966 5 Sheets-Sheet 3

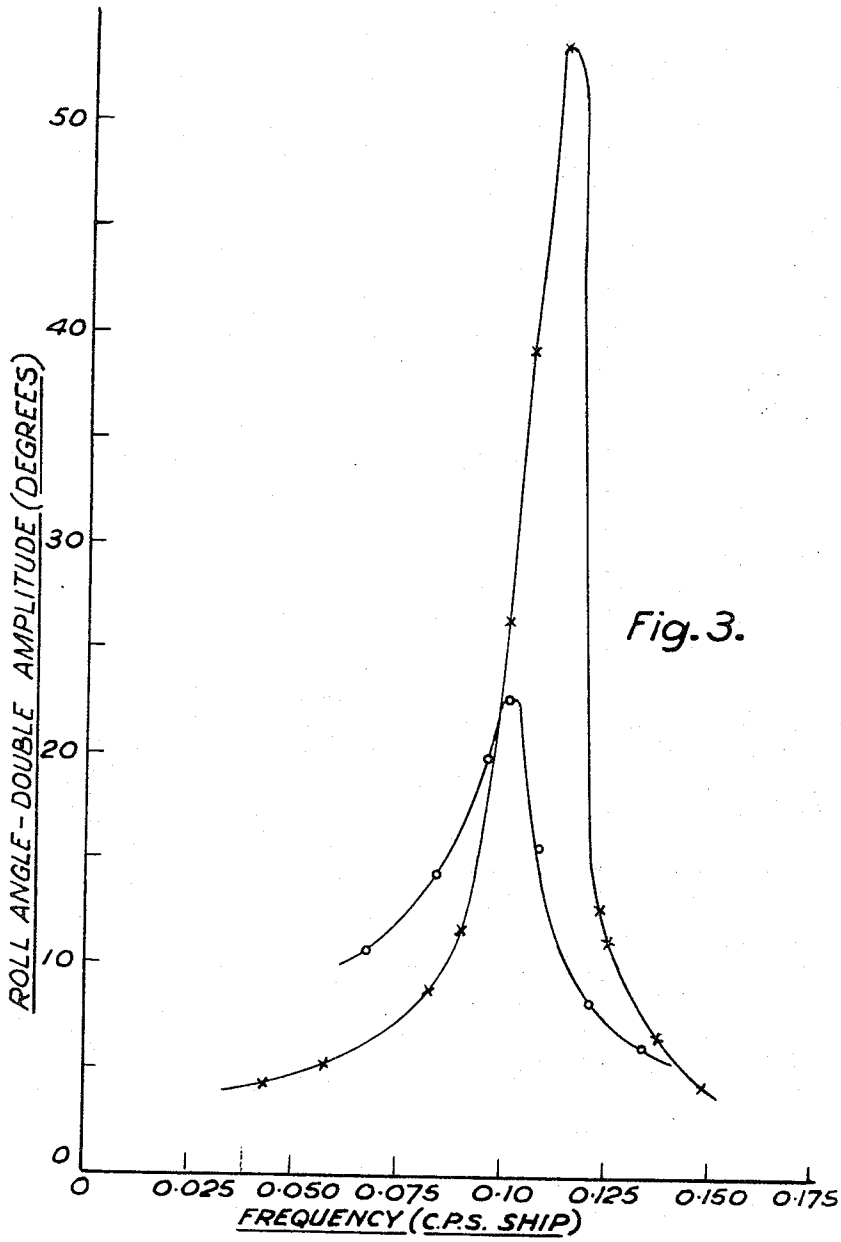


Fig. 3.

INVENTORS
G. J. GOODRICH
R. A. WILLIAMS
BY
Cameron, Kerkam & Sutton
ATTORNEYS

Oct. 17, 1967 G. J. GOODRICH ET AL 3,347,199

ROLL STABILIZERS

Filed Jan. 28, 1966 5 Sheets-Sheet 4

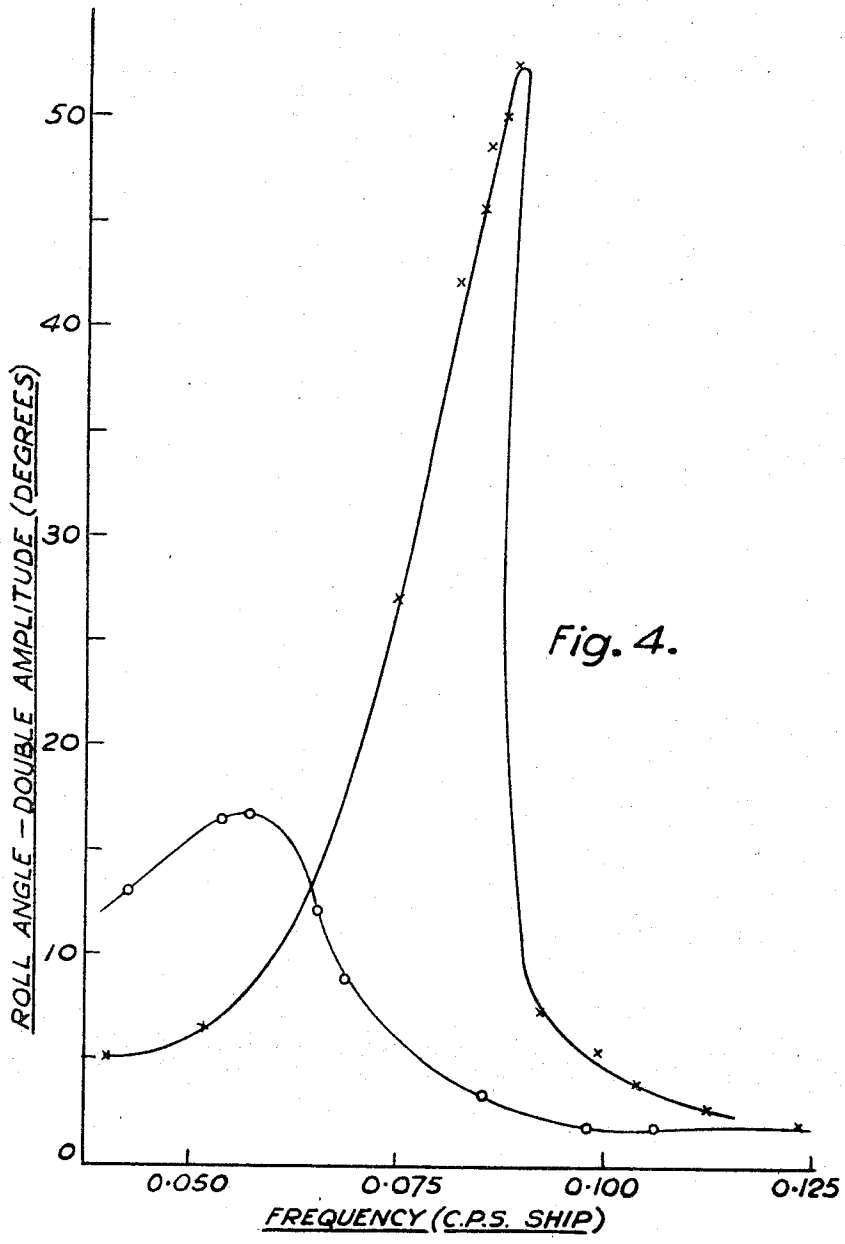


Fig. 4.

INVENTORS
G. J. GOODRICH
R. A. WILLIAMS
BY
Cameron, Kerkam & Sutton
ATTORNEYS

Oct. 17, 1967 G. J. GOODRICH ET AL 3,347,199

ROLL STABILIZERS

Filed Jan. 28, 1966 5 Sheets-Sheet 5

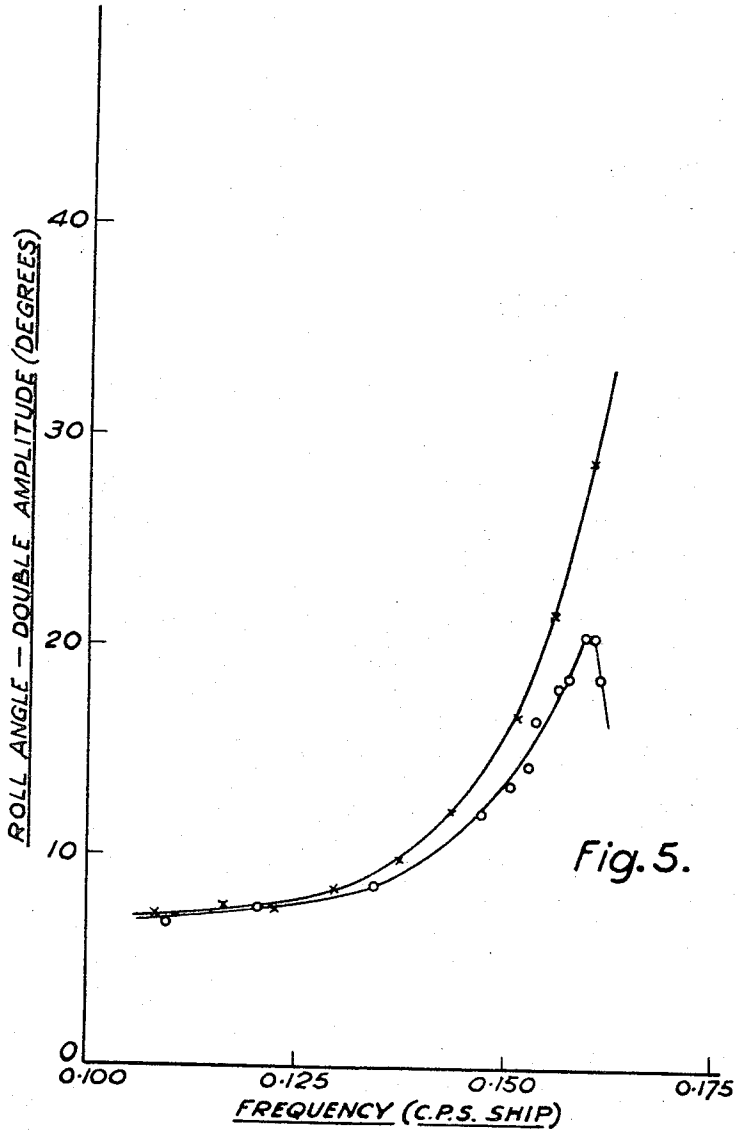


Fig. 5.

INVENTORS
G. J. GOODRICH
R. A. WILLIAMS
BY
Cameron, Kerkam & Sutton
ATTORNEYS

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ROLL STABILIZERS

Geoffrey John Goodrich, Feltham, England, and Robin Andrew Williams, Edinburgh, Scotland, assignors to National Research Development Corporation, London, England, a body corporate of Great Britain

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Claims priority, application Great Britain, Jan. 29, 1965, 4,170/65
7 Claims. (Cl. 114—125)

ABSTRACT OF THE DISCLOSURE

A floating structure such as a ship is stabilized against rolling about a horizontal axis by a passive stabilizing system consisting of a liquid-containing tank set transversely of the structure with a free air space above the liquid and a divider of plate-like form extending the full fore-and-aft dimension of the tank and for form 40% to 60% of the athwartship dimension thereof, the divider being located substantially below the static level of the liquid so that when the ship rolls liquid flows both over and beneath the divider, the lateral edges of the divider preferably being pointed to facilitate such flow. At the natural frequency of rolling, the flow over and under the divider should be at different mass rates. The horizontal mid-plane of the divider is desirably at approximately half the static depth of the liquid, while the vertical thickness of the divider is substantially twice the depth of the liquid below it. The level of the divider may be adjustable.

This invention relates to passive systems for stabilizing structures floating in liquid about a horizontal axis. Such a structure is typically a ship, and though a passive stabilizing system could be constructed to deal with oscillation about any horizontal axis it is usual to resolve the oscillations into pitching motion about a transverse axis and rolling motion about a longitudinal axis, and when a passive stabilizing system is provided, to construct it to deal with rolling motion, because such systems, if constructed to deal effectively with pitching motion, become too bulky to be acceptable. The invention is however applicable to such structures as floating drilling platforms or floating aerodromes when the ratio of length to beam may be such that a stabilizing system for pitching motion is feasible, or when the form may be such that the terms "length" and "beam" cease to have any clear application.

The innvention is concerned with systems of the kind in which a quantity of liquid is contained in a bounded space symmetrically located athwart the vertical plane containing or parallel and close to the axis about which stabilization of the structure is to be effected, the dimensions of the space and the quantity of liquid being chosen so that for a particular loading of the structure the oscillating motion of the structure at its natural frequency and the motion of the liquid athwart the axis of oscillation are as nearly as practicable 90° out of phase with each other. A stabilizing system as just set forth will hereinafter be referred to as a "stabilizing system of the kind set forth."

Hereinafter ships and rolling motion will mainly be referred to for convenience and because such structures and motion are the principal field of application of the invention, without the scope of the invention being limited thereby.

A specific example of a known system of the kind set forth applied to the reduction of rolling of a ship comprises a tank set athwart the ship (in which partial bulkheads may be included in the path of the liquid (water) moving from side to side), the height of the tank and depth of liquid being such that there is substantially no impediment to the movement of air over the free surface

of the liquid. A fuller description of this system is to be found in the paper by P. Watts, "On a Method of Reducing the Rolling of Ships at Sea," read at the twenty-fourth session of the Institution of Naval Architects on Mar. 16, 1883.

Other known systems of the kind set forth comprise two closed tanks, one on each side of the ship, connected at their lower ends by a (sometimes valved) duct always full (so that the tanks and duct form a U-tube) and with the air spaces of the tanks interconnected by a (sometimes valved) tube. Two examples of such systems are to be found in the paper by H. Frahm, "Results of Trials of the Anti-Rolling Tanks at Sea," read at the fifty-second session of the Institution of Naval Architects on Apr. 7, 1911, and in British patent specification No. 1,006,036.

Another prior proposal for a system of the kind set forth comprises an open topped tank on each side of the ship, joined by an open topped channel of less fore-and-aft dimension than the fore-and-aft dimension of the tanks, and with a fore-and-aft constriction of the flow across section at the junctions of each of the tanks with the channel.

A prior proposal for reducing the effect of free surface loss on the metacentric height of a ship (that might in fact have had a stabilizing effect) comprised a single tank athwart the ship with free air movement over the liquid, and it was suggested that it would be an advantage to vary the free surface area of the liquid as the ship rolls, to which end a body having a triangular cross section in vertical planes athwart the ship was disposed with its base parallel and close to but not touching the bottom of the tank and its apex at the same level as the static level of the liquid.

In broad outline the steps in designing a system of the kind set forth, comprising a single tank in which the movement of air over the liquid is substantially unrestricted, are as follows:

(1) The larger the mass of liquid, most usually water, (up to some limit of safety) the more effective the stabilization, but there is a limit to the space which can be spared both for the liquid and the free space above. A practical compromise is that the mass should be such that if it were all on one side of the vertical longitudinal midplane of the ship (and tank) it would cause the ship to heel through about 2°. This quantity can be calculated from a knowledge of the characteristics of the ship in which the system is to be fitted.

(2) The time period of transfer of liquid from side to side in an open unrestricted tank of constant cross section is approximately

$$\frac{2B}{\sqrt{gh}}$$

where h is the static depth of liquid in the tank, g is the acceleration due to gravity and B is the athwartship dimension (beam) of the tank. The velocity (i.e., rate of translation) is proportional to $\sqrt{gh}$. Thus the rate increases as the depth increases.

(3) For each particular loading of the ship, the ship has a natural frequency of roll and (assuming the tank is deep enough) the depth of liquid can be made such that the rate of movement of the liquid matches this frequency when the ship rolls, and the necessary 90° phase relationship can then be obtained and at this particular frequency stabilization would be achieved. Though this depth of liquid can be calculated, in all probability it will need to be adjusted by model experiments.

(4) The athwartship dimension (beam) of the tank is fixed by the design of the ship and the fore-and-aft dimension for a simple open tank can be calculated from the mass of liquid called for by (1) above to give the depth called for by (2) and (3) above.

(5) Such a simple tank filled to the correct depth can constitute the best passive stabilizing system of all at the natural frequency of the ship, but the fore-and-aft dimension calculated according to (4) above is usually greater than can be accommodated and a smaller fore-and-aft dimension determined by the design and function of the ship must be used, resulting in an increased depth for the required mass of liquid.

(6) Such increased depth would give an increased velocity and therefore mass rate of transfer to the liquid, see (2) above, and the required phase relationship would be lost. Among prior proposals a throttle or threat between the port and starboard ends of the tank, i.e., separation into virtually two tanks one on each side of the vertical longitudinal mid-plane of the ship, has been provided. This does not substantially affect the velocity but it slows down the mass rate of transfer to the required value.

(7) If only rolling at the natural frequency of the ship had to be provided for, nothing further would be required. But depending on the motion of the sea the ship may be set into forced rolling oscillation at a frequency above or below its natural frequency, with an amplitude great enough to require stabilization. Furthermore with the tank system and mass of liquid dimensioned to provide a 90° out of phase relationship between liquid transfer and roll at the natural frequency, under conditions of forced rolling oscillation the system will have a different phase relationship which in some circumstances will cause the amplitude of forced roll to be even greater than if the system were not provided at all, and there will be peaks of amplitude of roll at frequencies above and below the natural frequency.

(8) The action of the system so far discussed is based entirely on the dynamic action of the liquid. The velocity of flow from side to side depends almost entirely on the static depth of liquid and the athwartship dimensions (beam) of the tank, while the mass rate will depend on the velocity and the dimensions of any throttle, threat or similar device relative to the horizontal cross section of the side tanks. This action would take place if there were no damping forces at all due to such factors as viscosity of the liquid, friction against the wetted surface of the enclosure, and turbulence. The stabilizing system acts by feeding energy imparted to the ship by the water on which it floats back to that water via the ship. For this reason complete elimination of rolling by a passive system at any frequency is impossible. The term stabilizing used herein means amelioration as compared with conditions when there is no stabilizing system present. The stabilizing system has "resonance" frequencies, and it is because of these that the amplitude peaks of roll above mentioned arise.

(9) Damping forces exist in the tank and, though in general they increase with the frequency, they are not subject to resonance and have little effect on the frequencies at which the peaks occur. But they do reduce the peaks of amplitude and thus by regulating the damping, particularly the turbulence in the water, the height of the peaks can be regulated. Since the damping forces rise with frequency, the peak on the higher frequency side of the natural frequency will be reduced more than on the lower frequency side.

(10) If experimental investigation shows that the low frequency peak is higher than acceptable, the damping forces must be increased. This reduces the destabilizing effect at that peak and also reduces the stabilizing effect at the natural frequency but to a lesser extent. The result is a closer approach to a constant roll angle over the whole frequency range to be allowed for.

An object of the present invention is to provide a stabilizing system of the kind set forth comprising a single tank with substantially free air movement over the liquid, which is less sensitive to the frequency of oscillation of the floating structure (without introducing undue damping), whereby a flatter characteristic curve of magnitude of oscillation against frequency of waves in the water on which the structure floats is obtained.

According to the present invention there is provided a stabilizing system of the kind set forth comprising a single tank with substantially free air movement over the liquid, in which a substantially plate-like divider is located in the tank below the static level of the liquid, the divider being arranged symmetrically and perpendicular to the vertical mid-plane of the tank containing or parallel to the axis about which stabilization is to be effected, having a dimension perpendicular to that plane which is from 40 to 60 percent of the dimension in that direction of the tank, and extending in the horizontal direction parallel to the axis of oscillation substantially completely across the tank, the arrangement being such that in use the divider is located below the static level of the liquid and during oscillations about the axis about which stabilization is to be effected, at least at the natural frequency of oscillation of the structure, liquid flows beneath and over the divider at different mass rates.

The mass rate of flow V*b* beneath the divider will mainly depend on both the total depth of liquid in the tank and the ratio of the vertical cross section of the passage formed beneath the divider to the horizontal cross section of the unrestricted part of the tank beyond the end of the divider, while the mass rate of flow above the divider V*a* will primarily depend only on the depth of liquid above the divider (as explained above under (2)). By manipulating the available parameters, the requirement that these two mass rates of flow, and therefore the natural frequencies of these two flows, should be different, at least at the natural frequency of the oscillations to be stabilized, can be satisfied with acceptable dimensions of the system. The relative rates of mass flow will generally vary with the frequency and may in some cases reach equality within the total range of frequencies provided for.

Model experiments have shown surprisingly that a ship has a flatter characteristic curve of (magnitude of roll)/(frequency of sea waves), i.e., the desired phase lag of 90° is more nearly approached over the range needed to be provided for, when fitted with a stabilizing system according to the invention (if of appropriate dimensions and containing a suitable quantity of liquid), as compared with a simple open rectangular tank, i.e., rectangular in horizontal section with vertical walls, or with two open side tanks connected by an open topped channel of smaller fore-and-aft dimension than the tanks. This may be due to the different natural frequencies of the flow above and the flow below the divider. Additionally it may be due to the fact that a substantial reduction in the cross-sectional area (vertically taken in the fore-and-aft direction) of the tank in the central portion thereof, brought about by a throttle or channel of the known kind in the system, reduces the quantity of liquid that can be present within the central portion of the system and hence reduces the range of distances from the fore-and-aft center line of the system at which the mass of the liquid can be considered to act to produce a stabilizing moment, so that such a stabilizer is more sensitive to rolling frequency than a stabilizer according to the present invention.

As is known a stabilizing system of the kind set forth should be installed in the ship at as high a level as possible. In general the liquid will be water, since this is so readily available and is of higher density than such fairly easily available liquids as oil. However, any other liquids of suitable viscosity and density could be used, e.g., a liquid (or more truly a fluid) such as described in British patent specification No. 1,010,865.

It will be understood that the terms vertical and horizontal refer to the structure at rest and also ignore small variations in trim.

For a better understanding of the invention and to show how the same may be carried into effect, reference will now be made to the accompanying diagrammatic drawings in which:

FIGURES 1*a*, 1*b* and 1*c* are a longitudinal section on YY, transverse section on XX and plan of a stabilizing system according to the invention.

FIGURE 1*d* is a modification of FIGURE 1*c* showing the hydraulic rams for adjusting the divider.

FIGURE 2 shows characteristic curves of magnitude of roll plotted against frequency of sea waves achieved with such a stabilizing system for different depths of liquid, and

FIGURES 3, 4 and 5 are characteristic curves for a specific example of system according to the invention.

Referring now to the drawings, in FIGURES 1*a*, 1*b* and 1*c* a rectangular tank **1** is shown partially filled with a liquid **2** and having a horizontal divider **3** located centrally below the static liquid level of the fluid, the greater part of the divider being on top and bottom but the free ends **4** being tapered to a sharp edge.

It will be understood that the tank is set symmetrically athwartships and that to make the best use of the space available it may be necessary to set the ends of the tank at a slope in plan, but the rectangular form is preferred.

Desirably, the proportions of the tank and divider are as follows:

l is the athwartships dimension of the divider
b is the depth below the divider and should be about equal to C which is half the depth of the divider
a is measured to the horizontal mid-plane of the divider and should be about half h which is the total static depth of the divider
θ should be about 30°
W the fore-and-aft dimension is dependent on the ship's characteristics
T the total depth should be at least 2 h

As seen in FIGURE 1*b*, the sectional area of the divider should not be more than 40 to 60 percent of the sectional area of the water when static.

In general the larger the tank the better, but there is usually a practical limit to the size and, as a first approximation for a particular loading of the ship, for a single tank, the static depth of liquid h and the size of the tank should be chosen such that, if all the liquid were concentrated to one side of the vertical center line of the ship and tank, the resulting moment would induce a static heel of 1 to 2°. In practice, therefore, h, W, B, and T are determined by the ship's natural roll characteristics and the space available, and then a, b and c are found for optimum stabilization.

The extent to which the ends of the divider are streamlined depends on the degree of damping (creation of turbulence in the liquid) required. Simple pointed ends at any appropriate angle with the flat surfaces of the divider are easy to construct but other forms are possible including a section which as seen in FIGURE 1*b*, comprises two opposite shallow curves.

It should be noted that for best performance of the stabilizer different loadings of the ship will require different values of h. If the divider is immovable then it will be in effect at different depths. In practice therefore the depth at which the divider is located is the optimum for the most frequent expected loading conditions of the ship. Ideally $a=\frac{1}{2}h$ so that approximately there is the same depth of liquid over and under the divider. With this equality the rate of flow above and below will be different.

FIGURE 2 shows characteristic curves of roll angles plotted against the frequency (of a ship model) with increasing depth of water in a tank having a divider, both of which have fixed dimensions, the tank being of the kind shown in FIGURE 1.

The curve **0** in FIGURE 2 is for the stabilizing system empty, while curves **1** to **7** relate to increasing depths of water. The abscissa represents frequency and the ordinate represents roll angle. It will be seen that as the depth was increased the peak fell while the frequency at which the peak occurred increased. The left-hand part of the curve,

the lower frequency part, rose and even for the curve **2** crossed the curve **0** so that at very low frequency the stabilizer in action was not so good as the stabilizer empty. Curve **4** has two peaks at practically the same level, and for still greater depths of water the low frequency peaks become higher while the high frequency part continues to fall. It will be clear that curve **4** represents the optimum depth, since any decrease in depth raises the high frequency peak and any increase in depth raises the low frequency peak.

From considerations of strength of the ship structure or to avoid excessive movement of liquid due to the ship pitching, it may be necessary to provide a transverse bulkhead in the tank as shown in dotted lines in FIGURE 1*c*, but this would not impair the operation of the stabilizer.

Two separate tanks can be provided and be tuned to two different frequencies to increase the flatness of the response curve. Such separate tanks could additionally, or alternatively to being differently tuned, be placed at different heights from the center of roll of the ship.

Desirably the level of the divider **3** is variable during operation by hydraulic rams **5** so that the characteristic of the system can be changed when adjusting the depth of liquid whilst the ship is at sea to suit the loading of the ship and the frequency of the sea waves.

FIGURES 3, 4 and 5 are curves relating to a design according to the invention prepared for a single screw coaster of 188.75 feet (57.5 meters) length and a maximum beam of 32 feet (9.75 meters). The system comprises two superposed tanks each as in FIGURES 1*a*, 1*b* and 1*c*, and in this case both tanks and dividers are of the same dimensions, as follows:

l=15 ft. (4.58 meters)
B=32 ft. (9.75 meters)
b=7½ inches (19 cms.)
a=1 ft. 3 inches (38 cms.)
c=7½ inches (19 cms.)
h=2 ft. 6 inches (76 cms.)
θ=30°
W=7 ft. 6 inches (2.29 meters)
T=4 ft. 9¼ inches (1.52 meters)

This design was investigated by model experiments for three different loading conditions which, referred to the dimensions of the ship, were as follows:

Condition	Load 1	Load 2	Load 3
Mean draught at mid length:			
(Ft.)	11.92	9.67	12.0
(Meters)	3.63	2.95	3.66
Trim by the stern:			
(Inches)	[1] 7½	[1] 58½	[1] 57
(Cms.)	19	148.5	144.7
Displacement (tons)	1,482	1,148	1,490
Metacentric height:			
(Ft.)	2.43	1.47	4.73
(Cms.)	74	37.4	144

[1] Down.

These conditions are with the stabilizer tanks empty. The tanks were designed for the Load 1 conditions, i.e., a displacement of 1482 tons and a metacentric height of 2.43 ft. (74 cm.).

The tests were carried out for an equivalent wave slope of 2°, and FIGURES 3 to 5 show the characteristics for the stabilizing system out of use (plotted points indicated by a cross) and with the stabilizing system in use (plotted points indicated by a circle), respectively, for Load 1, Load 2 and Load 3. It will be seen that in every case there is a very considerable reduction in the maximum roll.

What we claim is:

1. A stabilizing system of the kind set forth for a structure floating in a liquid and oscillatable about a horizontal axis comprising a single liquid-containing tank fixed to

the structure with substantially free air movement over the liquid, and a plate-like divider of substantial vertical thickness located in the tank with its upper surface substantially below the static level of the liquid, the divider being arranged symmetrically and perpendicularly to the vertical mid-plane of the tank containing or parallel to the axis about which stabilization is to be effected, having a dimension perpendicular to that plane which is from 40 to 60 percent of the dimension of the tank in the same direction, and extending in its horizontal direction parallel with the axis of roll substantially completely across the tank, the arrangement being such that in use the divider is wholly located below the static level of the liquid and during the oscillations of the structure about the axis which stabilization is to be effected, at least at the natural frequency of oscillation of the structure, liquid flows beneath and over the divider at different mass rates.

2. A stabilizing system according to claim **1** in which the horizontal mid-plane of the divider is located approximately at half the static depth of the liquid in the tank.

3. A stabilizing system according to claim **1** in which

the vertical thickness of the divider is equal to substantially twice the depth of the liquid below the divider.

4. A stabilizing system according to claim **1** in which the free ends of the divider are shaped to facilitate flow above and beneath the divider.

5. A stabilizing system according to claim **1** in which the tank is rectangular in horizontal section and has vertical sides and ends.

6. A stabilizing system according to claim **1** including means for adjusting the level of the divider.

7. A ship including a stabilizing system according to claim **1** for stabilizing rolling motion of the ship.

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MILTON BUCHLER, *Primary Examiner.*

T. M. BLIX, *Assistant Examiner.*