Final Report

Engineering Report No. 9

DESIGN STUDY FOR CONTROL OF WAVE RESONANCES IN RESILIENT MOUNTINGS

Research

ILLINOIS INSTITUTE OF TECHNOLOGY

Final Report

Engineering Report No. 9

DESIGN STUDY FOR CONTROL OF WAVE RESONANCES IN RESILIENT MOUNTINGS

Contract N7onr-32904
Project NR-264-003

"Resilient Mountings for Reciprocating and
Rotating Machinery"

Sponsored by

Department of the Navy
Office of Naval Research

Mechanical Engineering Department
Vibration Laboratories
Illinois Institute of Technology
3300 Federal Street
Chicago 16, Illinois

Dated: 25 May 1954

Copy No. 8

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENT iv

LIST OF FIGURES v

SECTION

I. INTRODUCTION 1

Background
Scope

II. PROCEDURE 1

Experimental Mountings
Laboratory Tests

III. DISCUSSION OF TEST RESULTS 5

Soft Steel Coil Molded in Rubber Element
Various Materials Introduced Concentrically Through the Longitudinal Axis of the Rubber Element

IV. CONCLUSIONS 18

BIBLIOGRAPHY 20

DISTRIBUTION LIST 21

ACKNOWLEDGEMENT

The study "Design Study for Control of Wave Resonances in Resilient Mountings" was made possible through sponsorship by the Department of the Navy, Undersea Warfare Branch, Office of Naval Research.

This research program was performed under the direction of the undersigned with the assistance of Messrs. O. E. Curth and R. A. Einweck.

Respectfully submitted,

Chester A. Arents

Professor Chester A. Arents
Project Director

LIST OF FIGURES

Figure Page

1. Experimental Resilient Mounting 3

2. Metal Elements of Experimental Resilient Mountings . 4

3. Decibel Change vs. Frequency Curves--Natural Solid Rubber Element 4-1/8 in. Long 11

4. Decibel Change vs. Frequency Curves--Natural Solid Rubber Element 5-1/2 in. Long 12

5. Decibel Change vs. Frequency Curves--Natural Rubber Element 4-1/8 in. Long with Solid and Molded Coil 14

6. Decibel Change vs. Frequency Curves--Natural Rubber Element 4-1/8 in. Long with Hollow Element, Water-filled and Air-filled 15

7. Decibel Change vs. Frequency Curves--Natural Rubber Element 4-1/8 in. Long, Hollow Element Filled with Mercury and Steel Rod. 16

I. INTRODUCTION

Background

Transmissibility tests of resilient mountings have shown the existance of wave resonances (1, 2). Also, it has been shown by actual field tests that these wave resonances cause the resilient mounting to lose part of its efficiency or increase its transmissibility in the high frequency range and pass sound vibrations into the water through the hull of a submarine (3). Since the d^*-distance, the shortest metal-to-metal distance measured through the rubber resilient element of a mounting, affects the frequencies where the wave resonances occur (1, 2), credence has been given to the idea that the wave resonances in a resilient mounting can be shifted to higher frequencies as the d^*-distance is decreased. Transmissibility tests previously performed give rise to this opinion.

Scope

This study was developed to substantiate the supposition that a short d^*-distance will shift the wave resonance frequencies to a higher value; or that the d^*-distance can be such as to reduce the possibility of enemy detection to a minimum in the low frequency range. Cylindrical resilient mountings were designed and constructed and their transmissibility characteristics were obtained by laboratory tests. Alterations were made in the mounting to see how it might affect the d^*-distance in raising the frequency of the first wave resonance and its harmonics.

II. PROCEDURE

Experimental Mountings:

Five experimental cylindrical resilient mountings were designed and constructed using natural rubber and molded to the end pieces as shown in Fig. 1. It will be noted that the end pieces provide for attachment of accelerometers.

Mounting No. 1, with a natural rubber element 4-1/8" long, is a plain cylindrical unit with a 35 Durometer hardness (Shore "A"). However, the unit was completed and tested in 1952 but the hardness was measured approximately two years hence when the data was analyzed and a transmissibility curve plotted. It is quite possible that it had hardened during this long period and the hardness was less at the time of test.

Mounting No. 2, with a natural rubber element 5-1/2" long, is a plain cylindrical unit with a 35 Durometer hardness (Shore "A"). It was tested and its data analyzed the same as No. 1 above.

Mounting No. 3, with a rubber element 4-1/8" long, is a plain cylindrical unit with a 33 Durometer hardness (Shore "A"). This unit was molded and tested during April and May 1954.

Mounting No. 4 has the same dimensions and hardness as No. 3 above but the rubber element was altered. It had a soft steel coil molded into the rubber element and fastened to driven end, see Fig. 2. Thus one end of the steel coil was fastened to the driven end piece while the opposite end of the spring was allowed to remain free in the rubber and extend within 1/4" of the other end piece.

Mounting No. 5 was the same as No. 3 above except a 3/8" diameter hole was made lengthwise through the center of the rubber element. A threaded plug was fitted into the driven end piece in order to fill the hole in the resilient element with a liquid or a solid. The purpose of this construction

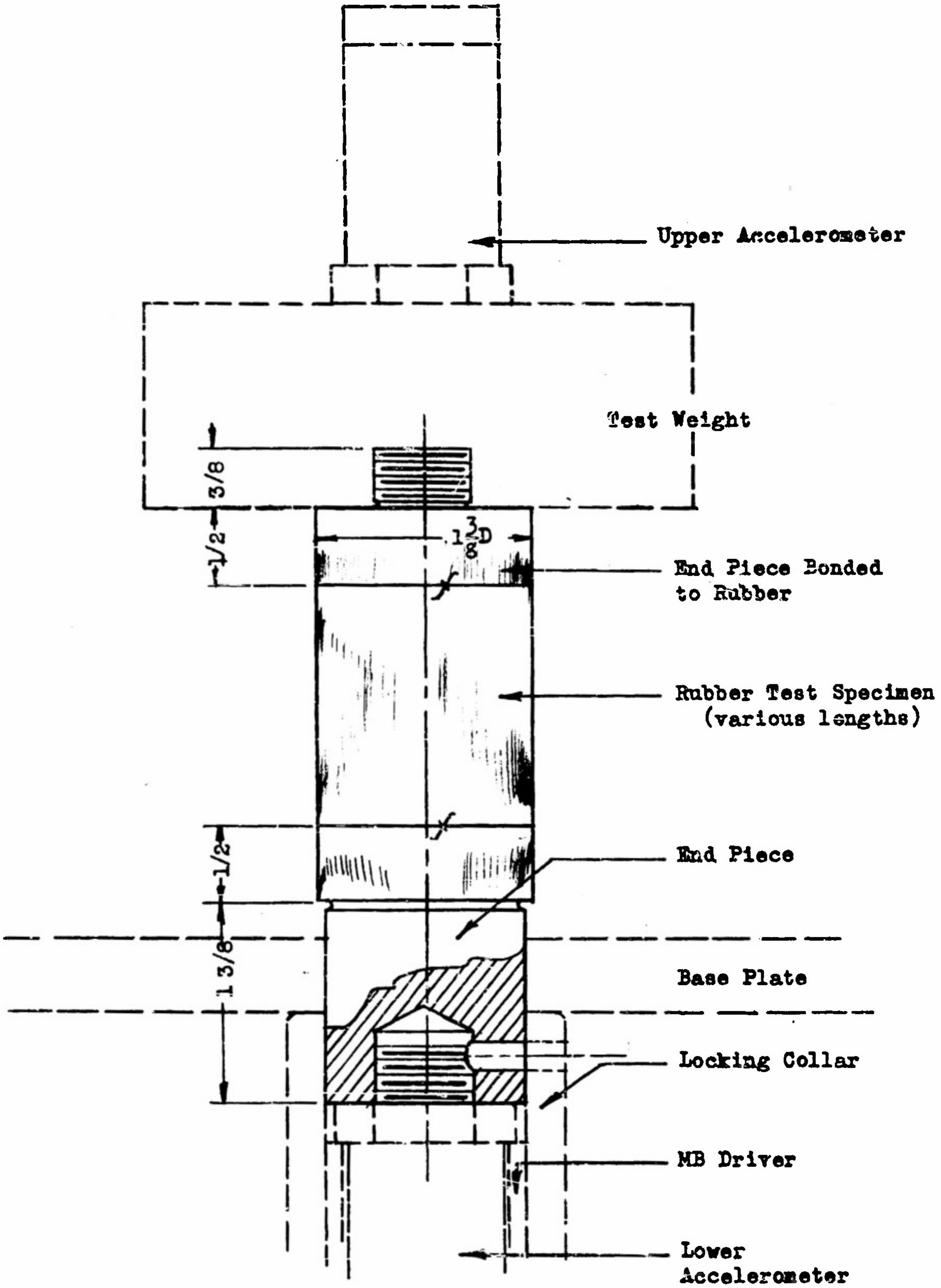

Fig. 1. Experimental Resilient Mounting

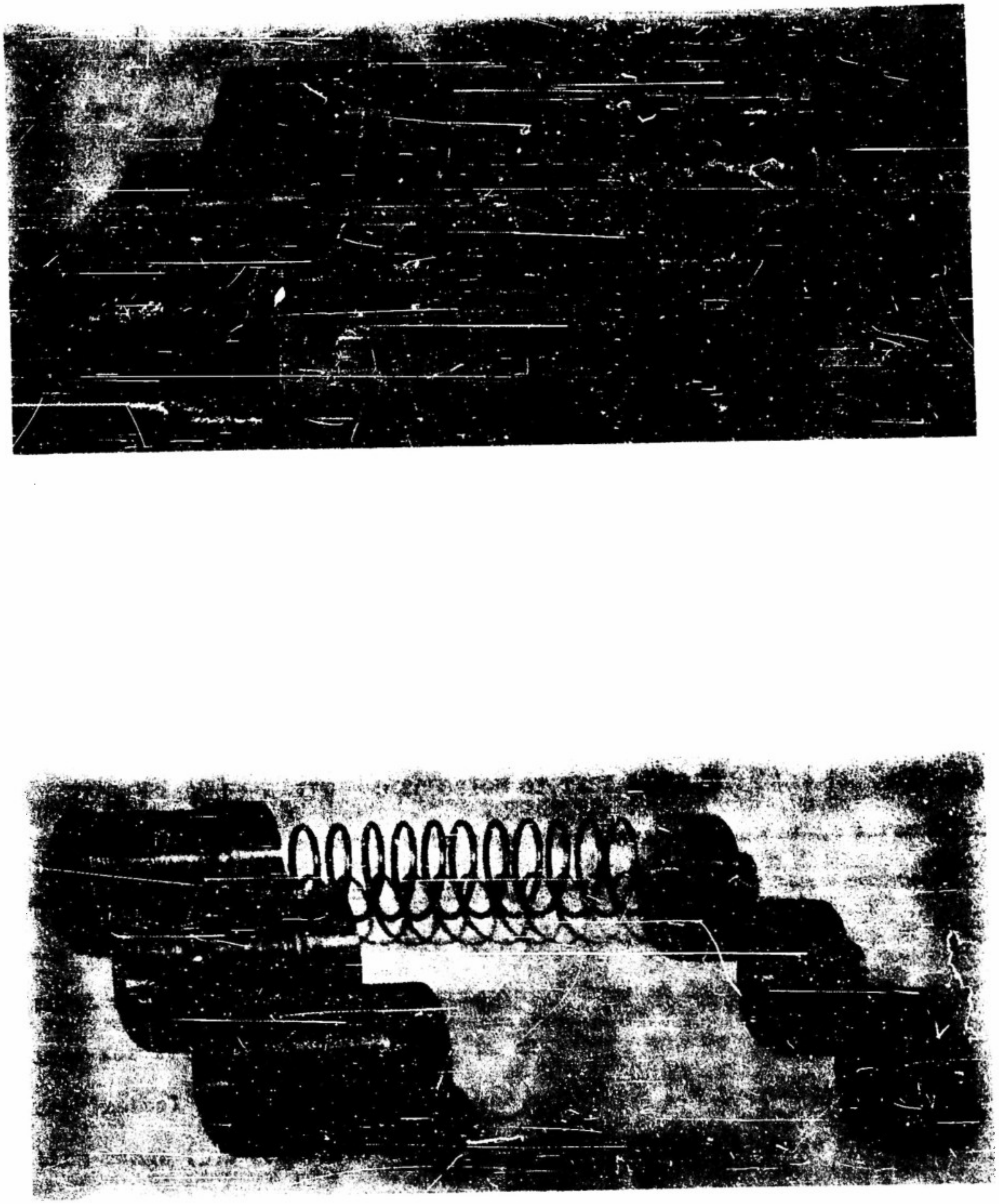

Fig. 2. Metal Elements of Experimental Resilient Mountings

was to permit the use of a liquid or a solid having a different velocity of sound than the rubber in order to determine this affect upon the wave resonances within the rubber element. In addition, a test was run with a 3/8" diameter solid steel rod in the hole. The rod extended within 1/4" of the weight or load end of the mounting. The rod was threaded into the driven end piece.

Laboratory Tests

Transmissibility tests were made for each mounting. The improved testing apparatus described in Engineering Report No. 8 (4) was used to test mountings 3, 4 and 5. The general procedure for conducting the transmissibility test was previously outlined in Engineering Report No. 3 (1). Transmissibility curves were plotted of decibel change vs. forcing frequency.

III. DISCUSSION OF TEST RESULTS

These data are presented to show that wave resonances in a resilient mounting can be controlled by varying the dimensions of the resilient element and to discuss possible ways of increasing the frequency of the first wave resonance and its harmonics. Thus it is believed that mountings for reciprocating and rotating machinery can be made to eliminate detrimental wave resonances from the important low frequency ship detection range (3). Previous transmissibility studies (1) have shown that at the higher forcing frequencies the wave length of the vibrations propagated in a resilient element were of the same order of magnitude as the element itself and wave resonances occurred in the mounting material. These resonances tend to decrease the possible sound attenuation through the mounting and, in effect, increase the transmission of sound at these wave resonant frequencies (3).

Tables I, II, and III give data on experimental, cylindrical rubber mountings. Tables I and III are for mountings with the same dimensions but with a slight variation in the composition of the resilient element. Since hardness tests were not made on mounting No. 1 at the time of the test, no definite conclusions can be made regarding hardness. The 35 Durometer hardness reported was taken approximately 24 months after the transmissibility tests. It is believed that the rubber was considerably softer at the time of the transmissibility tests. Table III includes data where the resilient element had been altered to include another material in an attempt to raise the frequency of the first wave resonance. Tables I and II are for mountings of different length—composition and other dimensions remaining the same.

Comparing the data in Table I with that in Table II for equal loads on the mountings, it is seen that the first wave resonance of the 5-1/2" long mounting is lower in frequency than for the 4-1/8" long mounting. In fact this frequency is approximately inversely proportional to the length of the resilient element. This comes from the formula that $f = \frac{v}{2L}$ where f is the frequency of the first wave resonance in cycles per second, v is the velocity of sound in the resilient element (in./sec), and L is the length of the resilient element in inches. Also, it will be noted that these mountings were tested for different loads and it can be seen from the transmissibility curves, Figs. 3 and 4, that the transmissibility increases with a decrease in load on the mounting. Therefore, a rubber-type resilient mounting should not be under-loaded for best sound attenuation. The transmissibility tests

Table I. Wave Resonance Data on Mounting No. 1 - 4-1/8" Natural Rubber Element, 1-3/8" Diameter. (35 Durometer Hardness, Shore "A", Taken 2 Years After Test)

	Wave Resonance No.	1	2	3	4	5	6
Test A	Frequency, cps.	242	455	630	750		
Load 1.39 lb.	Frequency Ratio	1	1.88	2.60	3.10		
	Sound Velocity, fps.	166	156	144	129		
	Wave Resonance No.	1	2	3	4	5	6
Test B	Frequency, cps.	242	455	650	788	940	1020
Load 2.55 lb.	Frequency Ratio	1	1.88	2.68	3.26	3.88	4.2
	Sound Velocity, fps.	166	156	149	136	129	117
	Wave Resonance No.	1	2	3	4	5	6
Test C	Frequency, cps.	235	450	645	790		
Load 4.78 lb.	Frequency Ratio	1	1.91	2.74	3.36		
	Sound Velocity, fps.	163	155	148	136		

Table II. Wave Resonance Data on Mounting No. 2 - 5-1/2" Natural Rubber Element, 1-3/8" Diameter. (35 Durometer Hardness, Shore "A", Taken 2 Years After Test)

	Wave Resonance No.	1	2	3	4	5	6
Test A	Frequency, cps	172	353	503	638		
Load 1.39 lb.	Frequency Ratio	1	2.05	2.92	3.71		
	Sound Velocity, fps.	157	162	154	146		
	Wave Resonance No.	1	2	3	4	5	6
Test B	Frequency, cps	184	362	503	650	760	858
Load 2.55 lb.	Frequency Ratio	1	1.93	2.74	3.53	4.13	4.66
	Sound Velocity, fps.	169	166	154	149	140	132
	Wave Resonance No.	1	2	3	4	5	6
Test C	Frequency, cps	180	356	500	640	748	858
Load 4.78 lb.	Frequency Ratio	1	1.96	2.78	3.55	4.15	4.77
	Sound Velocity, fps.	165	163	153	147	137	132

Table III. Wave Resonance Data on Mountings with a 4-1/8" Natural Rubber Element, 1-3/8" Diameter and 33 Durometer Hardness, Shore "A"

Test A	Wave Resonance No.	1	2	3	4	5	6
Load 1.39 lb.	Frequency, cps.	220	415				
Solid	Frequency Ratio	1	1.89				
	Sound Velocity, fps.	151	143				
Test B	Wave Resonance No.	1	2	3	4	5	6
Load 1.39 lb.	Frequency, cps	272	540	730	960		
With Coil	Frequency Ratio	1	1.97	2.68	3.53		
	Sound Velocity, fps.	187	186	168	165		
Test C	Wave Resonance No.	1	2	3	4	5	6
Load 1.39 lb.	Frequency, cps	223	415				
Air in Hole	Frequency Ratio	1	1.86				
	Sound Velocity, fps.	154	143				
Test D	Wave Resonance No.	1	2	3	4	5	6
Load 1.39 lb.	Frequency, cps	225	430	640	833	1020	
H_2O in Hole	Frequency Ratio	1	1.91	2.84	3.70	4.54	
	Sound Velocity, fps.	155	148	147	143	141	
Test E	Wave Resonance No.	1	2	3	4	5	6
Load 1.39 lb.	Frequency, cps	227	430	620	783	1020	
Hg in Hole	Frequency Ratio	1	1.90	2.73	3.54	4.50	
	Sound Velocity, fps.	156	148	142	135	141	

Table III. (Continued)

Test F Load 1.39 lb. Steel Rod in Hole	Wave Resonance No.	1	2	3	4	5	6
	Frequency, cps	270	470	650	830		
	Frequency Ratio	1	1.74	2.41	3.08		
	Sound Velocity, fps.	186	156	149	143		

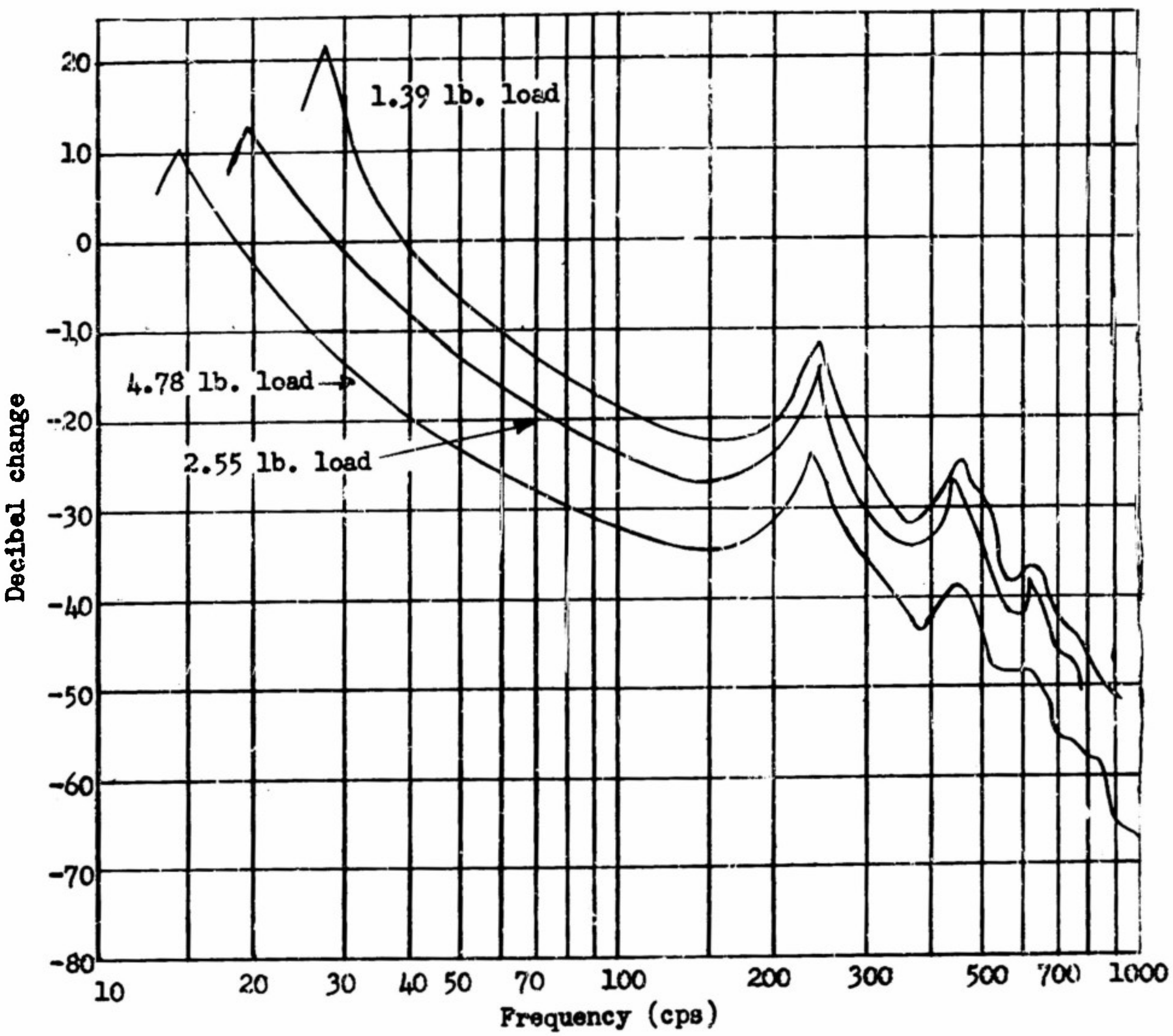

Fig. 3. Decibel Change vs. Frequency Curves--Natural Solid Rubber Element 4-1/8 in. Long

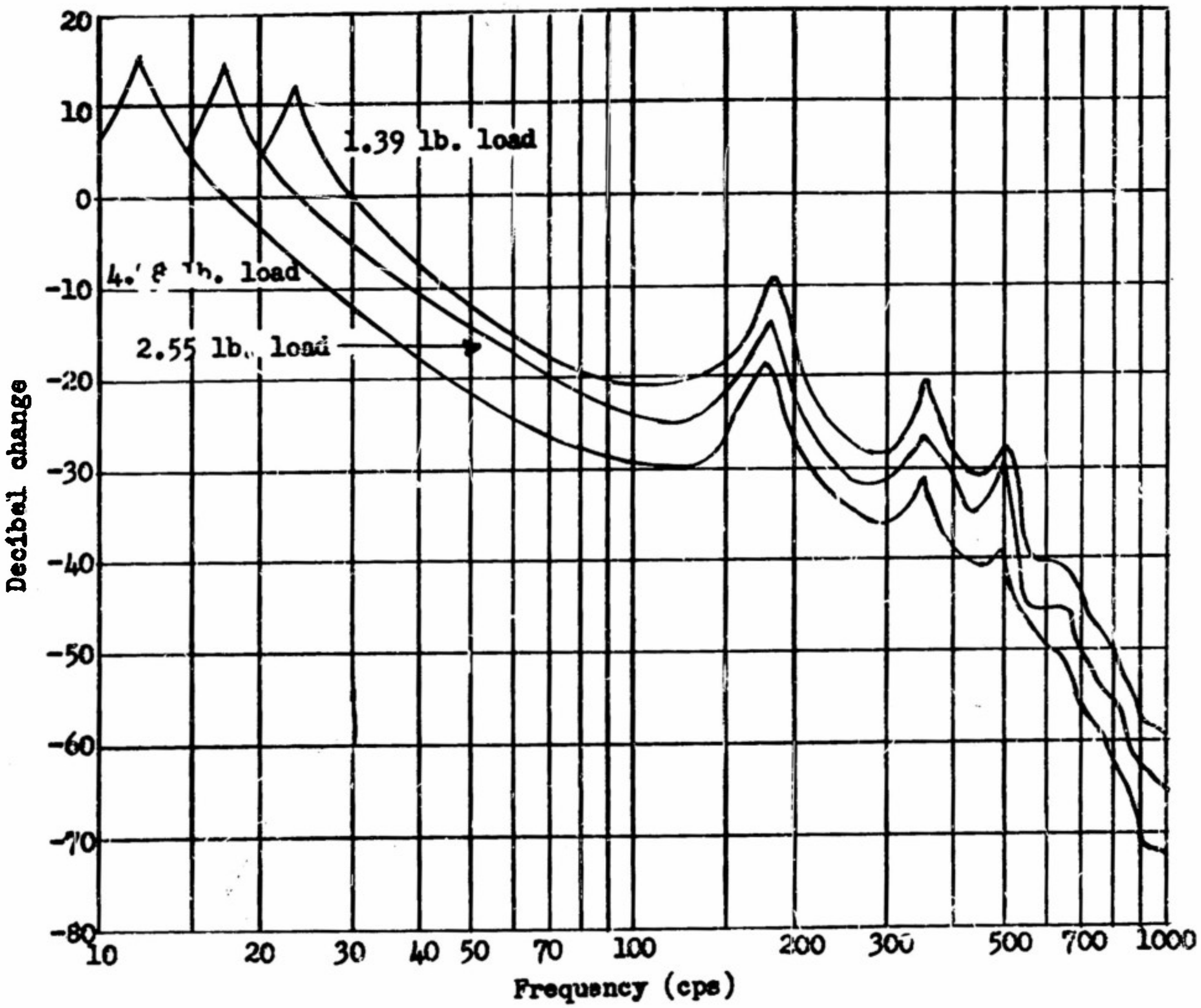

Fig. 4. Decibel Change vs. Frequency Curves--Natural Solid Rubber Element 5-1/2 in. Long

using experimental mountings with resilient elements 4-1/8" and 5-1/2" long showed that the first wave resonance and its harmonics could be shifted to a higher frequency range by decreasing the rubber resilient path between the metal driven element of the mounting and the fixed metal fixture of the mounting which is used to fasten it solidly to a foundation. The fact that the harmonics of the first wave resonance are less than multiples of the resonant frequency, Tables I, II, and III, indicates a deviation in the findings of theory as developed by Guth, et.al. (5, 6). This may be due to the influence of the metal elements of the mounting or of the compound used.

Since the shortest distance of the rubber resilient path between the driven metal element and the fixed metal element, was known to determine the frequency of the first wave resonance, it was thought feasible to try to shorten this path to a smaller value by inserting another material in the rubber element. Table III-B, C, D, E, and F and Figs. 5, 6 and 7 show the results of this study. Each alteration in the resilient element will be discussed separately as follows:

<u>Soft Steel Coil Molded in Rubber Element</u>: It was hoped that this alteration in the rubber element would raise the first wave resonance to a higher value. Examination of the data, Table III-B, and the transmissibility curves, Fig. 5, show about a 10 cps rise in the natural frequency and an increase in the frequency of the first wave resonance from 220 cps to 272 cps. It appears that the main contribution of the soft steel coil was to stiffen the rubber element and perhaps raise the velocity of sound through the element, thus slightly increasing the first wave resonant frequency.

<u>Various Materials Introduced Concentrically Through the Longitudinal Axis of the Rubber Element</u>: A study was made where a 3/8" hole was

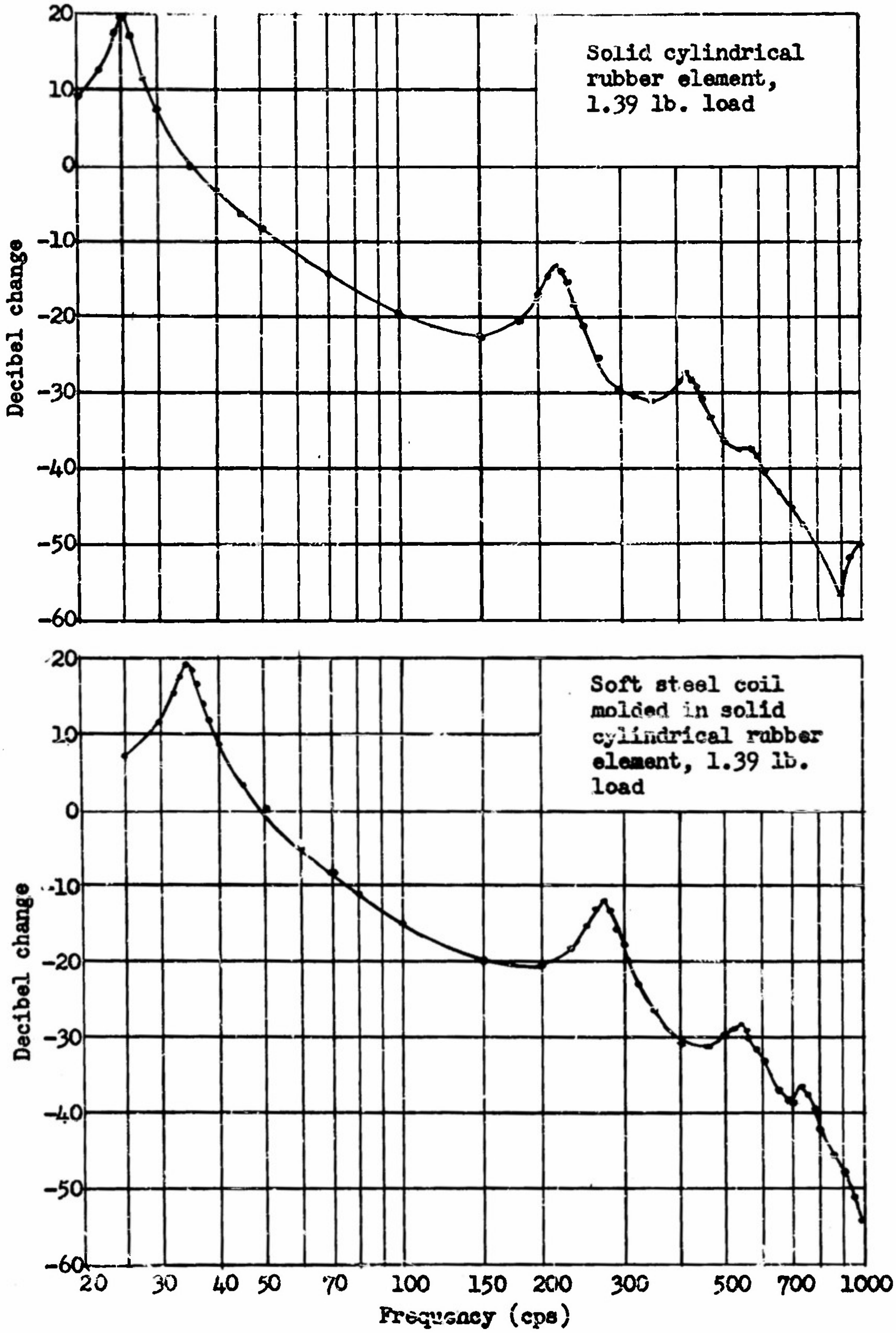

Fig. 5. Decibel Change vs. Frequency Curves—Natural Rubber Element 4-1/8 in. Long with Solid and Molded Coil

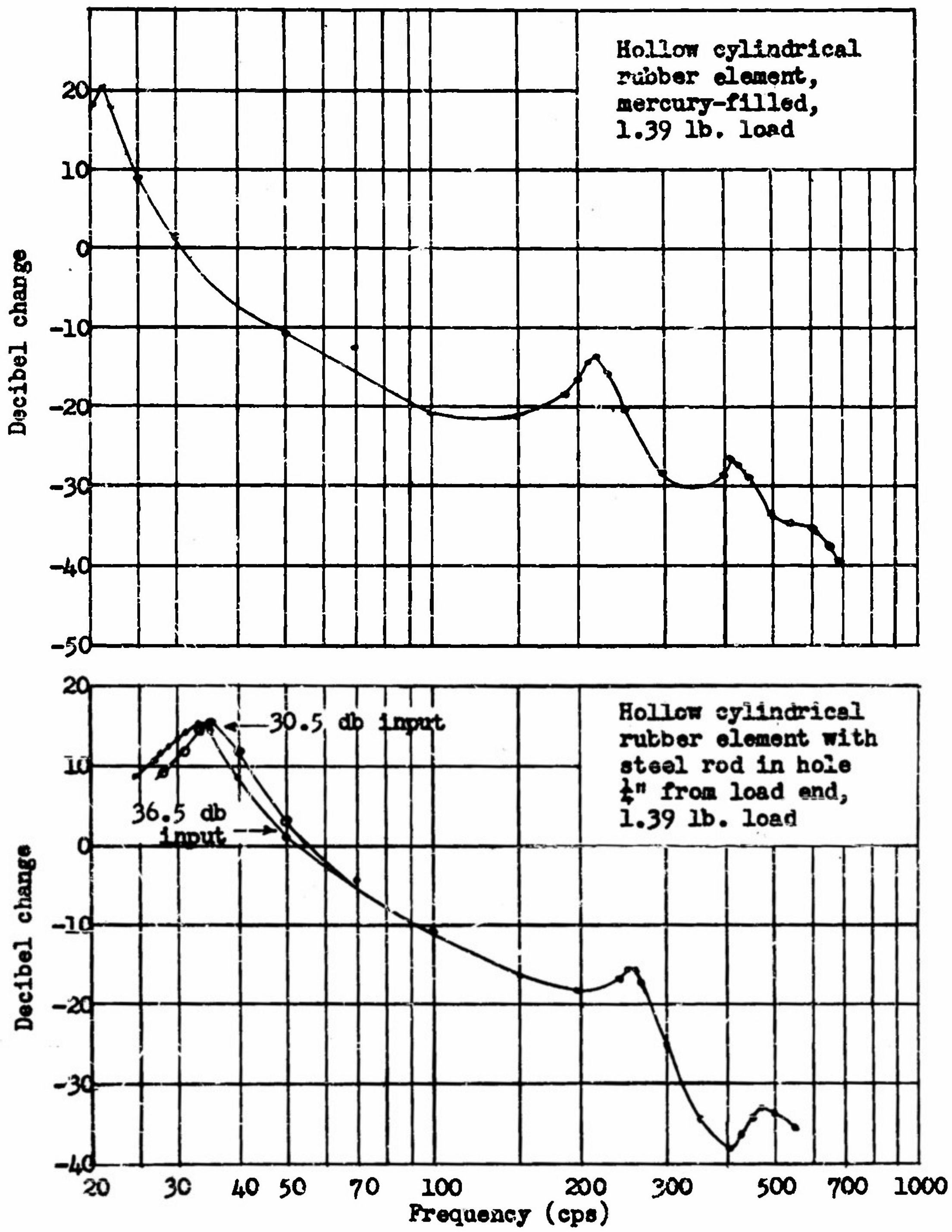

Fig. 7. Decibel Change vs. Frequency Curves—Natural Rubber Element 4-1/8 in. Long, Hollow Element Filled With Mercury and Steel Rod

molded concentrically through the longitudinal axis of the rubber element. Various materials were introduced into this cavity and transmissibility tests were made. The cavity was completely filled with water, mercury and partially filled with a 3/8" steel rod which extended from one end piece to 1/4" of the opposite end piece.

Table III-C gives data for the mounting with an empty cavity or air-filled cavity. Tables III-D and E give data for the cavity filled with water and mercury, respectively. Fig. 5, 6, and 7 show the transmissibility curves. Comparing the data of Table III-C with that of III-A no change was made in the frequency of the wave resonances...this result was expected. Also, it will be seen that filling the cavity with water or mercury had little or no effect in changing the first wave resonance and its harmonics.

Looking at Figs. 5 and 7 one can see that introducing the steel rod into the cavity gave about the same result for the first wave resonant frequency as molding a soft steel coil in the rubber element. However, the second, third and fourth wave resonant frequencies were about the same as the unaltered mounting—see Table III-A and F...only the frequency was slightly increased. During the transmissibility tests, it was found that the natural resonant frequency of the mounting with the rod was a function of the driven amplitude. A study was made where readings were taken using two values of input acceleration, approximately 0.5 g and 1.0 g. These curves are shown in Fig. 7. It will be noted that the dampening was introduced by friction between the rod and the rubber element as indicated by a transmissibility value less than that for either the solid rubber unit (Fig. 5) or the mounting with the soft steel coil (Fig. 5).

Time did not permit the molding of many rubber, cylindrical mountings with varying degrees of hardness. However, it is believed that with all elements of the mounting being equal in dimension and shape, the harder rubbers will give a higher frequency value for the first wave resonance and its harmonics than the softer rubbers.

IV. CONCLUSIONS

Experimental tests on resilient mountings to date at Illinois Institute of Technology have shown that:

A. The frequency of first wave resonance and its harmonics can be increased by designing a rubber type resilient mounting where the driven metal element is brought closer to the fixed metal element of the mounting and thus shorten the rubber path from one metal element to the other...the shorter the distance the higher the frequency of the first wave resonance.

B. Devices may be molded into the rubber element that tend to stiffen it and thus increase the frequency of the first wave resonance. Although tests on resilient mountings with rubber of various hardness have not been made, credence is given to the proposition that as the hardness of the rubber is increased one will obtain an increase in the frequency of the first wave resonance.

C. Introducing a column of liquid from the driven element to the fixed element through the rubber element was a failure insofar as increasing the frequency of the wave resonances in the resilient mountings tested.

D. Tests introduced in this report show that the transmissibility at the wave resonance will increase if a rubber type resilient mounting is lightly loaded. This gives poor sound attenuation through the mounting at these frequencies.

BIBLIOGRAPHY

(1) "Resilient Mountings for Reciprocating and Rotating Machinery." Engineering Report No. 3, Illinois Institute of Technology, ONR Contract N7onr-32904, July 1951.

(2) Harrison, M. A. Sykes and M. Martin. "Wave Effects in Isolation Mounts," David Taylor Model Basin Report 766, August 1952.

(3) "Evaluation of Resilient Mountings Tested Aboard a Submarine." Engineering Report No. 7, Illinois Institute of Technology, ONR Contract N7onr-32904, February 1954.

(4) "The Effect of Paint Upon the Transmissibility of a Resilient Mounting - Tested with Improved Apparatus." Engineering Report No. 8, Illinois Institute of Technology, ONR Contract N7onr-32904, May 1954.

(5) Witte, R. S., B. A. Mrowca, and E. Guth. "Propagation and Audio-frequency Sound in High Polymers," J. Applied Physics. V20 (1949) p. 481-485.

(6) Ivey, D. G., B. A. Mrowca, and E. Guth. "Propagation of Ultrasonic Bulk Waves in High Polymers," J. Applied Physics, V20 (1949) p. 486.

DISTRIBUTION LIST

Office of Naval Research
Washington 25, D. C.
Attention: Code 466 (5)

Armed Services Technical Information Agency
Documents Service Center
Knott Building
Dayton 2, Ohio (5)

Office of Technical Services
Department of Commerce
Washington 25, D. C. (1)

Director, Naval Research Laboratory
Technical Information Officer
Washington, D. C.
(Further distribution to be made by NRL
Code 2000 to B.J.S.M. and Canadian Joint Staff) (6)

Chief, Bureau of Ships
Department of the Navy
Washington 25, D. C.
Attention: Code 300 (1)
Code 344 (1)
Code 362 (1)
Code 371 (1)
Code 430 (1)
Code 490 (1)
Code 503b (1)
Code 515 (1)

Commander
Mare Island Naval Shipyard
Vallejo, California (1)

Commander
Materials Lab, New York
Naval Shipyard, Naval Base
Brooklyn 1, New York (1)

Commander
Design Division, Philadelphia
Naval Shipyard, Naval Base
Philadelphia, Pennsylvania (1)

Commander
Boiler and Turbine Laboratory
Philadelphia Naval Shipyard
Naval Base
Philadelphia, Pennsylvania (1)

Commander
Boston Naval Shipyard
Boston 28, Massachusetts (1)

Commander
Charleston Naval Shipyard
Naval Base
Charleston, South Carolina (1)

Commander
Portsmouth Naval Shipyard
Portsmouth, New Hampshire (1)

Commander
Pearl Harbor Naval Shipyard
Navy No. 128 Fleet Post Office
San Francisco, California (1)

Commander
Puget Sound Naval Shipyard
Bremerton, Washington (1)

Commander
New York Naval Shipyard
Naval Base
Brooklyn 1, New York (1)

Commander
Long Beach Naval Shipyard
Long Beach, California (1)

Commander
Norfolk Naval Shipyard
Portsmouth, Virginia (1)

Commander
San Francisco Naval Shipyard
San Francisco, California (1)

Commander
Mare Island Naval Shipyard
(Rubber Laboratory)
Vallejo, California (1)

Commanding Officer
U. S. Naval Submarine Base
Navy No. 128 Fleet Post Office
San Francisco, California (1)

Commanding Officer
U. S. Naval Submarine Base
New London, Connecticut (1)

Commanding Officer
U. S. Naval Ordnance Laboratory
White Oak, Maryland
Attention: Mr. B. Snavely (1)

Commanding Officer and Director
U. S. Navy Underwater Sound Lab.
Fort Trumbull
New London, Connecticut (1)

Director
David Taylor Model Basin
Washington 7, D. C. (1)

Director
U. S. Navy Engineering Experiment Station
Annapolis, Maryland (1)

Director
U. S. Navy Electronics Lab.
San Diego, California (1)

Chief, Bureau of Ordnance Re6
Department of the Navy
Washington 25, D. C. (1)

U. S. Department of Commerce
National Bureau of Standards
Van Ness Street and Conn. Avenue
Washington, D. C. (1)

Supervisor of Shipbuilding USN and
Naval Inspector of Ordnance
Electric Boat Company
Groton, Connecticut (1)

Office of Naval Research Branch Office
150 Causeway Street
Boston, Massachusetts (1)

Office of Naval Research Branch Office
Tenth Floor
The John Crerar Library Building
86 East Randolph Street
Chicago 1, Illinois (1)

Office of Naval Research Branch Office
346 Broadway
New York 13, N. Y. (1)

Office of Naval Research Branch Office
1030 E. Green Street
Pasadena 1, California (1)

Office of Naval Research Branch Office
1000 Greary Street
San Francisco 9, California (1)

Officer-in-Charge
Office of Naval Research
Navy No. 100
Fleet Post Office
New York, N. Y. (2)

University of Michigan
Engineering Research Institute
Ann Arbor, Michigan
Attention: Mr. R. N. Hamme (1)

General Electric Company
General Engineering and Consulting Lab.
Schenectady, New York
Attention: Dr. R. Fehr
Via: NavInspect of Ord,
G. E. Company
Schenectady, N. Y. (1)

Commander
Submarine Development Group Two
Box 70 U. S. Naval Submarine Base
New London, Connecticut
Attention: LCDR. O. B. Nelson, USN (1)