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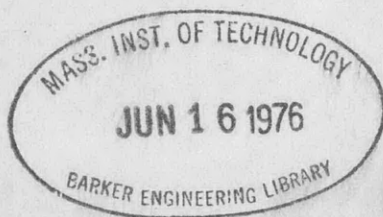
## EXPERIMENTAL MODEL BASIN

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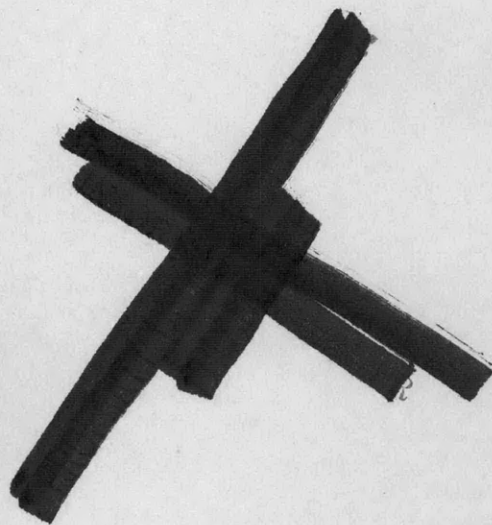
### BILGE KEEL CAVITATION

BY

J. G. THEWS

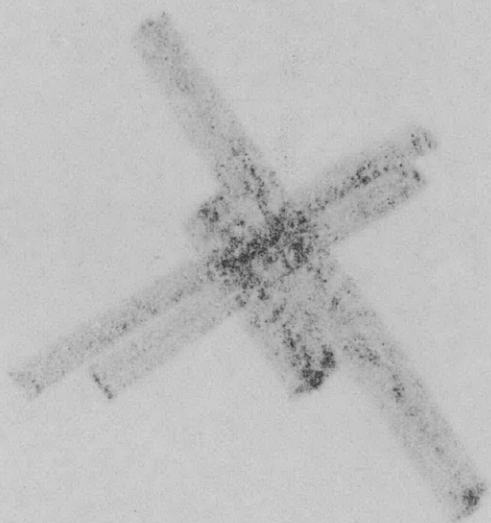


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BILGE KEEL CAVITATION

By

J. G. Thews

U.S. Experimental Model Basin  
Navy Yard, Washington, D.C.

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## BILGE KEEL CAVITATION

### Introduction

The work here described was performed to answer the question: Do the bilge keels of a rolling ship cavitate and those of its model not? If the answer is yes, then model rolling data cannot be used in predicting, for otherwise corresponding conditions, the rolling behavior of its prototype.

The velocity in rolling at which cavitation sets in is a function of the total pressure head existing above the bilge keels, i.e. atmospheric plus water head, and the greater the pressure the greater is the velocity before cavitation begins.

In order that similar conditions exist for model and ship the total heads should vary as their length ratio. Thus in the case of a model 5 feet long and a ship 600 feet long, the length ratio is 1/120 and the pressure head ratio should be the same. Where model and ship are tested in the open this condition is not obtained. For example, assume the average depth of submergence of the ship's bilge keel to be 30 feet. The model's would then be three inches. Atmospheric head in both cases is 34 feet of water. The ratio of pressure heads is then  $34.25/64.0$  or  $1/1.87$  instead of 1 to 120. Thus the ship would have cavitating bilge keels long before the model and should cavitating conditions exist the damping data from the latter would predict safe damping when such would not be the case for the ship under corresponding conditions. However, unless cavitation exists, there appear to be no other reasons for suspecting that model rolling data are vitiated because of the existence of this unnatural ratio of pressure heads.

### Method of Investigation, Part I

As a first step in this work a metal rolling model of circular section and parallel body was constructed and tested in the E.M.B. Water Tunnel. See Figs. 1 and 2. The test consisted of taking declining angle curves of the model with and

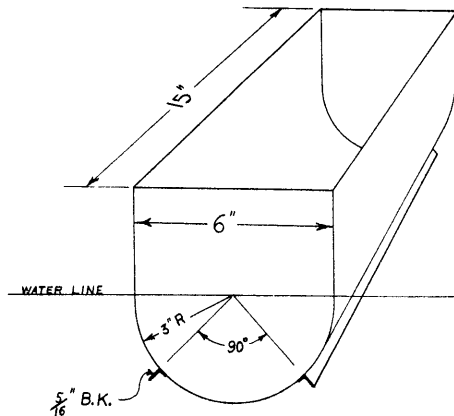


FIG. 1. SKETCH OF ROLLING MODEL

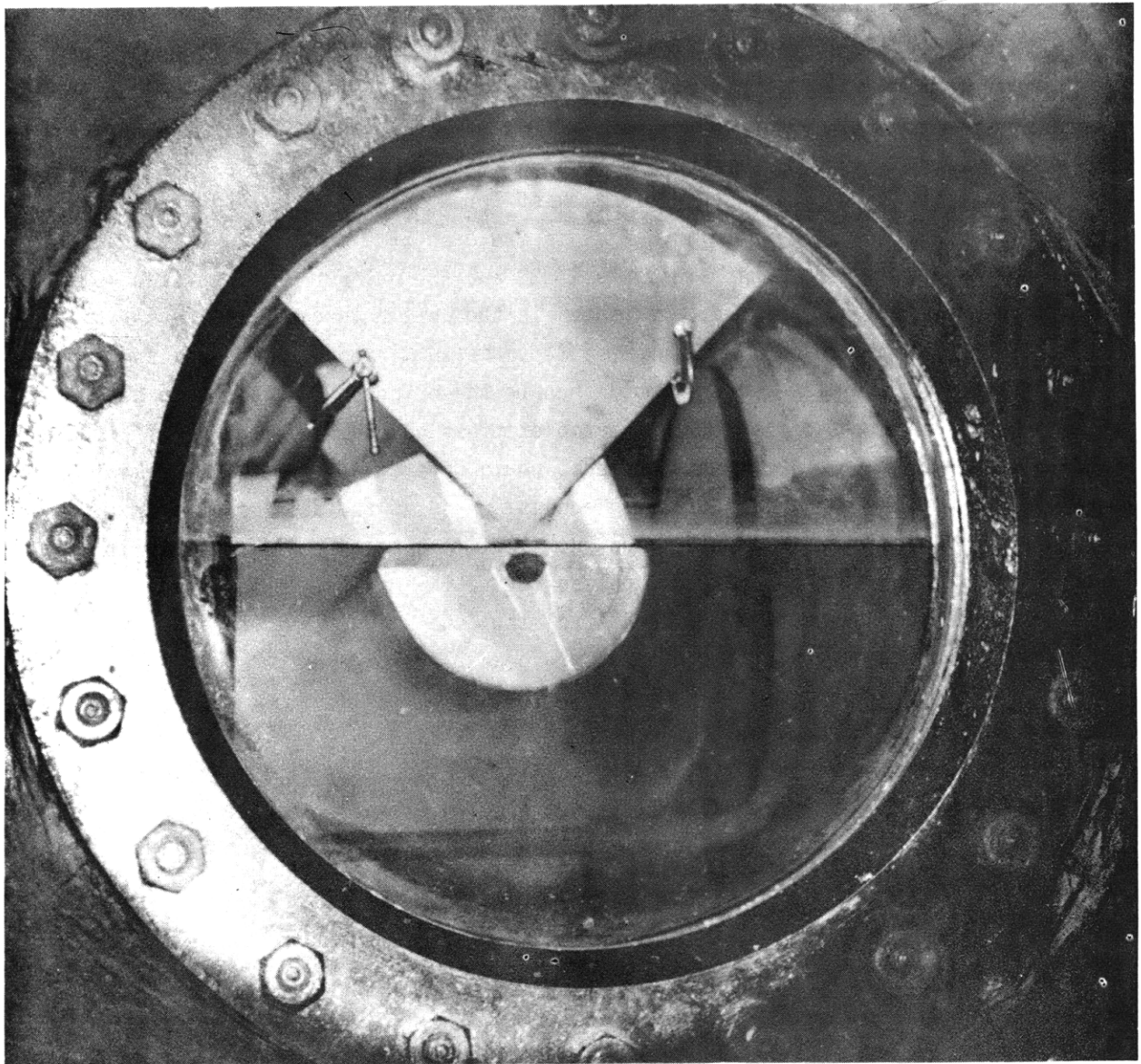


FIG. 2.

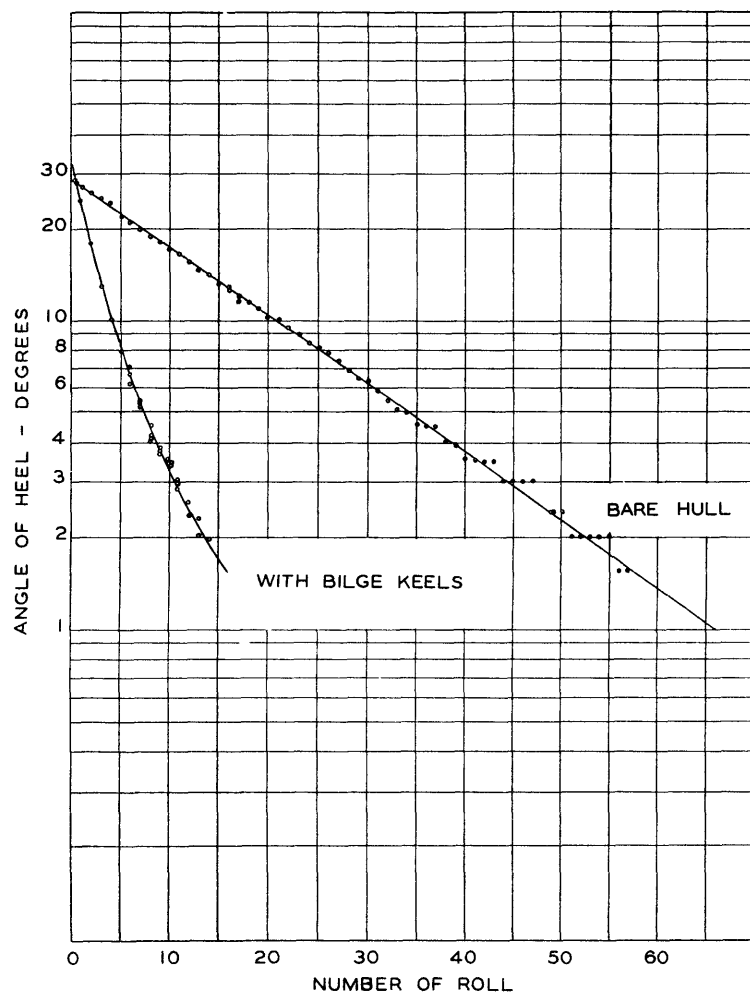


FIG.3. DECLINING ANGLE CURVE, ATMOSPHERIC PRESSURE.

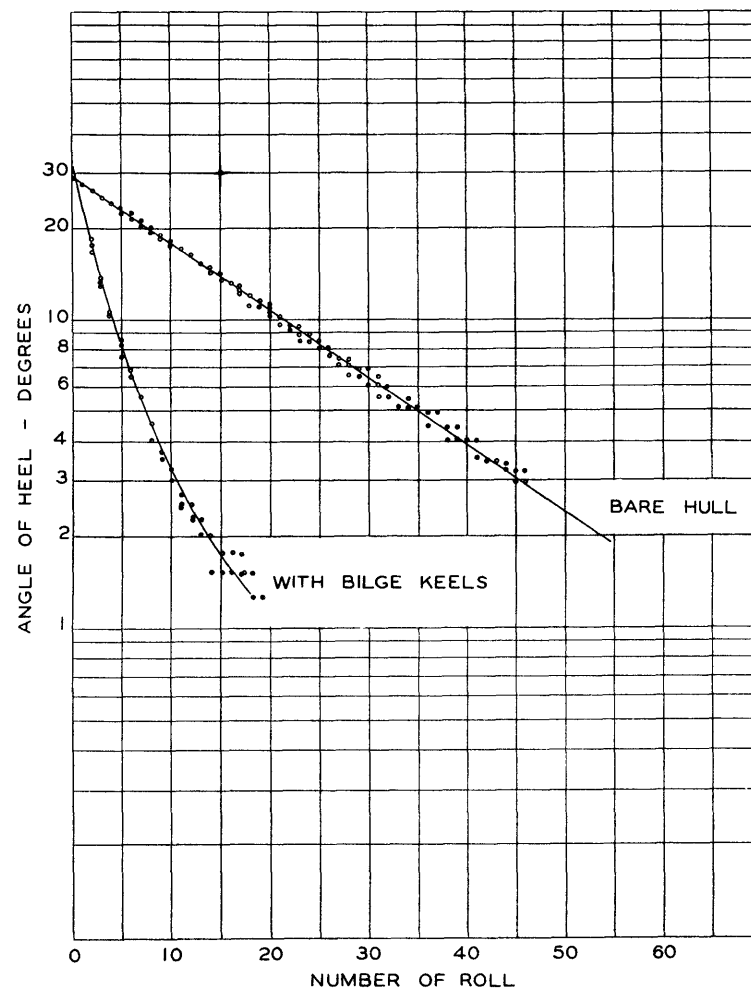


FIG. 4. DECLINING ANGLE CURVE, 1.09 IN. HG. PRESSURE.

without bilge keels under different total pressure heads. The latter was varied from atmospheric + 3 inches of water to 1.09 inches Hg. + 3 inches of water, or from 34.25 to 1.48 feet of water. The declining angle curves, Figs. 3 and 4, show that over this range the variable pressure had no observable effect on the damping of the model when with or without bilge keels.

The minimum pressure obtainable in the tunnel is not low enough to give the proper reduction of total head for the model. It would have to be approximately  $64/120$  or 0.53 feet, i.e. one third of that obtained. The reduction of pressure as obtained would apply for the case of a 5 foot model of a 200 foot ship, assuming a beam-length ratio of 0.10. In this case no cavitation would exist and model data would be valid.

#### Method of Investigation, Part II

The second part of the work consisted in equipping a cylinder with bilge keels and rotating it, varying the speed and pressure to determine the conditions under which cavitation would exist. Fig. 5 shows the principal dimensions of the cylinder and attached blades.

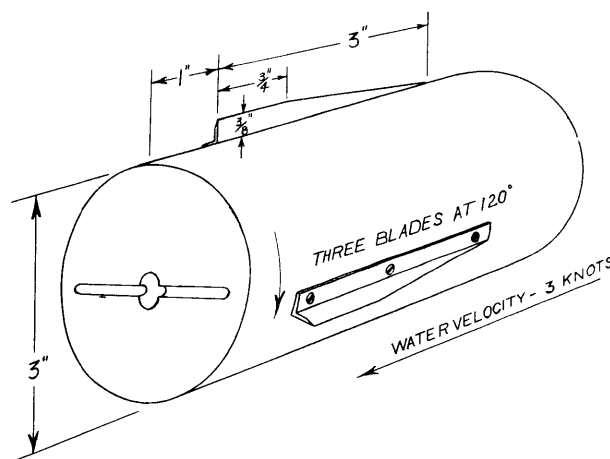


FIG. 5. CYLINDER WITH BLADES

Five runs were made at 650, 800, 1000, 1280, and 1480 R.P.M. In each case the pressure was varied and the corresponding torques necessary to drive the cylinder measured.

The curves in Fig. 8 show the results. Cavitation is indicated by the breaks in these curves. In the case of 650 R.P.M., cavitation did not develop over the range of available pressures. Figs. 6 and 7 are photographs of the blades cavitating.

The points indicated by arrows in Fig. 8 near the breaks in the curves are the computed points at which cavitation will begin. The assumption made for computing these was: Cavitation in the case of a sharp edged plate moving at right angles to the water should set in and exist when the velocity head equals and exceeds the pressure head.

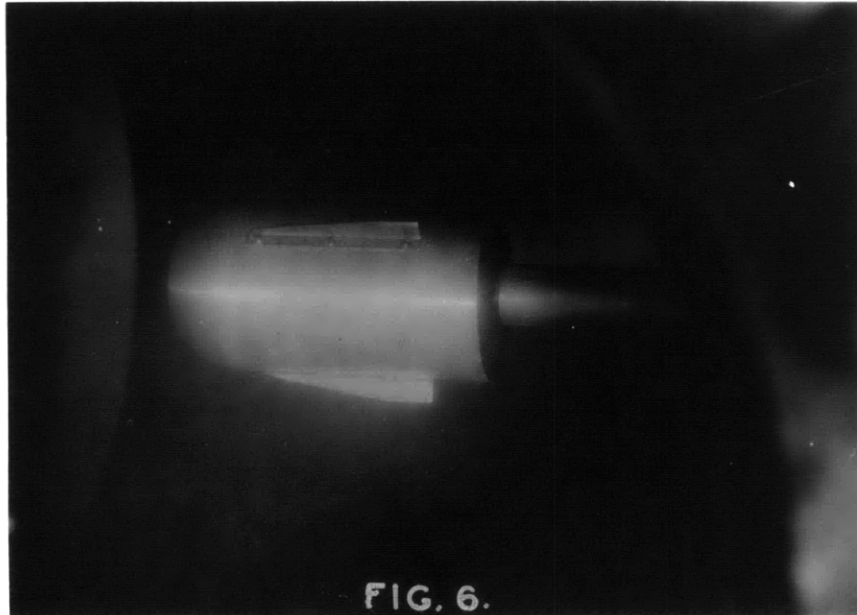


FIG. 6.

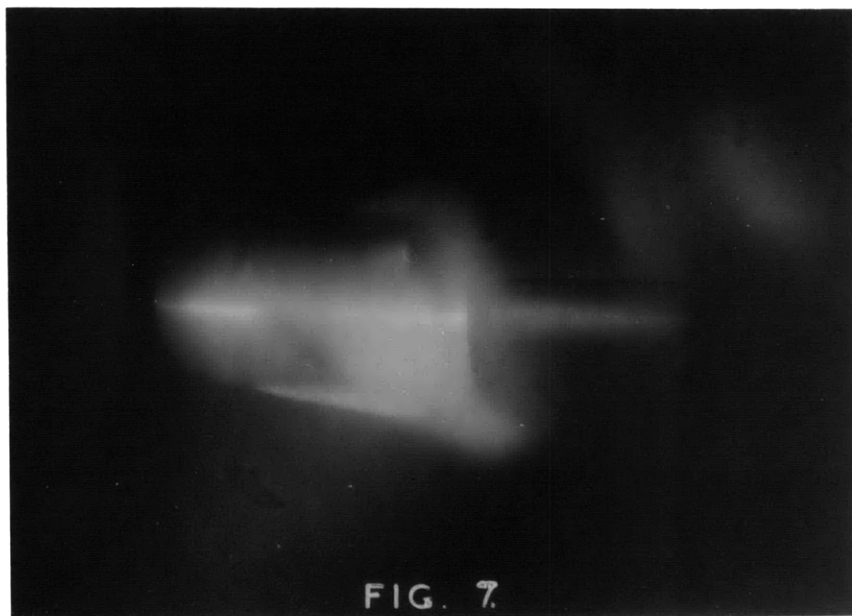


FIG. 7.





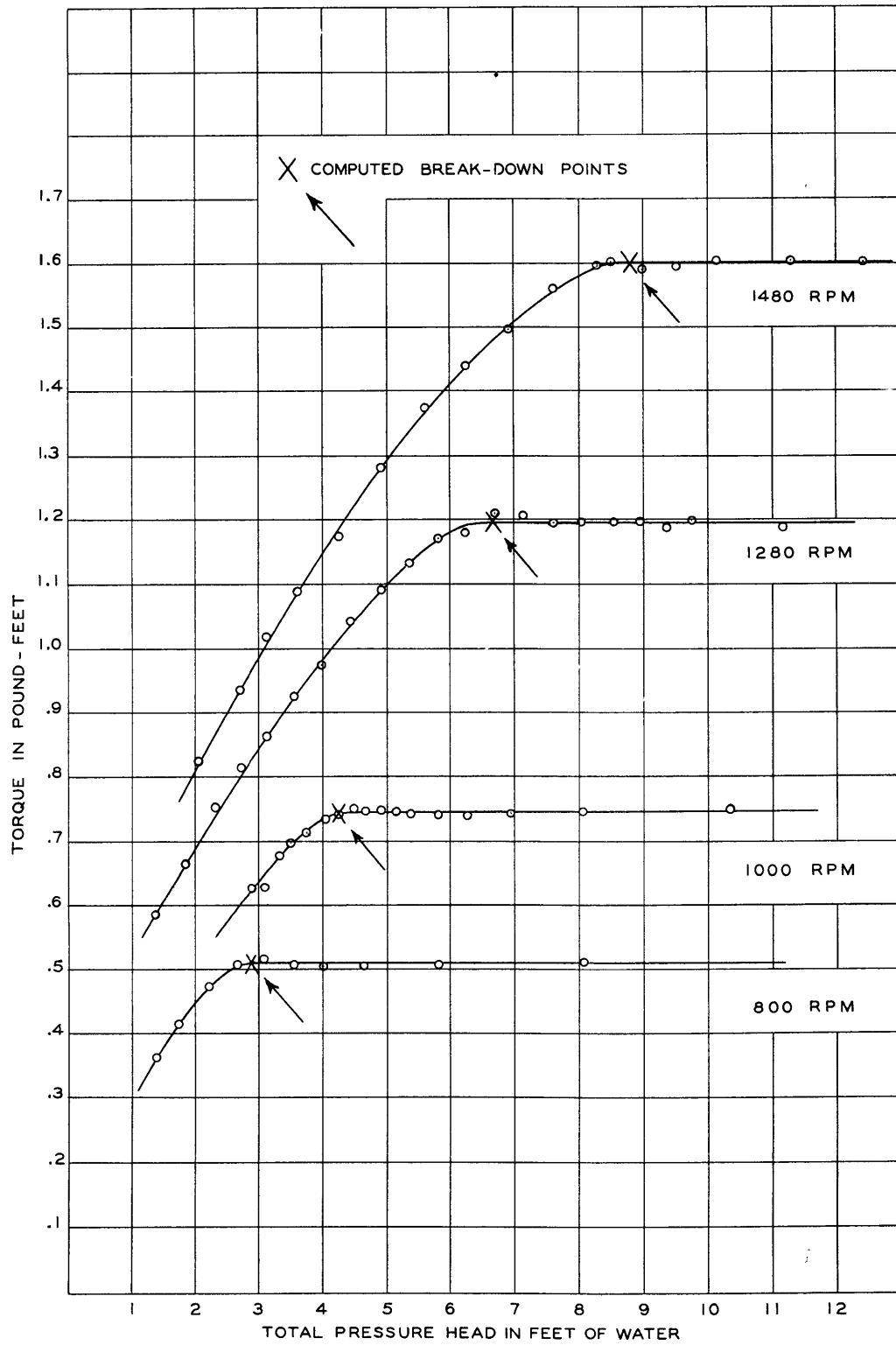


FIG. 8. CAVITATION OF ROTATING BILGE KEELS

## Method of calculation

$$h = V^2/2g$$

where  $h$  = velocity head in feet.

$g$  = gravitational constant 32.2 ft./sec<sup>2</sup>.

$V$  = velocity of water over blades in ft./sec.

$$V^2 = V_w^2 + V_p^2$$

where  $V_w$  = velocity of water in tunnel which was 3 knots or 5.07 ft/sec.

and  $V_p$  = peripheral velocity of edge of blade and is equal to  $2\pi rn$

where  $r$  = mean radius to edge of blade

$$= 1.80 \text{ inches or } 0.15 \text{ feet}$$

and  $n$  = revolutions per second.

$$V_p = 2\pi \times 0.15 \times n = 0.943 n \text{ ft/sec.}$$

From this  $h = (V_w^2 + V_p^2)/2g$  feet

$$= [25.7 + (0.943 n)^2] / 64.4 \text{ feet.}$$

The calculations are summarized in the following table:

RPM	$V_p$	$V_w$	$V_p^2$	$V_w^2$	$V^2$	$V$	$h$
650	8.71	5.07	75.8	25.7	101.5	10.07	1.58
800	12.56	5.07	157.8	25.7	184.0	13.56	2.86
1000	15.72	5.07	247.0	25.7	273.0	16.52	4.24
1280	20.12	5.07	404.7	25.7	430.0	20.73	6.68
1480	23.26	5.07	541.0	25.7	567.0	23.8	8.80

These theoretical points check the experimental breaks in the curves remarkably well in each of the four cases plotted. It is too close to be coincidental or accidental and it appears reasonable to assume that the formula  $v^2 = 2gh$  will hold in predicting the angle of roll at which cavitation will begin in the case of a ship.

## Discussion and Conclusions

The main difficulty in applying the above results to a ship is in determining the velocity of the water past the edges of the bilge keels. Professor Bryan\*

\*The Action of Bilge Keels, TINA Vol. 42, 1900.

estimates that the velocity of the water around the bilge of a ship of rectangular midsection with rounded corners is about 1.4 to 1.5 times the actual velocity of the bilge as referred to the axis of roll of the ship.

To make an estimate of the angle to which a 600 foot ship with period of 11.0 seconds must roll in order to have its bilge keels begin to cavitate the above assumption for estimating water velocity is made and the ship is considered to have zero forward velocity. The depth of submergency of the keel is 30 feet and atmospheric pressure is 33 feet of sea water. Therefore, total pressure head is 63 feet.  $V = \sqrt{2gh} = \sqrt{63 \times 64.4} = 64 \text{ ft./sec.}$ , velocity of keel relative to water. The velocity of the ship's bilge keel in space will be  $64 \times 2/3$  or 42.7 ft. per second according to Professor Bryan.

The velocity of a ship's bilge keel will be a maximum when the ship rolls thru its vertical or upright position. If cavitation does not exist during this part of its cycle, it will not exist during any other, neglecting, for the moment, the possibility of the bilge keel breaking thru the water's surface.

Let  $\Theta$  = maximum angle of roll to a side.  
 $T$  = Period of ship = 11 seconds. (complete cycle)  
 $R$  = mean radius to bilge edge = 35 ft.  
 $s$  = motion of edge of bilge keel in feet.  
 $v$  = critical velocity where cavitation begins.  
 $\phi$  = angle of heel at any instant.

Then

$$s = R\phi = R\Theta \sin \frac{2\pi t}{T}$$

$$v = \frac{ds}{dt} = \frac{2\pi}{T} R \Theta \cos \frac{2\pi t}{T}$$

$$\text{Max. velocity } V_m = \frac{2\pi R \Theta}{T} = 42.7$$

$$\text{or } \Theta = \frac{11 \times 42.7 \times 57.3}{2\pi \times 35}$$

$$= 122 \text{ degrees.}$$

As this angle is practically unattainable this ship may be considered to be safely removed from cavitating conditions.

As a general case, consider a series of ships of the cruiser type. The depth of submergence of the bilge keels at the time of greatest velocity in rolling is approximately one-twentieth of the length or  $D = .05 \times L$ . The length of the radius on which the edge of the bilge keel moves is about one-sixteenth of the length of the ship, or  $R = .06 \times L$ . Assume the greatest angle of roll attainable to be 70 degrees to a side. Atmospheric pressure head,  $A$ , is equal to 33 feet of water. The safety pressure head in feet of water which still exists before cavitation can begin

to set in is then

$$\begin{aligned} H_s &= A + D - H_v \\ &= 33 + .05L - H_v. \end{aligned}$$

where  $H_v = V_m^2/2g$

now  $V_m = 1.5 \frac{2\pi R \Theta}{T}$

For this type of ship  $T = 0.465 \sqrt{L}$  approximately.

$$\text{Then } V_m = \frac{1.5 \times 2\pi \times .06 L \times 70}{0.465 \sqrt{L} \times 57.3} = 1.49 \sqrt{L}$$

$$\text{and } H_v = (1.49 \sqrt{L})^2/2g = 2.22L/64.4 = 0.035 L$$

$$\text{Therefore } H_s = 33 + (0.05 L - 0.035 L)$$

$$= 33 + 0.015 L \text{ feet of water.}$$

This states that the head in excess of the velocity head will always be greater than atmospheric pressure and that moreover it increases with the length of the ship. Should the bilge keel break thru the water's surface so that there is at this phase zero water head there still remains all of the atmospheric pressure to prevent cavitation. Also, as most large ships have greater periods than the cruiser type has, and, since the margin of safety pressure head is so great in the above case, it appears safe to say that no ship at sea will ever have cavitating bilge keels. Therefore, as far as cavitation is concerned, damping data obtained from rolling models can be used in predicting the damping conditions existing on their corresponding ships.







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