CONFIDENTIAL

NAVY DEPARTMENT

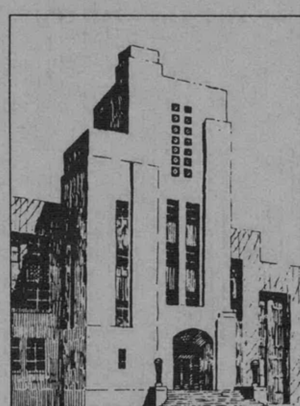
THE DAVID W. TAYLOR MODEL BASIN

WASHINGTON 7, D.C.

HYDRODYNAMIC INDUCED VIBRATIONS OF CYLINDERS TOWED IN VARIOUS COMBINATIONS

by

A. Borden, Ph.D, D. B. Young, and W.M. Ellsworth, Jr.



[redacted]

62

September 1951

Report C-452

NS 712-068

CONFIDENTIAL

INITIAL DISTRIBUTION

Serials

1 - 15 Chief, BuShips, Project Records (Code 324), for distribution:
- 1 - 5 Project Records
- 6 Technical Assistant to the Chief of the Bureau (Code 106)
- 7 - 8 Research and Development Division (Code 330)
- 9 - 10 Applied Science (Code 370)
- 11 Preliminary Design and Ship Protection (Code 420)
- 12 - 15 Submarines (Code 515)

16 - 19 Chief of Naval Research
- 16 - 17 Undersea Warfare
- 18 - 19 Fluid Mechanics Branch

20 - 21 Director, Naval Research Laboratory, Shock and Vibration Division, Washington 20, D.C.

22 - 23 Commander, Portsmouth Naval Shipyard, Portsmouth, N.H.

24 - 25 Commander, Mare Island Naval Shipyard, Vallejo, California

26 - 27 Commander, Norfolk Naval Shipyard, Portsmouth, Virginia

28 - 29 Inspector of Naval Material, Building 3, New York Naval Shipyard, Brooklyn 1, N.Y., for Kollmorgen Optical Company, 2 Franklin Avenue, Brooklyn, N.Y.

30 - 31 Bureau of Aeronautics Representative, Edo Corporation, College Point, Long Island, N.Y.

32 - 37 British Joint Services Mission (Navy Staff) (IEP No. B-14)

38 - 44 Naval Attache, London (IEP No. B-14), for distribution:
- 38 Director, Naval Construction Dept., Admiralty, Bath
- 39 Admiralty Experiment Works, Haslar, Gosport, Hants
- 40 Royal Naval Scientific Service, Admiralty, London
- 41 Admiralty Research Laboratory, Teddington, Middlesex
- 42 Underwater Detection Establishment, Portland
- 43 Torpedo Experimental Establishment, Greenock, Scotland
- 44 Underwater Countermeasures and Weapons Est., Havant

HYDRODYNAMIC INDUCED VIBRATIONS OF CYLINDERS TOWED IN VARIOUS COMBINATIONS

by

A. Borden, Ph.D., D.B. Young, and W.M. Ellsworth, Jr.

September 1951 Report C-452

TABLE OF CONTENTS

ABSTRACT

Cylinders in various combinations were towed in the basin of the David Taylor Model Basin to determine possible relative positions in which hydrodynamic-induced vibrations might be reduced or eliminated. Tests were made with the following combinations of cylinders: two of the same size towed in tandem, a pair of cylinders of which the forward one was smaller and towed both dead ahead and slightly to one side of the rear cylinder, and a single cylinder with an adjustable cable towed ahead of it.

INTRODUCTION

On submarines presently being built there are so many shafts for periscopes, snorkel, radar masts, etc. which may be extended individually or severally that it has become important to know the vibration characteristics of various combinations. In addition, the positioning of two cylinders in tandem appeared to be a feasible scheme for reducing the hydrodynamic-induced vibrations in such cylinders. This project was accordingly initiated at the David Taylor Model Basin in connection with investigations of methods for reducing submarine periscope vibration.[1]

When a cylinder is rigidly supported at one end and towed through the water in a direction normal to its length it tends to be set into vibration by the shedding of vortices. If the frequency of vortex shedding is close to the natural frequency of the cylinder the vibrations may become very violent. If, on the other hand, the vortex pattern can be interrupted and broken up, the induced forces would be diminished. Thus it was hoped that the vortex wakes from two cylinders placed close together might interact and destroy the regularity of the vortex pattern to such a degree that the vibrations would be reduced.

This report describes several tests made with vibrating cylinders:

1. Two cylinders of the same size towed in tandem.
2. Two cylinders of different sizes towed in line and slightly out of line.
3. A single cylinder with an adjustable cable towed ahead.

Tests 1 and 2 were previously described in TMB progress reports.[2,3]

---

[1]References are listed on page 9.

TEST APPARATUS AND PROCEDURE

Measurements of the amplitude of vibration were made on a 2.5 in. standard weight steel pipe (2.875 in. OD and 2.469 in. ID) mounted as rigidly as possible on the arresting gear on one of the basin carriages. The pipe had a vertical unsupported length of 61 in., 43 in. of which extended below the water surface, see Figure 1. To keep air from being sucked into the low pressure region of the wake the pipe was closed at the bottom and was fitted with a surface plate just below the water surface. A circular end plate was

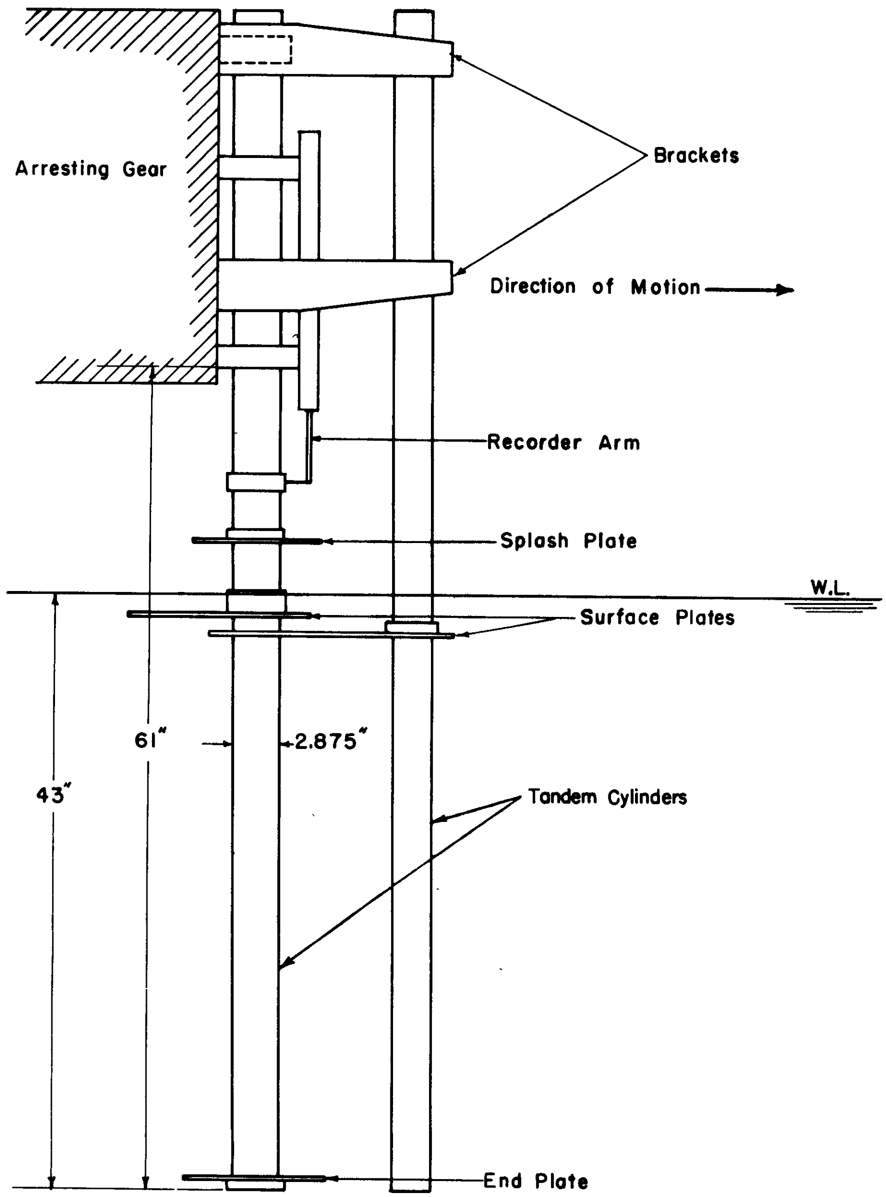


Figure 1 - Diagram of Test Setup for Towing Tandem Cylinders

fixed to the lower end of the pipe to eliminate end conditions. Vibrations of the cylinder were recorded mechanically on a moving strip of waxed paper by means of a lever arm and stylus. The recording arm was attached to the cylinder at a point 12 inches below the lower clamp. The vibrations recorded are in terms of the double amplitude at this point.

The second cylinder or cable was mounted just ahead of the fixed cylinder and the distance between centers could be varied between 1.5 and 4 cylinder diameters. Although no vibration measurements were made on the forward cylinder or cable, the vibrations were noted visually.

TANDEM CYLINDERS OF THE SAME SIZE

In Figure 2 the amplitude of vibration of the rear cylinder is plotted as a function of the flow velocity for different spacings between cylinders of the same size.[2] When the spacing was 2.5 diameters or less, the amplitude of vibration was reduced to half the value obtained with the cylinder alone. When the distance between centers was 3 or 4 diameters the

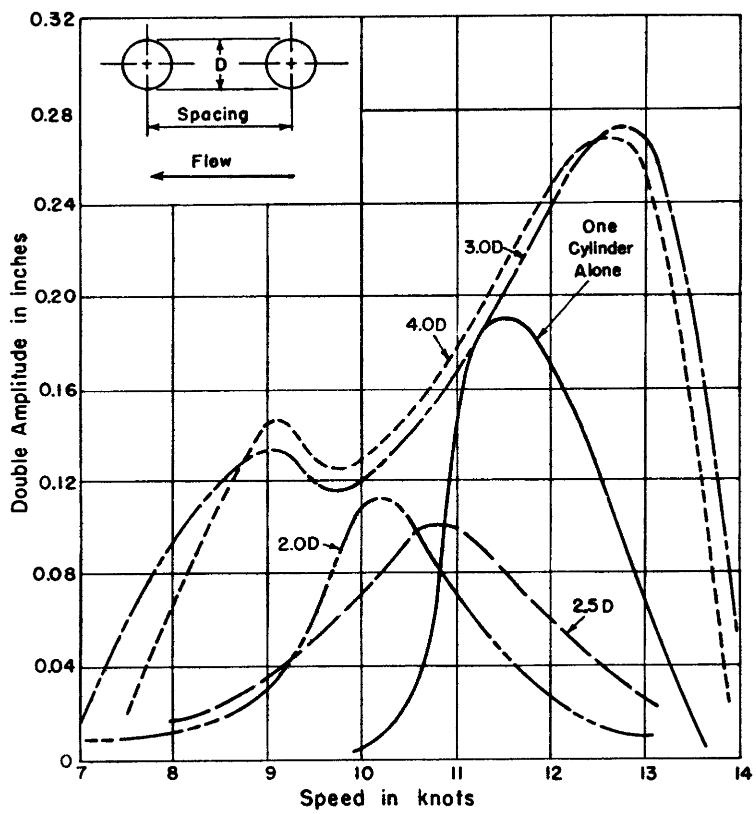


Figure 2 - Amplitude of Vibration of the After Cylinder for Different Positions of a Forward Cylinder of the Same Size Towed in Tandem

vibrations became much more violent. It was observed that when vibrations were violent on one cylinder they were violent on the other also.

Although both cylinders were fabricated from 2 1/2 in. standard weight steel pipe they were not dynamically similar. The forward cylinder had a longer unsupported length and was less rigidly supported. The forward cylinder also had a lower natural frequency than that of the rear cylinder. The vibration records of the rear cylinder showed pulsations in amplitude indicating that the cylinders were periodically in and out of phase. At low speeds when the vibration amplitude was small the pulsations came every two or three seconds. At higher speeds the pulsations occurred with a frequency of about two per second. If the pipes had been dynamically similar the vibrations would have become even more violent at the 3 and 4 diameter spacings.

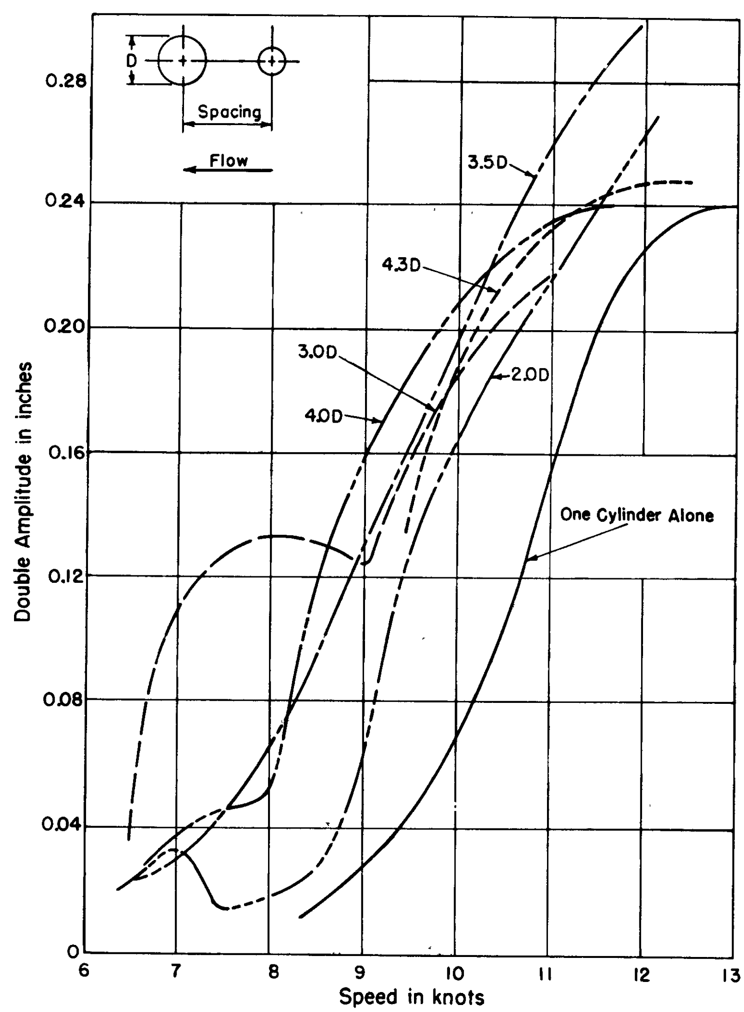


Figure 3 - Amplitude of Vibration of After Cylinder for Different Positions of a Smaller Forward Tandem Cylinder

SMALLER CYLINDER TOWED AHEAD OF FIXED CYLINDER

Figure 3 shows the results obtained when a 1 in. steel pipe of standard weight (1.315 in. OD and 1.049 in. ID) is towed directly ahead of the after cylinder. The spacings are given in multiples of the diameter of the after cylinder. Similarly, Figure 4 shows the results obtained when the small forward cylinder is mounted 2.5 inches off the tandem line.

Figure 3 also shows that the vibrations become worse when a smaller cylinder is towed directly ahead of a larger cylinder for all spacings up to 4.3 cylinder diameters. The small cylinder was set into vibration and reached resonance near 3.5 knots. At velocities above 6 knots the vibrations had almost completely damped out except at the 2 diameter spacing. At this spacing the vibrations were particularly violent in the resonance range and continued to be violent at velocities up to 12 knots. At 3 diameters this anomaly did not occur. Unfortunately the pipe broke off before the 2.5 diameter position could be investigated.

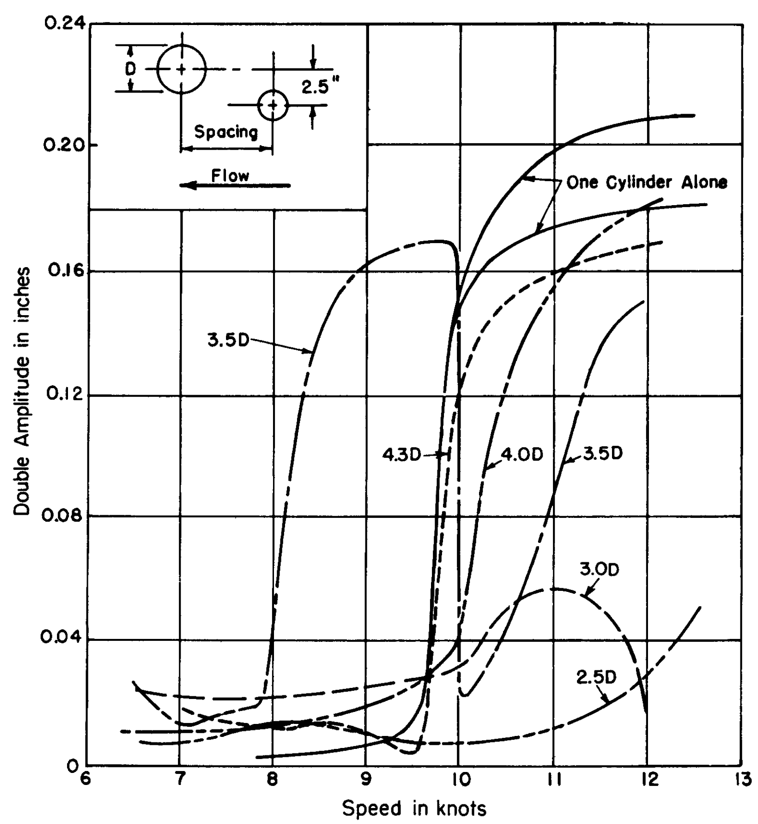


Figure 4 - Amplitude of Vibration of After Cylinder for Different Positions of a Smaller Forward Cylinder Displaced from the Tandem Line

Figure 4 shows that for certain positions of a smaller cylinder slightly off the tandem line of flow, vibrations in the rear cylinder are considerably reduced. At 2.5 and 3.0 diameters the vibrations are small; at larger spacings the vibration onset is delayed and the amplitudes are reduced. An anomaly occurred at 3.5 diameters in that a new resonance region appeared between 8 and 10 knots. As the data for the portion of the curve between 6 and 10 knots were obtained in a single run there could have been an error in setting the speed in this lower range.

In this set of tests also the small cylinder was set into resonance vibration near 3.5 knots. At speeds in excess of 6 knots the vibrations of the small cylinder were barely discernible at all spacings, in contrast to the tandem position.

ADJUSTABLE CABLE TOWED AHEAD OF A SINGLE CYLINDER

A steel cable (0.25 in. diameter) was extended from a notched bar at the lower end of the cylinder to the upper bracket on the arresting gear. The notches in the bar and the bolt holes in the upper bracket made it possible to vary the distance between the cable and the cylinder. A helical spring and turnbuckle were attached to the top of the cable to vary the tension in the cable. Tests were run with the cable 3.5, 2.5, and 1.2 cylinder diameters ahead of the cylinder. During each run the cable sagged slightly from its vertical position bringing it about 1 inch closer to the cylinder at the maximum towing speed. In one test the cable was very slack and came into contact with the cylinder during the run.

The amplitude of vibration of the cylinder as a function of towing speed is shown in Figure 5. The vibrations began at low towing speeds, were unstable at first, then increased to a greater amplitude than for the cylinder alone. The onset of the resonance vibrations was not changed appreciably by the tight cable. With the slack cable close to the cylinder the onset of resonance and the peak value were delayed by 1 knot. The maximum value was about 50 percent greater than that for the cylinder alone.

During the tests with the cable 3.5 cylinder diameters ahead of the pipe the vibrations were also enhanced. During these runs, however, the pipe was not closed off at the bottom and an air pocket was formed around the cylinder which made comparison with other tests impossible.

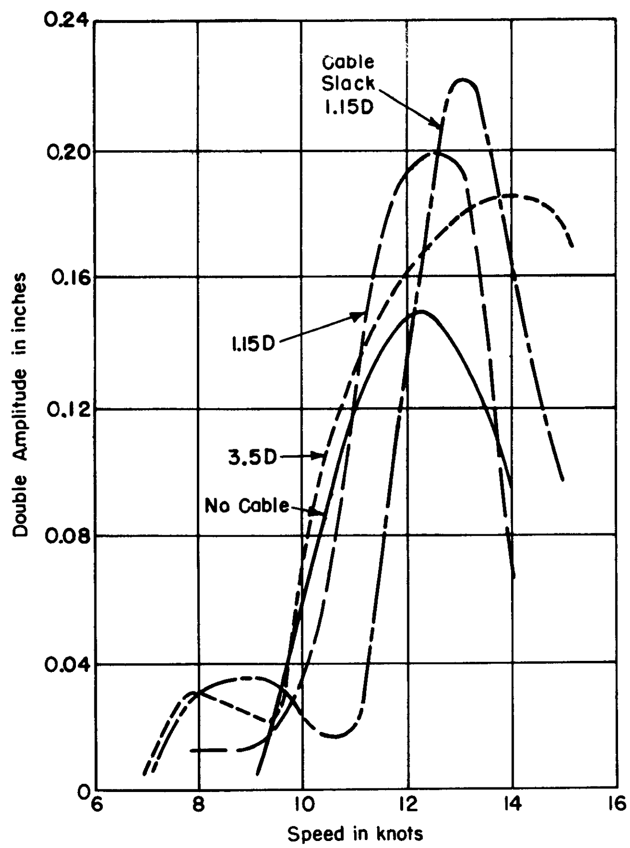


Figure 5 - Amplitude of Vibration of Cylinder for Different Positions of an Adjustable Cable Directly Forward of the Cylinder

DISCUSSION OF RESULTS

Although the vortex-excited forces may be reduced on a pair of cylinders in certain combinations, in many combinations the forces are considerably increased. In general, if the forward cylinder is close enough and large enough to shield the rear cylinder, the pair acts like a partially streamlined body and the vibrations are reduced. If the forward cylinder is too small the vortex forces appear to become larger rather than smaller. A smaller cylinder off the tandem line of flow, however, appears to distort the vortex pattern on one side of the rear cylinder and reduces its vibration. Two adjacent cylinders in a line normal to the flow are also known to vibrate excessively due to the interaction of the vortex wake under certain conditions. The possibility of vibration in this arrangement is discussed in References 4 and 5.

Since the positions for which vibrations are reduced are extremely critical, caution should be exercised in the positioning of a number of masts.

If the results of the present investigation are used as a basis for determining the best positions, each combination should be carefully tested to determine its vibration characteristics.

Drag measurements were not made in the present studies; however, the drag of various combinations of nonvibrating cylinders and struts has been investigated in one of the NACA wind tunnels.[6] It was found that the forward cylinder of a pair of tandem cylinders of the same size is very little affected by the presence of the rear cylinder. The drag of the latter cylinder, however, is appreciably reduced when the distance between centers is less than four cylinder diameters. Presumably, a similar reduction in drag would be obtained with cylinders of different size, with a greater drag reduction for relatively larger forward cylinders. Although there are no data available for vibrating tandem cylinders it is believed that the results would be essentially the same. The vibrations, however, would increase the drags of both cylinders.

In the same NACA report[6] information is given for designing a minimum drag strut to enclose a tandem pair. Such a strut would not only reduce the drag but would also ameliorate vibration. If, however, there are to be occasional side forces on the strut, a low-lift section should be used. The lift of any streamlined section may be considerably reduced by rounding off the trailing edge of the strut.[7]

CONCLUSIONS

In most positions the wake interaction between various combinations of adjacent cylinders or between a cable and a cylinder is of such a nature that the hydrodynamic forces producing vibration are enhanced. On the other hand, the drag of almost any combination of nonvibrating cylinders will be less than the sum of the drags of the component cylinders.

The following specific results were obtained in these experiments:

1. Vibrations of both cylinders of a tandem pair of the same size may be reduced if the distance between centers is 2.5 diameters or less. Vibrations are much worse at greater distances.

2. The vibrations of a larger cylinder may be reduced if a smaller cylinder is placed within three (large) cylinder diameters ahead and about one diameter off the tandem line of flow.

3. A smaller cylinder or cable ahead of a cylinder in tandem tends to increase the amplitude of vibration at all spacings.

REFERENCES

1. BuShips CONFIDENTIAL ltr C-SS/S24-9 (332-5815) of 7 July 1947 to TMB.

2. Borden, A. and Young, D.B., "Reduction of Periscope Vibration. Progress Report 1 - Vibration Tests of Cylinders Towed in Tandem," TMB CONFIDENTIAL Report C-167, November 1948.

3. Young, D.B. and Borden, A., "Reduction of Periscope Vibration. Progress Report 3 - Effects on Vibration of an Adjustable Cable Towed in Front of a Vertical Cylinder," TMB CONFIDENTIAL Report C-193, February 1949.

4. Landweber, L., "Flow About a Pair of Adjacent Parallel Cylinders Normal to a Flow, Theoretical Analysis," TMB Report 485, July 1942.

5. Landweber, L. and Wiener, B.A., "Development of Parallel-Pipe and -Cylinder Devices for Acoustic Mine Sweeping," TMB CONFIDENTIAL Report 486, September 1942.

6. Biermann, D. and Herrnstein, W.H., Jr., "Interference Between Struts in Various Combinations," NACA Report 468, 1933.

7. Borden, A. and Rosenberg, B., "Hydrodynamic Studies of Fixed Fairings for a Submarine Periscope," TMB CONFIDENTIAL Report C-281, February 1950.

NAVY-DPPO PRNC WASH D C

CONFIDENTIAL

CONFIDENTIAL