REPORT OF A STUDY WITH MODELS OF THE ROLLING OF CRUISERS

U. S. Experimental Model Basin
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I

INTRODUCTION

1. Numerous complaints have been received from the operating personnel of the excessive rolling of the scout cruisers. In accordance with Bureau of Construction and Repair letter No. S29-5(DN), dated April 10, 1931, an investigation was made of the damping effect of 36" bilge keels, outside tanks, and a combination of bilge keels and tanks on the rolling of these ships.

2. The theory of rolling is very complicated and depends on assumptions which are not entirely satisfactory. As the data of this report were obtained by experiment there is no need to develop or discuss the theory underlying analytical analysis.

3. The period of roll of a ship varies directly as its radius of gyration and inversely as the square root of its metacentric height. The amplitude of roll depends on the magnitude and period of external inclining forces and on the damping forces of the ship. Generally as damping is increased the period of roll is lengthened. For a ship which rolls quickly and to large angles we can:

(a) Increase the period of roll by increasing the radius of gyration, or decreasing the metacentric height, or both.

(b) Reduce the amplitude of roll by damping the oscillations.

4. For a ship already built it is difficult to either increase the radius of gyration or reduce the metacentric height. Reduction of amplitude can be accomplished by the installation of bilge keels, gyro stabilizers; anti-rolling tanks, etc. It is generally sufficient to confine ones efforts to increasing damping, unless the period is abnormally small. The period for the cruisers is about 12.2 seconds and is not considered small.

5. The total damping of roll of a ship is accomplished by several factors of resistance:

(a) Skin friction.

(b) Wave making.

(c) Eddy-making resistances (keel, bilge keels, flat surfaces, etc.).

(d) Extraneous forces such as applied by tanks, gyros, and swinging weights.

6 Any increase of skin friction damping increases resistance to propulsion in like ratio. Wave making damping is not susceptible of change. Increase of damping is

generally accomplished by the installation of bilge keels, tanks, gyros, or combinations of these.

7. Bilge keels add a drag to a ship that either materially reduces the speed or requires appreciable increases in power.

8. Gyro stabilizers due to space requirements are not well adapted for ships designed for active combat.

9. Tanks occupy space on a ship and increase the draft either by adding weight or by destroying buoyancy. The increased wetted surface as well as the flood openings add to the resistance to propulsion of the ship. In the case of external tanks the water flowing in must be accelerated to the velocity of the ship. However, the water spilling out imparts velocity to the wake so the loss is probably not great.

10. The experiments of this report were confined to bilge keels and external tanks. The latter are fitted into the sides of ships, utilizing wing spaces. In the cruisers the wing spaces formed by the double bottom extending up the sides will have to be utilized. The tanks are fitted with flooding openings and vents so arranged that the flood openings are submerged throughout the draft range from light to full load and when rolling. The action of the tank is based on the fact that the ship in rolling

moves faster than the water can follow by flowing through the flood openings. On the downroll buoyancy of the tank is submerged and on the uproll weight of water in the tank is lifted. The optimum condition is secured by the proper proportioning of flood and vent openings to the cross section area of the tank. Under normal load the mid height of the tank should be at the water line.

II

Description of Apparatus and Procedure of Conducting Test.

11. Before conducting tests on the 20 foot ship's model, a preliminary experiment was made on a small model of the middle body. Tanks were fitted (one on each side) which were proportional to those determined necessary for the ship (see Appendix I). Fifteen flood openings were provided, each corresponding to an opening in the ship 2 feet in diameter; and each being in area approximately one per cent of the longitudinal cross section of the tank. The flood openings were blanked and the model ballasted to a draft proportional to that of the ship and a period of roll corresponding to that of the ship (see Appendix II). Extinction of roll curves were obtained with tanks operating with various numbers of flood openings from zero to

fifteen. Bilge keels were then fitted and extinction of roll curves obtained with bilge keels and tanks operating together; again with flood openings from zero to fifteen in number. To obtain these curves the model was held in a fore and aft direction by taut wires attached at the center line in the water plane. A roll of 10° amplitude was built up by hand impulses and the model then allowed to roll free until extinction. A pointer attached to the model travelled over a fixed scale graduated in degrees. A float wire in one of the tanks travelled over a vertical scale on the same sheet with the angle scale. Motion pictures were taken of the two pointers while the model was rolling. A stopwatch was hung in the field of the camera. Thus the film gave a continuous record of angle of roll, height of water in the tank, and period of roll. Plate I shows the small model and recording apparatus. The additional damping with fifteen flood openings over that with thirteen or fourteen was slight. The orifice coefficient was .70. It was concluded that the total flood opening areas should be at least 10% of the cross section area of the tank. It was determined by experiment that for free flow the vent area should be 7% of the flood area. (100% flow assumed for both figures)

12. The 20 foot cruiser model No. 2697 was equipped with tanks corresponding to the wing tanks on the SALT LAKE CITY between bulkheads 61 and 85 from the second deck to the bottom of the armor belt. Twelve flood openings, each corresponding to 2' diameter, were provided below the armor line. The orifices were shaped to give a coefficient of flow of unity. Vents to allow free flow of air were provided. The ratio of aperture area to tank cross section was about 12%. Plate II shows the model equipped with tanks and bilge keels. The model was ballasted to a displacement corresponding to 11512 tons, GM 5.55 feet, and period 12.2 seconds. The model was secured to the carriage by a bow line in the water plane and prevented from yawing by bow and stern guy lines in the water plane. A continuous record of roll was obtained by using a gyroscope roll recorder with chronometer attachment. (See Plate III). The model was rolled by hand to about 10° and then allowed to roll free at speeds corresponding to zero, fifteen, eighteen, twenty, twenty-two, twenty-five and thirty knots on the ship. At each of these speeds the model was rolled:

(a) With bare hull.

(b) With tanks operating.

(c) With bilge keels corresponding to 3' keels on the ship over a length of 200 feet amidships.

(d) With bilge keels and tanks.

III

Analysis of Data

13. The records obtained from the roll recorder were plotted to show the amplitude in degrees against number of rolls, all amplitudes being plotted on the same side of the axis. The curves obtained are shown on Figures 1, 2, 3, 4.
From these curves were developed the ones shown on Figures 5, 6, 7, 8, 9, 10, 11.
Here the dimunition of roll per roll is plotted against angle of inclination. In all curves one roll is taken to mean a swing from port to starboard or vice versa. The curves, Figs. 5-11, are derivatives of curves Figs. 1-4, and are measures of the work expended per roll in damping the oscillations.

An analysis of these curves shows:

(a) At speed zero there is very little damping due to bare hull. At this speed the damping due to the tanks is nearly twice that due to bilge keels.

(b) Underway at speeds of 15, 18, 20, 22, 25 and 30 knots the curves are closely the same at all speeds but show a marked rise over the curves for zero speed. This increase in damping is due primarily to the increase of bare hull damping when underway. The damping due to bilge keels is nearly constant at all speeds including zero. The damping due to tanks falls off a little as speeds increase. The bare hull damping increases greatly between zero and 15 knots. Above 15 knots it is nearly constant.

14. If the length of the tanks were increased 50% keeping the same cross section damping would be greater than with the tanks now installed plus the bilge keels.

15. The period of roll was affected as follows:

(a) The bare hull period decreased slightly as speeds increased.

(b) The addition of tanks increased the still water period. As speed increased the period decreased but was always greater than the bare hull period.

(c) The addition of bilge keels apparently had no effect on the bare hull period in still water. Underway the period was increased slightly being a little longer than the period with tanks.

(d) The addition of tanks plus bilge keels produced the longest period measured. This period fell off slightly with increase in speed but remained everywhere longer than the periods for the other conditions.

As the periods of the model were small qualitative measures of increase or decrease were not attempted.

16. The addition of tanks 3' x 100' on each side at the center length of the cruisers would reduce the GM 0.5 feet. This reduction on the SALT LAKE CITY would leave her with 5.05 ft. GM. The reduction in GM would increase the period about 4%.

17. The addition of tanks on the model caused an increase of resistance due to the flood openings and to increased draft of 3%.

IV

CONCLUSIONS

18. At rest and underway, except at very high speeds, tanks as installed on the SALT LAKE CITY model are more effective in damping roll than bilge keels.

19. Any reasonable amount of damping desired (up to 5° per roll from 10° amplitude) can be obtained by tanks occupying space not more than three per cent of the displacement.

20. In any tank installation the flood openings should be kept as far below the tank bottom as possible. This can be accomplished by flooding through pipes. Such an arrangement precludes the possibility of rolling the flood openings out of water and further allows the tanks to be blown down if desired, leaving a free surface in the flood pipes only. This requires controlled venting.

21. The great gain in efficiency of damping of the various arrangements when underway is probably due almost entirely to the gain in bare hull damping when underway.

22. The increase in bare hull resistance due to tanks is 1% less than that due to bilge keels for the installations on the model tested.

23. Additional tests covering greater angles of roll are being planned.

APPENDIX I

Assume the ship to be inclined to 10° and released.

$D = 11512$ tons

$GM = 5.55$ feet

If the desired decrement of roll, $\Delta\theta$, from 10°, is 3°, then:

Mean maximum displacement of ship from upright =

$$\frac{10^\circ + 5^\circ}{2} = 7^\circ.5 = .1307 \text{ radians}$$

Energy lost by ship in one roll =

$D \times GM \times \theta \times \Delta\theta$ ft. tons =

$11512 \times 5.55 \times .1307 \times .0872$

This energy (neglecting bare hull damping) must be absorbed by work done by the tanks; that is, by $W \times H$, where W = weight of water and H = height it is lifted.

Then: $W \times H = 11512 \times 5.55 \times .1307 \times .0523$

$H = 1/2\ H'$ (about) where H' = the total vertical movement of the tank from top to bottom of roll

$H' = 2 \times 32 \times .1307 = 8.36$

$H = 4.18$

Whence $W = 104.5$ TONS

The space required is twice the water volume or about 105 tons capacity on <u>each</u> side of the ship.

APPENDIX II

The period for isochronous rolling in still water is given by

$$T = \pi \sqrt{\frac{K^2}{g \times GM}}$$

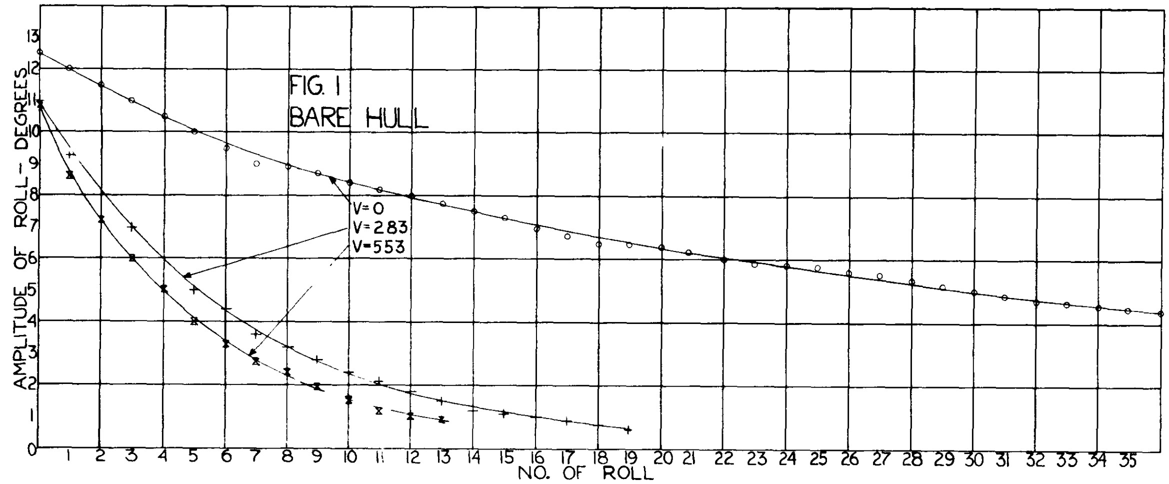
K = radius of gyration

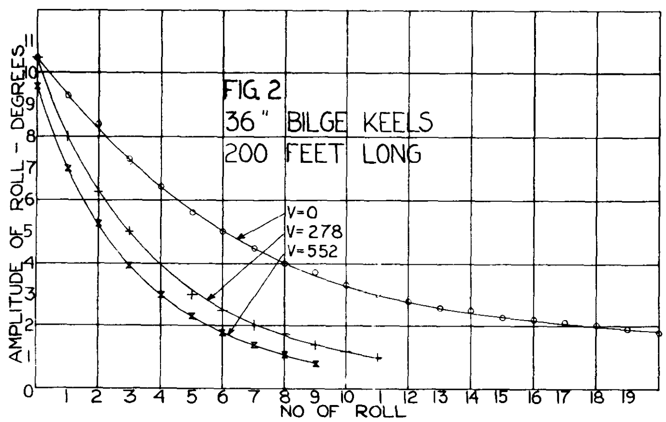
Then if linear ratio of model to ship is $1/\lambda$:

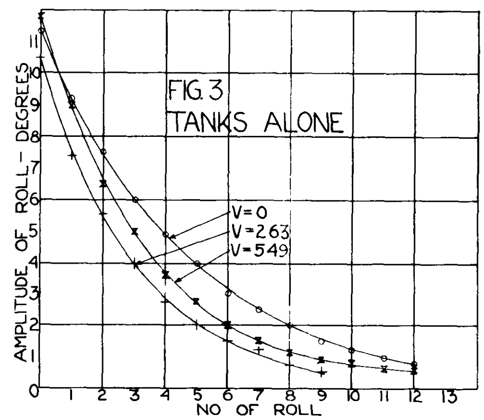
$$T_s = \pi \sqrt{\frac{K^2}{g \times GM}}$$

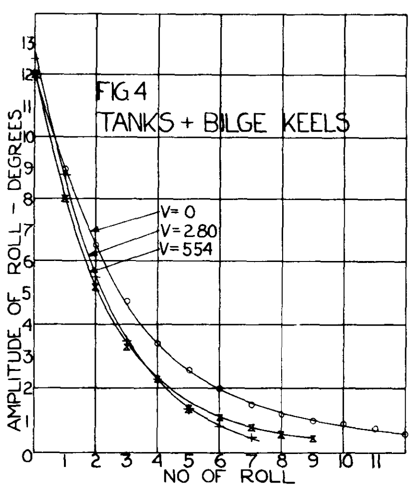
$$T_m = \pi \sqrt{\frac{K^2/\lambda^2}{g \times GM/\lambda}} = \pi \sqrt{\frac{K_2}{\lambda \times g \times GM}}$$

$$T_m = T_s \times \sqrt{\frac{1}{\lambda}}$$

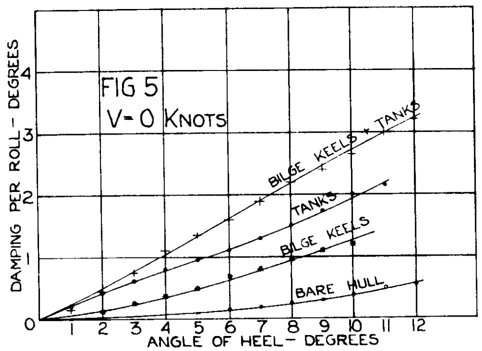


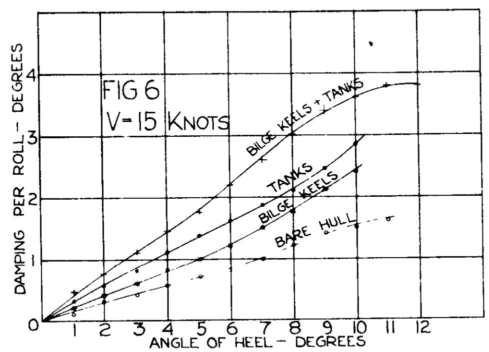


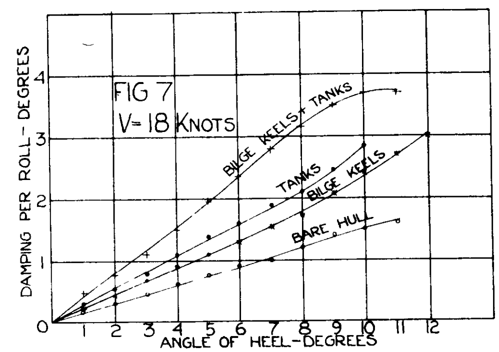


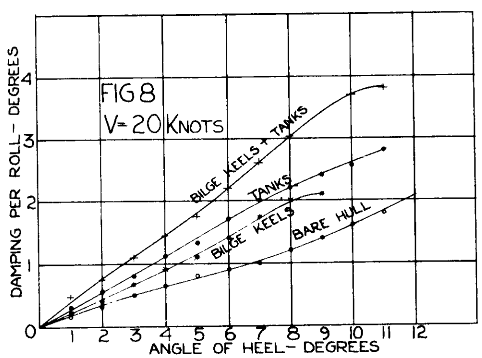


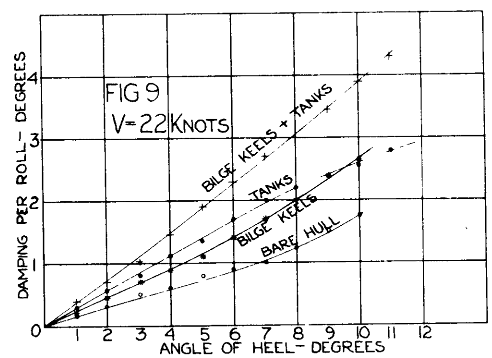
DECLINING ANGLE CURVES FOR
MODEL OF LIGHT CRUISER
SHOWING COMPARATIVE EFFECTS
OF ANTI-ROLL TANKS AND
BILGE KEELS (36"X 200') AT
VARIOUS SPEEDS

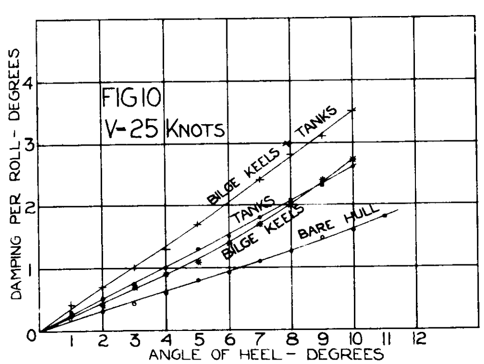


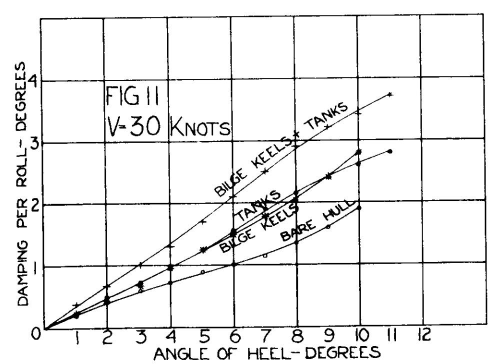












COMPARATIVE DAMPING EFFECTS OF ANTI-ROLL TANKS AND BILGE KEELS FOR SEVERAL SPEEDS OF MODEL