~~RESTRICTED~~ 9/26/51

THE DAVID W. TAYLOR MODEL BASIN

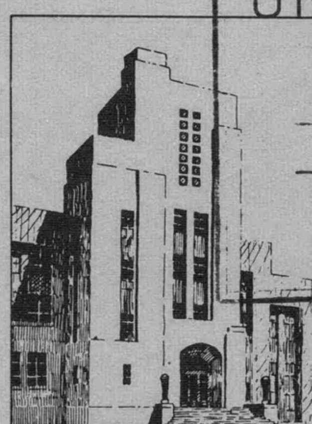
UNITED STATES NAVY

~~RESTRICTED~~
Per letter 9/26/51

VIBRATION SURVEY OF THE USS MIDWAY (CVB 41) CONDUCTED DURING SHIP TRIALS OF JULY AND AUGUST 1947

BY N. H. JASPER

CLASSIFICATION CHANGED TO
UNCLASSIFIED
IN ACCORDANCE WITH
BuShips ltr to TMB
/s/ O. P. Otteson
DATE 15 Feb 49



~~RESTRICTED~~

87

MARCH 1948

REPORT ~~640~~ 690

REPORT ~~C-40~~ 690

VIBRATION SURVEY OF THE USS MIDWAY (CVB 41) CONDUCTED DURING SHIP TRIALS OF JULY AND AUGUST 1947

BY N. H. JASPER

MARCH 1948

~~RESTRICTED~~

TABLE OF CONTENTS

VIBRATION SURVEY OF THE USS MIDWAY (CVB41) CONDUCTED DURING SHIP TRIALS OF JULY AND AUGUST 1947

ABSTRACT

A vibration survey of the USS MIDWAY (CVB41) was made jointly by several laboratories, principally to determine the vessel's vibration characteristics when operating with three-bladed and with four-bladed propellers. Design recommendations were to be made on the basis of the test results.

The author concludes that three-bladed propellers are preferable in relation to their effect on machinery vibration but that four-bladed propellers are more desirable when hull vibrations are considered. Since the vibration amplitudes of Main Propulsion Units 1 and 4 are of acceptable magnitude when either type of propeller is installed, the author suggests that the vessel be operated with three-bladed propellers on the inboard shafts and four-bladed propellers on the outboard shafts.

INTRODUCTION

A vibration survey of the USS MIDWAY (CVB41) was authorized by a joint Bureau of Ships and Board of Inspection and Survey directive (1)* which specifies the items to be investigated. The project number assigned to the work covered by this report is SRD 265(C172-37).

The survey represents the combined effort of the David Taylor Model Basin, the New York Naval Shipyard, the Naval Research Laboratory, the Bureau of Ships, and the Westinghouse Electric Corporation. The David Taylor Model Basin was directed by the authorizing letter to coordinate the efforts of the several activities and to submit a comprehensive report covering the vibration tests.

The purpose of these tests was, in the main, to determine the vessel's vibration characteristics when the vessel is operating with three-bladed and with four-bladed propellers and to make design recommendations on the basis of the test results. The results of the present tests were also to be compared with somewhat similar data available for the USS FRANKLIN D. ROOSEVELT (CVB42)(2). In addition, the vibration characteristics of several component structures were to be evaluated.

It was the intention, during this vibration survey, to make all the tests required by the joint directive (1) and to spend any additional available time investigating special items as required by the ship's commanding officer and by the trial board.

---

* Numbers in parentheses indicate references on page 43.

The trials were held in two parts. The first set of trials was conducted with four-bladed propellers during the period of 19 to 23 July 1947, enroute to and from Guantanamo Bay, Cuba. After these trials were completed, the ship returned to Norfolk, Virginia, and three-bladed propellers were installed. After drydock operations were completed and the ship had put to sea, the steady-speed runs and high-speed turns were made on 6 August 1947. A turbine casualty in Engine Room 2 during the crash-back operation precluded further trials.

Since the scope of this survey is rather extensive, involving many parts of the vessel, the report is divided into several sections. The first section presents some pertinent background data as well as general considerations. The second section describes test methods and procedure. The third section consists of subsections dealing with one particular item or a series of related items. In each subsection the pertinent data are presented, analyzed, and discussed, and conclusions are given when possible. The conclusions and recommendations are then summarized at the end of this report.

BACKGROUND AND GENERAL CONSIDERATIONS

A preliminary report of shipboard vibration experienced during the vessel's shakedown cruise had been received from the Commanding Officer of the CVB41 (3). Numerous examples of excessive vibration were mentioned in the report. A similar report (4) was received just prior to the subject trials. The Westinghouse Research Laboratory had made some incomplete vibration measurements on the machinery in February 1946 (5). A vibration survey similar to the one described here was made on the CVB42 (2) which at that time was operating with three-bladed propellers.

Several minor objectives were to be attained during the trials. The level of vibration existing in the present and former locations of Radio Room III was to be measured in order to determine the advisability of a similar relocation of Radio Room III on the CVB42. The David Taylor Model Basin had strongly advised against such relocation (6). The motion across the forward expansion joint of the flight deck was to be determined in order to evaluate the possibility of eliminating this joint for purposes of longer catapult-track installations. Reports of local excessive vibration were also to be investigated.

All vibration trials were made in water of 500-foot depth or more. The displacement of the vessel during the tests was approximately 56,000 tons. The sea was calm throughout these tests. Preliminary reports on these trials were made to the trial board (7)(8) immediately upon completion of each series of tests.

This report presents only the more pertinent information compiled from data obtained by the several cooperating laboratories. It is not considered necessary, for purposes of this report, to include details of instrumentation and test procedure. Vibration is defined in terms of amplitude and frequency. The amplitudes aboard ship are continually changing; the values given here are the maximum amplitudes sustained over a period of at least two cycles. The directions of the vibration are given with reference to the vertical, longitudinal, and transverse axes of the ship. The order of the vibration is referred to the revolutions of the propeller shaft.

TEST METHODS AND PROCEDURE

This section will describe briefly the manner in which the trial procedure was coordinated and will outline the different types of ship operations performed during the trials.

The vibration trials were directed by the coordinator from the trial-board room. A phone talker, detailed by the Commanding Officer, was stationed at each measurement station. The talker phone and trial-board phones were interconnected on a special circuit. A loudspeaker in the trial-board room, also wired into the special circuit, obviated the necessity of using a headphone. This proved to be a great convenience, especially as some of the trials ran continuously over a period of as much as 8 hours. It permitted the coordinator to hear everything that was said over the circuit without having to depend on his talker.

Vibration measurements were made during the following operations:

1. Steady-speed runs.
2. High-speed turns with full rudder.
3. Crash-astern—crash-ahead operation.

During the steady-speed runs the shaft speed was varied from 90 RPM to full-power RPM in increments of 10 RPM. The RPM was held steady at each speed, with the rudder amidships, until the vibration readings were completed. The deviation of the rudder from the amidships position was not more than 3 degrees during the steady-speed runs.

During the high-speed turns the vessel made full-power RPM, with the rudder amidships; the rudder was then brought hard over and maintained in that position until the vessel had completed a 360-degree turn. Starboard and port turns were made. Measurements were started as soon as the rudder was brought over.

During the crash-astern - crash-ahead operation the vessel crashed from full-power RPM ahead to full-power RPM astern. After reaching a steady speed astern the vessel crashed to full-power RPM ahead.

Additional steady-speed runs were made in order to determine more accurately the critical frequencies of the machinery and the flight deck.

An additional run was made at the resonance frequency of the flight deck during operation with four-bladed propellers, in order to obtain sufficient data to estimate the structural coupling between the flight deck, gallery deck, and hangar deck.

Measurements were made at the following stations during the steady-speed runs:

1. Along the centerline of the flight deck directly above the bents.
2. Along the centerline of the hangar deck directly below the flight-deck stations.
3. At the fantail.
4. At the bow.
5. At the flight-deck expansion joint, Frame 46 1/2.
6. At the pedestals of the radar antennas.
7. At the present and former locations of Radio Room III, on the gallery deck.
8. At several locations on the Main-Battery Director 3, the port and starboard after Mark-51 directors, and the port and starboard Mark-57 directors on the bow.
9. On the main switchboards in Switchboard Room 4.
10. At the main thrust bearings of Shafts 1, 2, 3, and 4.
11. At several locations on the Main Propulsion Units 1, 2, and 3.

The several structures were expected to attain their maximum amplitudes of vibration during either the high-speed turns or the crash-astern-crash-ahead operation. Furthermore, one or more of the natural frequencies of the structure were expected to be shock-excited during the crash-astern or the crash-ahead.

TEST RESULTS AND DISCUSSION OF RESULTS

This section presents, analyzes, and discusses the results obtained at each of the several stations. The severity of the vibration is evaluated and possible means of attenuation are suggested.

MAIN DECK

Vertical vibration amplitudes were measured along the centerline of the main deck with an Askania recording vibrograph. The frame numbers at which the measurements were made are indicated in Figure 1, which shows the maximum single amplitudes observed during the steady-speed runs plotted on a basis of longitudinal location along the deck. It is evident that the three-bladed propellers caused larger vibrations than the four-bladed propellers, with the notable exception of the location between Frames 159 and 176. The severe vibration encountered in this region was reported in Reference (4). In order to obtain a clearer picture of the extent of this vibration, a more detailed survey was made of the motion of these deck panels. The results of this survey are presented graphically in Figure 2. The amplitudes given in this figure for the three-bladed-propeller operation are the maxima observed during the steady-speed runs; they are considered to be of tolerable magnitude. When the vessel operated with four-bladed propellers, the amplitudes observed during steady speeds were excessive at speeds of 170 RPM and above; the maximum amplitudes were reached at 200 RPM.

The maximum amplitudes occurred during the crash-back, at which time the following single amplitudes were observed at the centerline of Frame 169: 25 mils, three-bladed propellers; and 80 mils, four-bladed propellers.

An inspection of Figure 2 shows that the amplitudes are rather small directly above the stanchions. The centerline of the deck, Frame 169, is subjected to the largest vibrations.

The main-deck section extending from Frames 167 to 171, 12 feet to port and to starboard of the centerline, is, for purposes of the following approximate analysis, considered to comprise several longitudinals simply supported by the heavy transverse deck beams at Frames 167 and 171.

The longitudinals are constructed as follows: The web of a 10-inch by 8-inch by 33-pound I-section, one flange of which has been removed, is welded to the main deck, which consists of two 40-psf courses of Special-Treatment Steel. These longitudinals are spaced about 60 inches on centers. A strip of deck plating 60 inches wide may be assumed to be acting with the longitudinal; see page 110 of Reference (9). The fundamental frequency of this longitudinal is calculated to be about 810 CPM. The maximum single amplitude of the panel was 58 mils at the centerline of the deck, Frame 169, during the 200-RPM steady-speed run with four-bladed propellers. At maximum power, the single amplitude at this location decreased to 30 mils. It is believed that the natural frequency of this deck structure is very nearly 800 CPM. At a shaft speed of 200 RPM the blade-frequency excitation is 800 CPM and is so close to the natural frequency as to induce severe vibrations. At

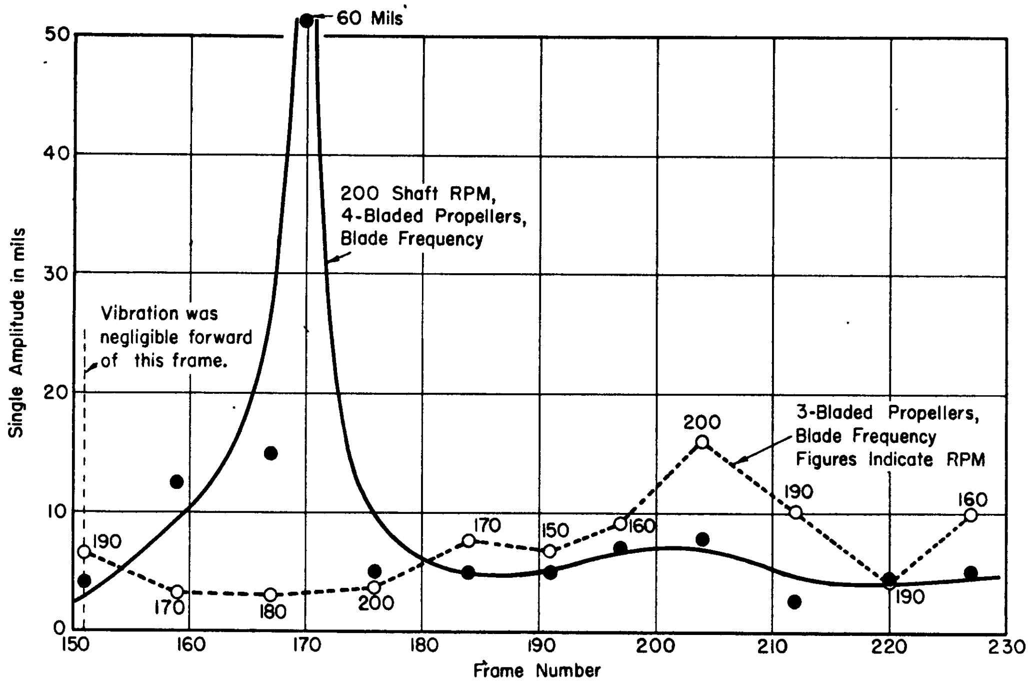


Figure 1 - Maximum Vertical Vibration Measured at the Centerline of the Main Deck of the USS MIDWAY (CVB41)

These measurements were made with an Askania vibrograph.

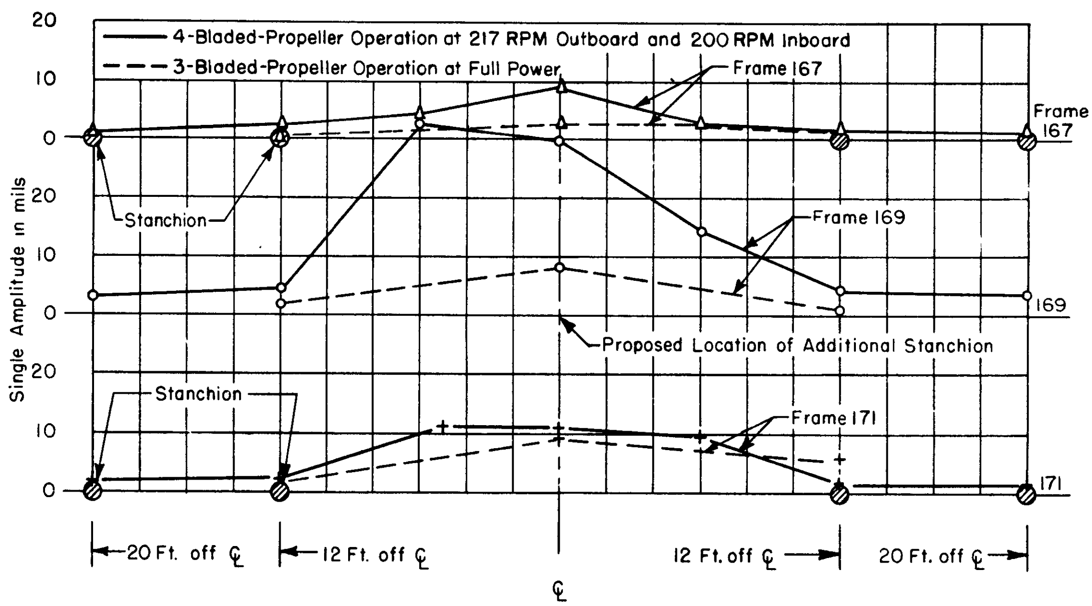


Figure 2 - Amplitudes of Vertical Vibration of the Main-Deck Plating between Frames 167 and 171 Measured on the USS MIDWAY (CVB41)

The measurements were made with an Askania vibrograph.
The vibrations were at propeller-blade frequency.

maximum power, the outboard shafts were making about 217 RPM with the inboard shafts turning near 200 RPM. Since the amplitudes measured were less at this speed than at 200 RPM, it may be assumed that the critical frequency lies near 800 CPM. The level of this panel vibration was greatly reduced when three-bladed propellers were installed because the blade-frequency exciting forces did not closely approach the resonance frequency of the panel. The stresses in the longitudinals corresponding to the large vibration amplitudes are not in themselves very dangerous; however, when stress concentration, endurance limit, and superimposed hull stresses are considered, it is apparent that these vibratory stresses may be of considerable importance. These large vibrations created undesirable noise and affected adversely the comfort and the operating efficiency of personnel. The crew's galley is located directly below the vibrating structure, and the ventilating ducts, piping, lagging, and galley equipment are shaken severely.

It is believed that the vibration experienced with four-bladed propellers could be greatly reduced by adding a stanchion at the centerline of the deck, Frame 169, and carrying this stanchion down into the inner bottom structure. Another way of solving the problem would be to install a deep transverse beam at Frame 169 similar to that at Frame 167 or 171.

FANTAIL

The amplitudes of vertical and transverse vibration measured at the fantail, when either three- or four-bladed propellers operated, are plotted on a basis of propeller RPM in Figure 3. The vertical vibration passes through a rather well-defined resonance near 180 RPM and near 100 RPM when three-bladed propellers are used. The maximum vertical amplitudes observed at any time were measured during the crash-back; however, the motion exceeded the capacity of the vibration recorder. The vibrations were greater than 83 mils, single amplitude. The three-bladed propellers excite a definitely higher level of vibration than the four-bladed propellers. This test did not give definite data for the determination of the fundamental flexural frequencies of the hull girder. This frequency is most easily obtained by means of shock excitation, as by dropping and snubbing of the anchor.

BOW

Vertical, transverse, and longitudinal accelerations were measured at Frame 5 on the forecastle deck. The accelerations at this location were very small during the steady-speed runs, being of the order of 0.05 g, which indicated a smooth sea.

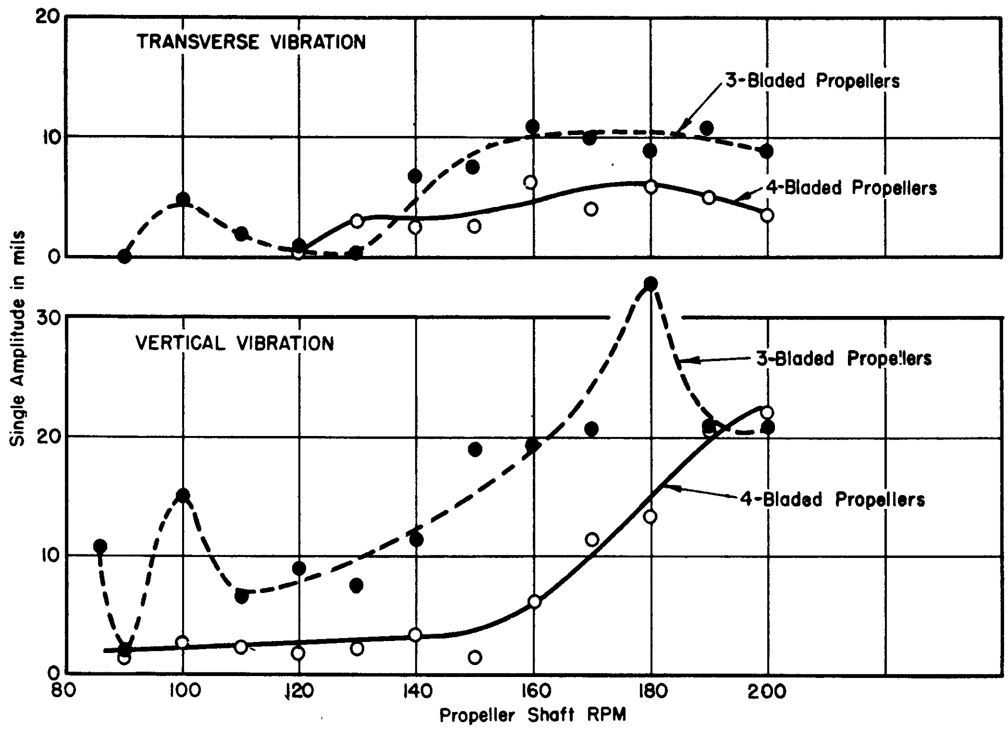


Figure 3 - Fantail Vibration of the USS MIDWAY (CVB41)

The Type V pallograph 100131 was used to record vertical vibrations and the Type B pallograph was used to record transverse vibrations. The vibrations were at propeller-blade frequency.

The maximum accelerations were observed during the crashes. With the three-bladed-propeller operation the peak acceleration in the vertical direction was 0.19 g single amplitude at a 250-CPM frequency and in the transverse direction 0.15 g single amplitude at a 290-CPM frequency. With four-bladed-propeller operation the peak acceleration in the vertical direction was 0.08 g single amplitude at 440 CPM and in the transverse direction 0.12 g single amplitude at 290 CPM. The frequencies noted during the crashes were 340 CPM, 250 CPM, 290 CPM, and 440 CPM in the vertical direction; 290 CPM, 340 CPM, and 390 CPM in the transverse direction; and an 800-CPM frequency in the longitudinal direction. This 800-CPM frequency is believed to correspond to the fundamental mode of longitudinal vibration of the hull. This is believed to be the first time that such a mode of vibration has been recorded on a naval vessel.

FLIGHT DECK

On the flight deck, vertical-vibration amplitudes were recorded with an Askania vibrograph along the centerline of the deck and at the center and off the starboard side of the forward and after elevators. In addition, some transverse vibrations were recorded. The flight deck consists of five sections separated by expansion joints. Each one of these sections acts as an independent structure; there is no direct transmission of forces across the expansion joints.

Vertical-vibration amplitudes were measured during several steady-speed runs; they are plotted on a basis of fore-and-aft location along the deck in Figures 4 and 5 for four- and three-bladed-propeller operation respectively. An inspection of these figures shows that the vibration of the aftermost section of the flight deck passes through a critical frequency near a propeller speed of 170 RPM.

A vibration-generator test was made on the flight deck of the CVB41 during the vessel's construction period (10), in order to determine the vibration resonances of the deck structure. The essentials of that test follow.

The longitudinal and transverse bulkheads of the gallery deck divide the flight deck into panels 16 feet long by 48 feet 9 inches wide. Panels are located on each side of the centerline of the deck. The lowest mode of

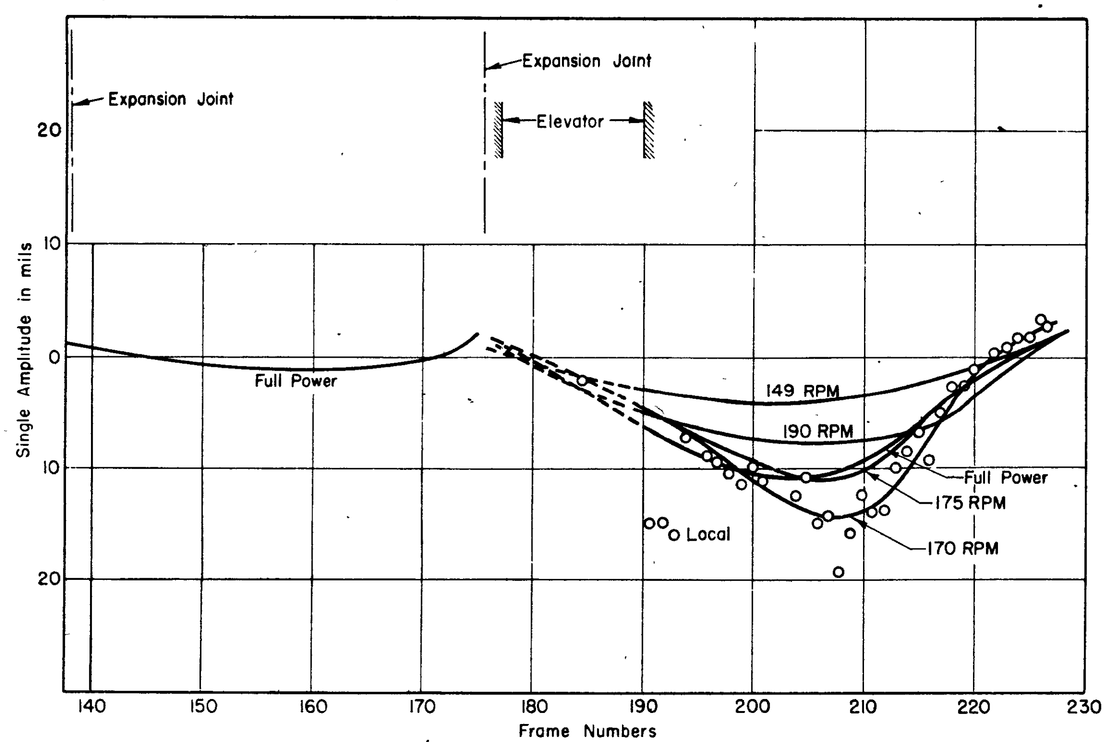


Figure 4 - Vertical-Vibration Amplitudes of the Flight Deck of the USS MIDWAY (CVB41) Fitted with Four-Bladed Propellers

These measurements were taken at the centerline of the deck with an Askania vibrograph. All vibrations plotted are of propeller-blade frequency. The phase relationships between deck sections are unknown. The measured vibration amplitudes were negligible forward of Frame 135.

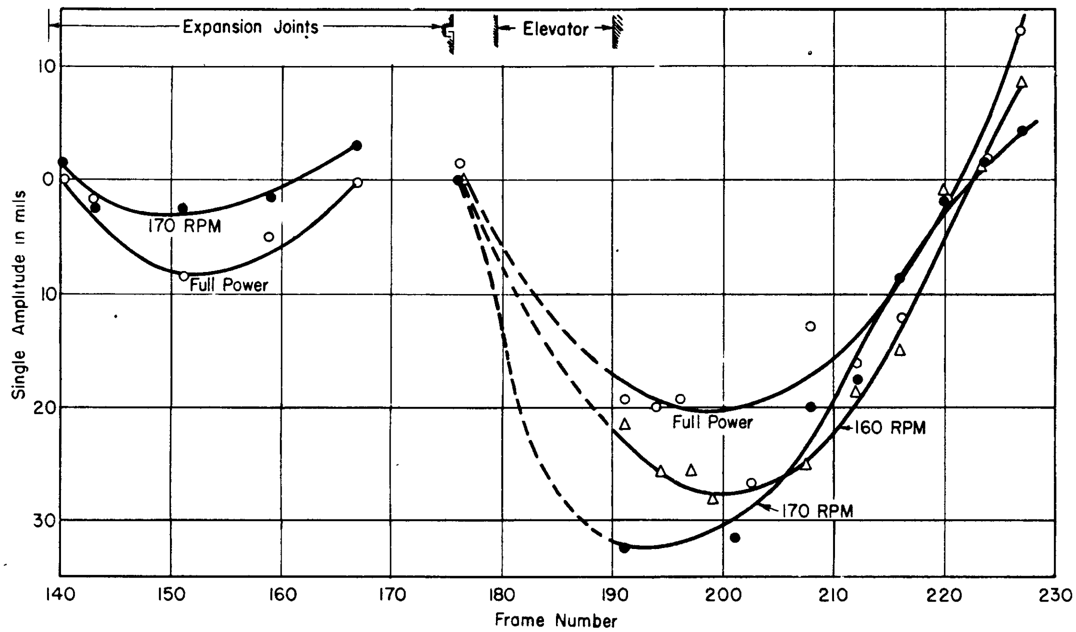


Figure 5 - Vertical-Vibration Amplitudes of the Flight Deck of the USS MIDWAY (CVB41) Fitted with Three-Bladed Propellers

These measurements were taken at the centerline of the deck with an Askania vibrograph. All vibrations plotted are of propeller-blade frequency. The phase relationships between deck sections are unknown. The measured vibration amplitudes were negligible forward of Frame 135.

vibration of the panel tested, when excited by means of a vibration generator located at the center of a panel near Frame 115, occurred at 625 CPM. After the vibration of a panel of armor had been investigated, the vibration generator was mounted directly over the bent, Frame 115, on the fore-and-aft centerline, where it produced vertical flexural vibrations of the armor-and-bent combination. The combined armor and bent was found to resonate at 510 CPM. The flight-deck armor plating forward of the after elevator is heavier than that aft of the elevator. The aftermost flight-deck section is therefore expected to have a somewhat different natural frequencies.

From the foregoing discussion, the motion of the flight deck may be analyzed. Both the CVB41 and the CVB42, when fitted with three-bladed propellers, evidenced a rather well-defined resonance of the flight deck near a propeller speed of 170 RPM, which corresponds to 510 CPM. It may be concluded on the basis of the vibration-generator tests that this critical frequency represents the fundamental vertical flexural resonance of the armor-and-bent combination. This resonance is excited by three-bladed propellers at 170 RPM and by four-bladed propellers at about 127 RPM. Practically, the resonance occurring at 127 RPM with four-bladed propellers is of no consequence, since the exciting propeller-blade forces are small and the damping is of sufficient magnitude to keep the amplitude negligible. When three-bladed propellers are used, however, the critical frequency occurs near the top speed of the vessel, where the propeller-blade exciting forces are relatively large and result in severe vibration, as may be seen by inspecting Figure 5 of this report and Figure 1 of Reference (2).

With four-bladed-propeller operation, a critical frequency of the vertical vibration of the flight deck was again found to occur near a propeller-shaft speed of 170 RPM, which corresponds to 680 CPM. The vibration-generator test, referred to previously, had shown that the gravest resonance frequency of the armor-deck panel occurred near 625 CPM. The discrepancy is probably due to the difference in thickness of the armor plating between the aftermost and the forward flight-deck sections.

Since the measurements plotted in Figure 4 were made along the longitudinal centerline of the deck and since, in general, the motion at the centerline was greater than that outboard of the centerline, it may be deduced that the observed 680-CPM resonance frequency represents that mode of vibration of the entire after flight-deck section in which the armor-plate panels are vibrating in their fundamental mode as plates. The figure of 680 CPM is accurate to within 20 CPM.

Comparison of amplitudes of vibration shows that the flight-deck vibration is much less with four-bladed propellers than with three-bladed propellers.

According to Reference (10) the most serious vibration on the flight deck is to be expected in the panels. The results of this vibration survey show, however, that the vibration of the deck-and-bent combination is of greater magnitude than the panel vibration when three-bladed propellers are fitted.

The largest vertical-vibration amplitudes were observed during the crash-back—crash-ahead operation, at which time 148 mils single amplitude of 360-CPM frequency was measured at the center of the bent, Frame 204, with three-bladed-propeller operation. During the crash-back operation with four-bladed propellers 160 mils single amplitude of about 460-CPM frequency was recorded at the center of the bent, Frame 197.

STRUCTURAL COUPLING BETWEEN FLIGHT DECK, GALLERY DECK, AND MAIN DECK

Reference (11) requested that a study be made of the vibration data obtained during the vibration trials of the CVB42, in order to determine the advisability of a proposed relocation of Radio Room III and of the radio stores from Frames 155 to 158, starboard, to Frames 204 to 208, starboard, on the gallery deck. The Taylor Model Basin (6) advised against the relocation. This decision was based on the following reasoning:

The gallery deck is structurally supported by bents, which also support the flight deck. Therefore the overall motion of the gallery deck is essentially determined by the motion of these bents. Each bent is rigidly attached to the flight deck and therefore moves with the flight deck. The vibratory motion of that part of the gallery deck and flight deck which is located in the immediate vicinity of the vertical columns of the bents will be proportional to the motion of the main deck. On the other hand, the motion at the centerline of the gallery deck should be the same as the motion at the centerline of the flight deck. Since the radio rooms are located somewhere between these two positions, the intensity of the vibration in the radio rooms was expected to be somewhere between that obtained at the center location and the outboard location of the gallery deck.

In order to ascertain the correctness of this reasoning, it was decided to make a more thorough determination of the motion of the several decks. It was possible to make such a survey during four-bladed-propeller operation only. For this purpose the vessel was operated at a propeller speed of 170 RPM, which is the speed at which the flight deck resonates. Measuring stations had been laid out on the three decks so that for each station located above a bent on the flight deck, another station was located directly below that bent, on both the gallery and the main decks. It was found possible, during this test, to take additional measurements at the centerline of the flight deck. Measurements were taken at the stations indicated on Figure 6. Three stations were located at each of these bents - one at the centerline of the deck, one in the immediate vicinity of the vertical column of the bent, and the third midway between the centerline and the outboard station.

The vibration amplitudes measured at the several locations on each of the three decks are plotted in Figure 6. The vibration was not constant over any length of time but waxed and waned even though the propeller speed remained constant. This explains some of the erratic points plotted in Figure 6, especially for the gallery deck and the main deck where fewer measurements were taken than on the flight deck. The data presented in Figure 6 have been evaluated with due consideration of the transient character of the vibration. The centerline, the outboard edge, and the midpoint of the flight and gallery decks were subjected to the same motion. The motion of the outboard edge of the main deck is similar to that of the gallery and flight decks. The other two groups of main-deck stations, however, do not have the same motion as the outboard edge. This indicates that all points on the main

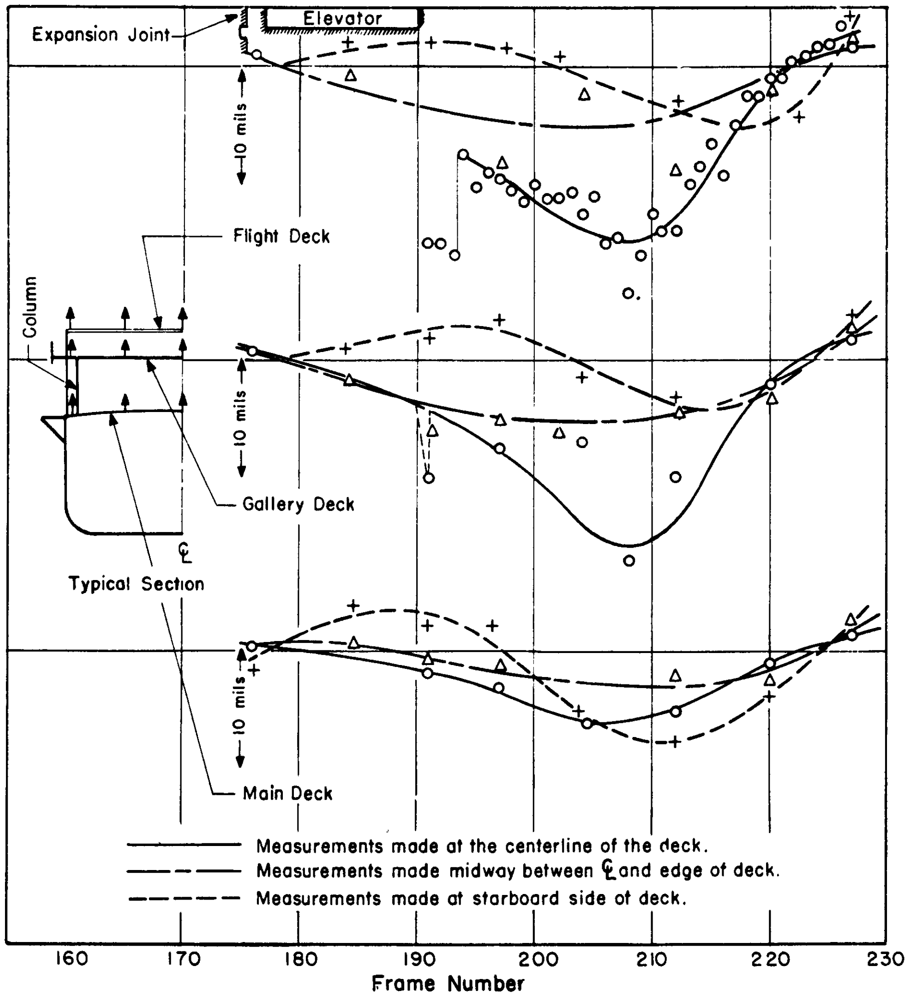


Figure 6 - Vertical Vibration Measured on the Flight Deck, Gallery Deck, and Main Deck of the USS MIDWAY (CVB41) Fitted with Four-Bladed Propellers

The measurements were made with an Askania vibrograph.
The vibrations were of propeller-blade frequency.

deck do not move in unison as the top flange of a beam in vertical flexure would. The difference may be attributed to local vibrations, the transient character of the vibration, and possible torsional oscillation of the ship girder.

It may be concluded from these data that the original assumptions made (6) were valid, that is, the gallery deck and the flight deck are subjected to the same motion and therefore act as a box girder. The portion of the main, gallery, and flight decks in the vicinity of the vertical columns of the bents have the same character of motion although the amplitudes at the main deck are generally higher than those at the flight and gallery decks. This difference is believed to be due to the strains in the legs of the bent resulting from the alternating compressive stresses in the bents. Stresses corresponding to these strains would be of the order of a few hundred pounds per square inch.

We may further conclude from this analysis that data such as plotted in Figures 4 through 6 may be used to determine the relative severity of vibration to be expected at any location on the gallery deck. These figures also show that the vertical vibration of the aftermost major flight-deck section, considering a major section to extend the entire distance between expansion joints, is a maximum near the center of the section, and that the proposed new location of Radio Room III, as well as the former location, is in one of these unfavorable areas. If gallery-deck installations that require relative freedom from vibration are desired, they should be located near the expansion joints, or forward of Frame 130. It must be remembered that this analysis applies to the main structural members and that local deck or panel vibrations may and do occur.

In Reference (12) the results of a series of structural tests on the flight deck of the CVB42 are discussed. During these tests concentrated loads were applied at certain points of the flight deck, and the resulting strains were measured. Some of these loads were applied near stations corresponding to those at which vibration measurements were made on the CVB41. Although this loading is different on the two vessels, the data may be compared to give an approximate idea of the existing stresses. For equal deflections at the center of a simple beam, the stresses are about 25 per cent higher for concentrated loading than for a uniformly distributed load. During the present tests the maximum vibration amplitudes were found to be excited with three-bladed propellers, near Frame 200; see Figure 5. The alternating-stress range corresponding to this vibration would be approximately between plus 1600 and minus 1600 pounds per square inch; this value is based on a comparison with the measurements given in Reference (12).

These stresses are not large. However, when combined with stress concentration and superimposed on dead-load and plane-landing stresses, the vibratory stresses may require consideration. During crash-ahead and crash-astern operation the vibratory stresses may attain dangerously high values, of the order of ten times the maximum stresses encountered during steady-speed runs.

FLIGHT-DECK EXPANSION JOINT AT FRAME 46 1/2

The Bureau of Ships, Code 440, requested orally that the Taylor Model Basin make measurements of the motion across the forward flight-deck expansion joint during the vessel's standardization and vibration trials.

These measurements were desired in order to determine whether this joint could be eliminated for purposes of longer catapult-track installations. The Bureau of Ships was interested in the gross motion only and did not require time-displacement data. It was, however, believed desirable to obtain time-displacement data, at least during the high-speed turns and during the crash-back in order to determine the amplitudes and frequencies of shock-excited natural modes of vibration. In order to measure the maximum motions that would occur in heavy seas, which were not likely to be encountered during the subject trials, it was decided to leave the measuring apparatus aboard ship for a period of about six months and to instruct the ship personnel in reading the gages at regular intervals.

The instrumentation used was very simple and rugged. A set of three scratch gages was installed on both the port and the starboard side of the expansion joint to measure the longitudinal, vertical, and transverse motion across the expansion joint. The instrumentation is illustrated in Figure 7.

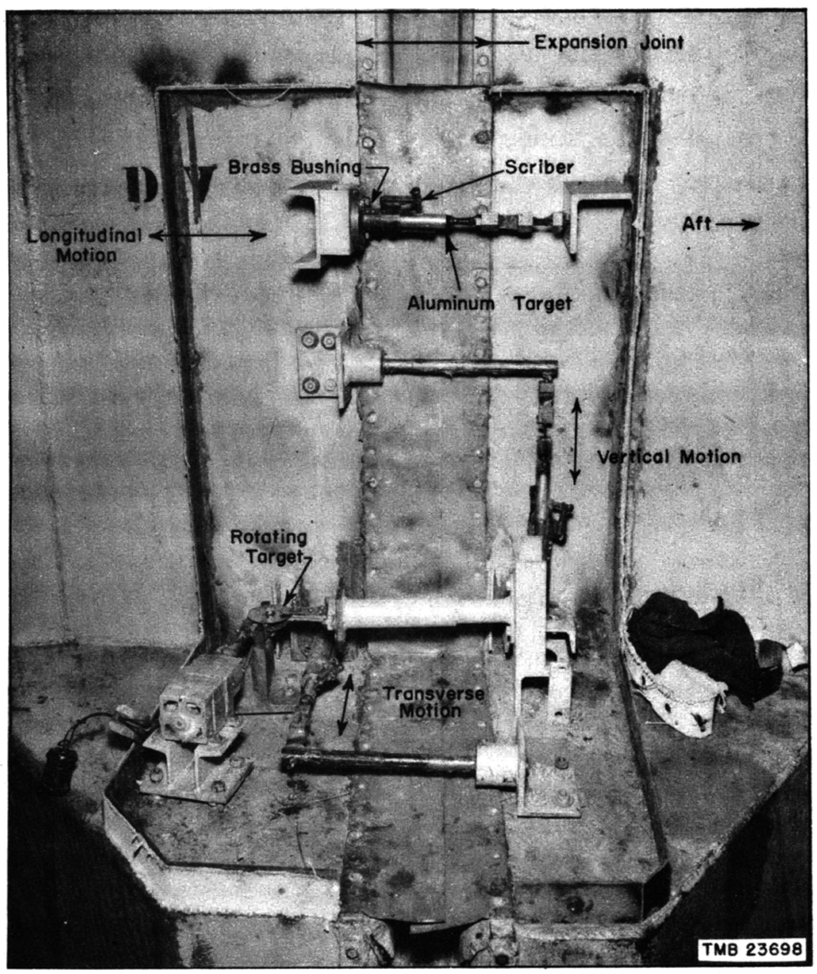


Figure 7 - Instrumentation at the Flight-Deck Expansion Joint of the USS MIDWAY (CVB41)

The scratch gage essentially consists of a brass bushing attached to one side of the expansion joint and an aluminum target which slides in this brass bushing and is attached to the other side of the expansion joint. A spring-loaded scriber, attached to the brass bushing, presses against the aluminum target, and any relative motion between the two sides of the expansion joint is recorded as a scratch on the aluminum target. In order to obtain time-displacement records during the high-speed turns and the crash-backs, a similar instrument was installed to measure longitudinal motion across the joint. This scratch gage was equipped with a moving circular target. The circular target made a complete revolution in 2 minutes. Figure 8 shows a typical record obtained during the high-speed starboard turn, three-bladed-propeller operation.

The maximum longitudinal motion across the joint during the period of the trials was 3/8 inch on both the port and the starboard side. The vertical and the transverse motions across the joint were less than 1/16 inch during the same period. The maximum vibratory longitudinal motion measured during the steady-speed runs was about 50 mils single amplitude, with both three- and four-bladed propellers. The amplitudes and frequencies of vibration measured during high-speed turns and crash operations are shown in Table 1.

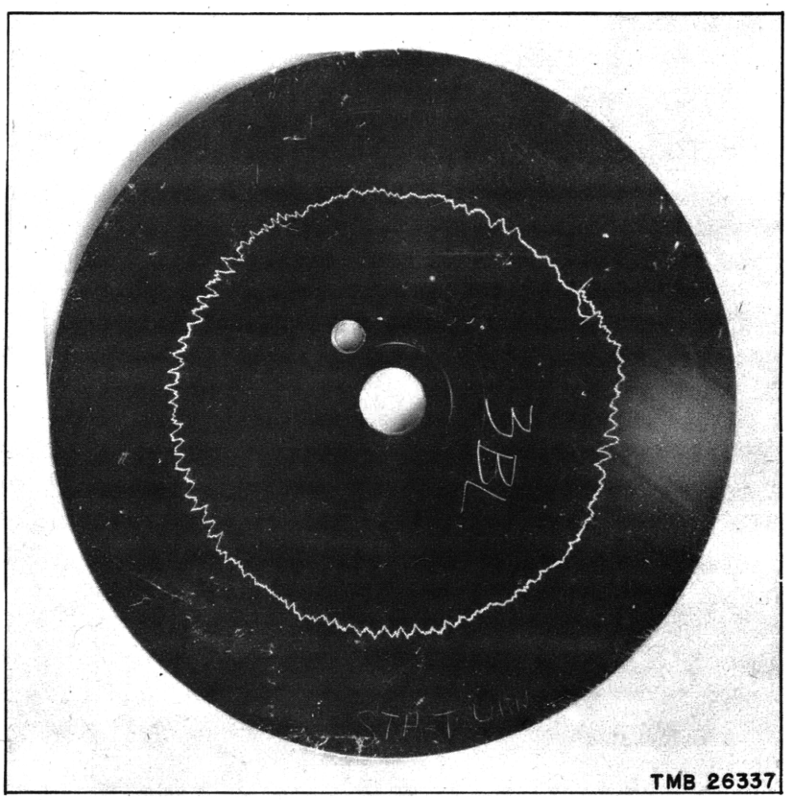


Figure 8 - Typical Scratch-Gage Record Obtained at the Expansion Joint, Frame 46 1/2, of the USS MIDWAY (CVB41) during the High-Speed Turn to Starboard

TABLE 1

Vibratory Motions across Forward Expansion Joint of the CVB41 during Crashes and Turns

Operation	Number of Propeller Blades	Single Amplitude of Longitudinal Vibration mils	Frequency CPM
Turn, starboard	4	30 16	45
Turn, starboard	3	20	45
Turn, port	4	25	45
Turn, port	3	30	45
Crash-back	4	13 20	360 45
Crash-back	3	26	360
Crash-ahead	4	120	95

Frequencies of 45, 95, and 360 CPM are seen to recur during these operations. They are believed to be shock-excited natural frequencies of the flight-deck section vibrating fore and aft on its bents.

The total displacements across the expansion joint measured during these trials are small. It is possible, however, that these motions may be much greater when the ship encounters heavy seas.

MAIN THRUST BEARINGS 1, 2, 3, and 4

One of the primary objectives of these trials was the determination of the resonance frequencies of the main propulsion system and evaluation of the effectiveness of the new type of thrust bearing which had been installed in this class of ships. A detailed study of the vibration of the propulsion system of the CVB41 Class of carriers, as well as a comparison of this class with previously studied classes of battleships, will be made in a later Taylor Model Basin report. For the purposes of the present report, only the more salient aspects will be discussed.

The propulsion system may be considered to consist of the propeller with its entrained water at one end of the main shaft and the bull gear with its pinions at the other end. Between the propeller and the gears is the thrust bearing and its pedestal, which connect the propulsion system to a large mass, i.e., the ship. In this analysis it is assumed that the turbine is effectively isolated from the bull gear by means of flexible couplings.

The spring constants of the port inboard and the port outboard main thrust bearings of the CVB41 were determined experimentally in June 1945 and were reported to the Bureau of Ships (13). The values of the spring constants determined by such a test are subject to considerable error. The longitudinal rigidities of the main thrust bearings as reported to the Bureau of Ships were 16,700,000 pounds per inch for the port outboard block and 18,800,000 pounds per inch for the port inboard block. The natural frequencies of the first and second mode of vibration, as calculated on the basis of these spring constants, are given in Table 2.

TABLE 2

Natural Modes of Vibration of the Main Propulsion Units of CVB41

Propulsion Unit	First Mode CPM	Second Mode CPM	R = Amplitude of Bull Gear / Amplitude of Thrust Bearing		Spring Constant of Thrust Bearing pounds per inch
			First Mode	Second Mode	
1, 4	860	1230	1.56	3.73	16,700,000
2	560	860	8.12	-0.94	18,800,000*
3	720	900	4.17	-5.66	18,800,000

* The spring constant for Thrust Bearing 2 is assumed to be the same as the experimental value for Thrust Bearing 3.

Amplitudes of longitudinal vibration of the four thrust bearings measured during the steady-speed runs are plotted on a basis of propeller RPM in Figures 9 through 12. Each figure presents the vibration data for both the three-bladed- and the four-bladed-propeller operation, thus permitting direct comparison of the vibration amplitudes obtained with the two propeller systems.

The longitudinal vibration of the thrust bearings was measured by means of seismic instruments, such as the pallograph and the Geiger vibrograph, as well as by means of electrical velocity pickups. The output of the velocity pickups was integrated and recorded on a direct-inking Brush oscillograph. A typical installation is illustrated in Figure 13.

Longitudinal vibrations of twice the propeller-blade frequency were recorded on Thrust Bearings 2 and 3 at a propeller-shaft speed of about 110 RPM during four-bladed-propeller operation. In order to determine these longitudinal resonances with greater accuracy, it was decided to operate the snaft to be tested at small increments of RPM while the other three shafts

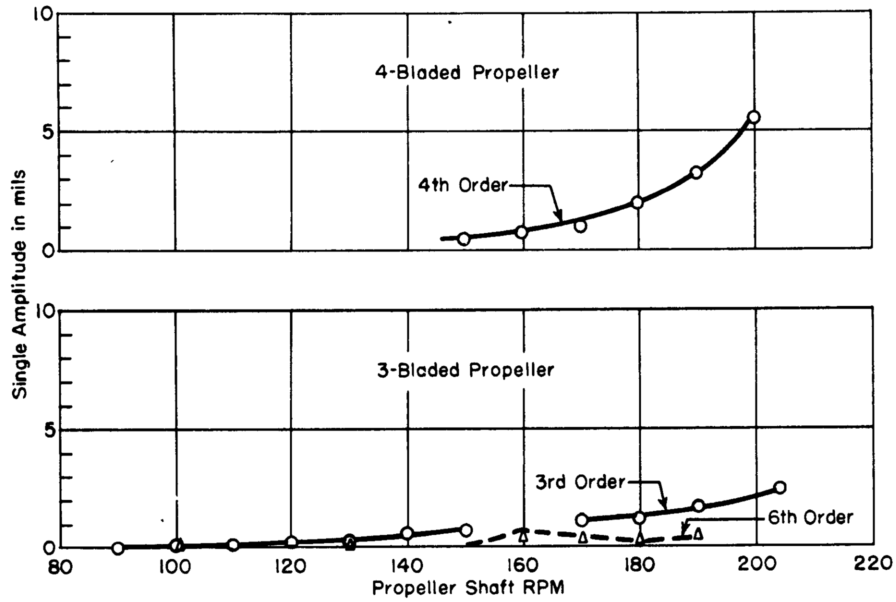


Figure 9 - Amplitudes of Longitudinal Vibration Measured at Thrust Bearing 1 of the USS MIDWAY (CVB41)

A Type C pallograph was used to measure the vibration with the four-bladed-propeller installation. A Consolidated Engineering Company pickup Type 4-102 was used to measure the vibration with the three-bladed-propeller installation.

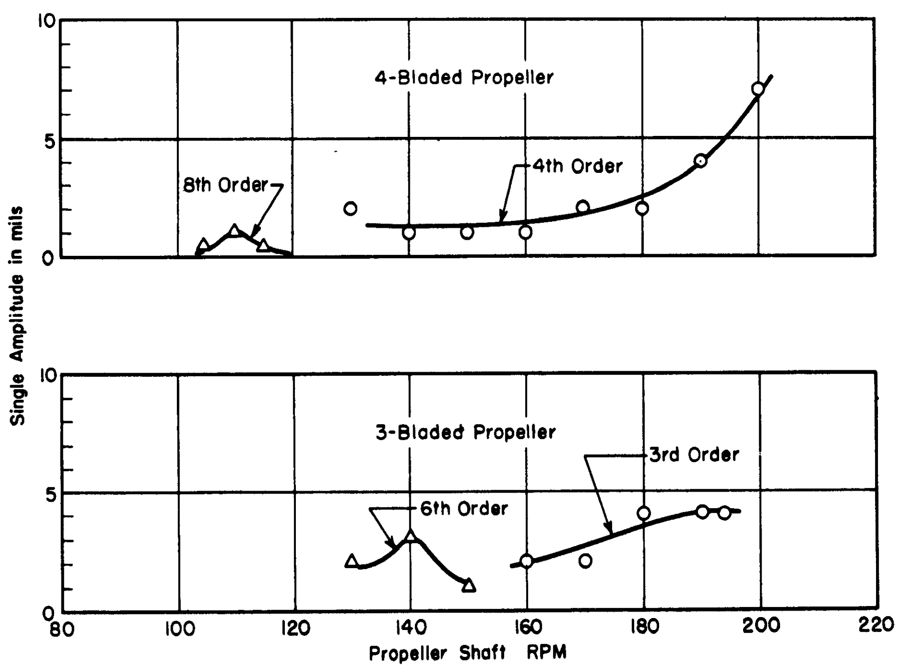


Figure 10 - Amplitudes of Longitudinal Vibration Measured at Thrust Bearing 2 of the USS MIDWAY (CVB41)

These vibrations were recorded with a Geiger vibrograph.

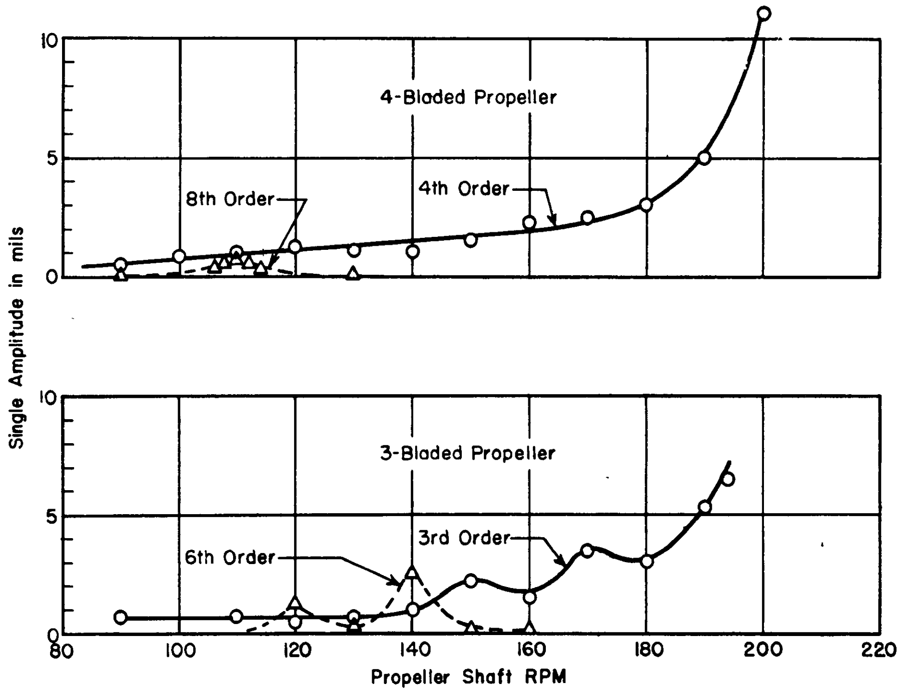


Figure 11 - Amplitudes of Longitudinal Vibration Measured at Thrust Bearing 3 of the USS MIDWAY (CVB41)

These measurements were made with a Consolidated Engineering Company pickup Type 4-102 and were recorded on a Brush oscillograph.

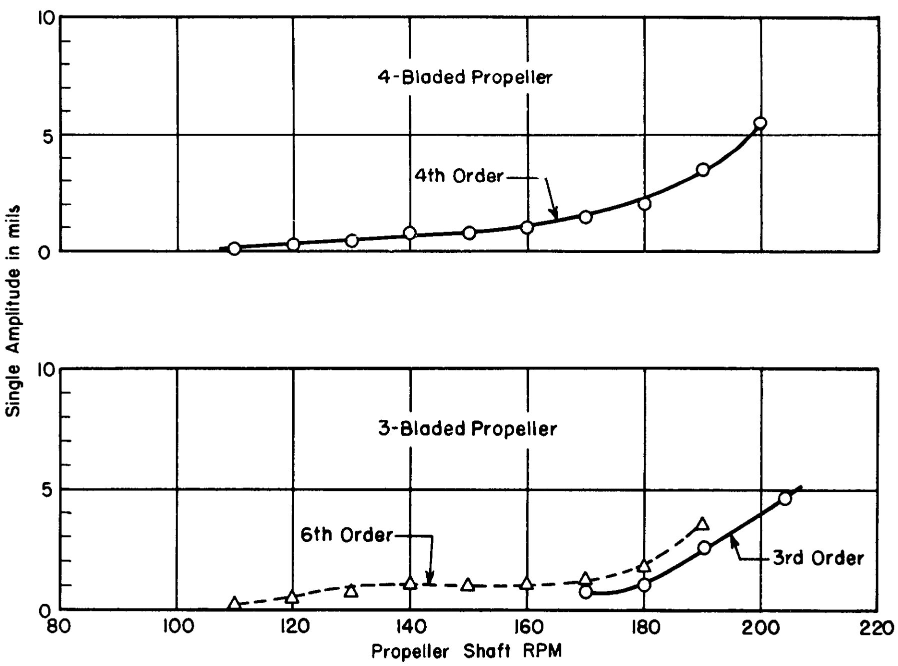


Figure 12 - Amplitudes of Longitudinal Vibration Measured at Thrust Bearing 4 of the USS MIDWAY (CVB41)

These measurements were made with a Type V pallograph converted to horizontal operation.

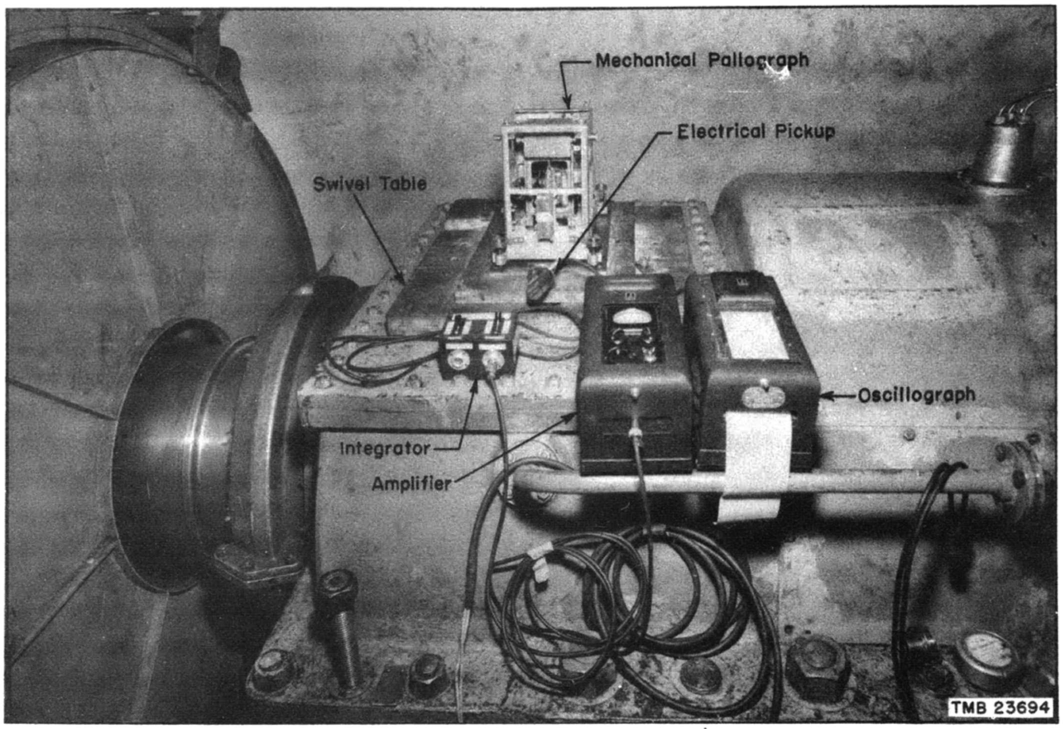


Figure 13 - Instrumentation for Measuring the Vibration Amplitudes of the Main Thrust Bearings of the USS MIDWAY (CVB41)

were rotating at a lower constant RPM. As a result of this procedure it was possible to determine a definite eighth-order resonance of longitudinal vibration of Shafts 2 and 3, which occurred at about 110 propeller RPM, corresponding to a frequency of 880 CPM. These resonances correspond to the second mode of longitudinal vibration for both Shafts 2 and 3. Shaft 2 is longer than Shaft 3 and therefore the resonances of these shafts are not expected to occur at the same frequency. The figure 880 CPM is accurate within 30 CPM.

When three-bladed propellers were fitted, the same resonance was in evidence as a sixth-order vibration near 140 RPM, corresponding to a frequency of about 840 CPM. Shaft 1 evidenced a sixth-order critical frequency at a shaft speed of 204 RPM, corresponding to the second mode of longitudinal vibration at about 1230 CPM. It was impossible to make additional runs for a more accurate determination of these critical frequencies during the trials with three-bladed propellers.

There should be no appreciable difference between the frequency of the resonances whether three- or four-bladed propellers are fitted, since the weights of these propellers are very nearly the same. The critical frequencies, as determined from the four-bladed-propeller operation, are considered more accurate owing to the greater care taken in their determination.

Axial vibrations of the main thrust bearings were induced by shock excitation during the crash-astern and crash-ahead operation. Such shock excitation generally induces vibration in the natural modes of the system. Table 3 gives the more important data obtained during the crashes.

TABLE 3

Shock-Excited Frequencies at the Main Thrust Bearing

Thrust Bearing	Number of Propeller Blades	Frequencies Excited CPM	Single Amplitudes Measured mils	Mode of Vibration
1	4	870-910	10	First
1	3	900	7.5	First
3	4	930	5.5	Second
3	3			
4	4	870-900	5.6	First
4	3	880	7.5	First

At full-power RPM, when the vessel is operated with four-bladed propellers, Propulsion Units 2 and 3 operate near the second-mode resonance and Propulsion Units 1 and 4 approach the first mode of longitudinal vibration. None of the four thrust bearings gave any indication of passing through the first mode of longitudinal vibration during either three- or four-bladed-propeller operation.

In order to determine the effect of variation of the thrust-bearing stiffness on the natural frequency of the system, an electrical analogy of the simplified three-mass propulsion system was set up in the vibration laboratory at the Taylor Model Basin. It was found that decreasing the rigidity of the thrust bearing to 1/10 of its former value resulted in a decrease of less than 5 per cent in the frequency of the second-mode vibration and a 60 per cent decrease in the frequency of the first-mode vibration. Only the second mode of vibration was observed during the field tests. The first mode of vibration and the thrust-bearing stiffness cannot be evaluated on the basis of the measured value of the second-mode natural frequency alone, since a small error in the value of this frequency will result in a large error in the value of the unknowns. These unknowns must be determined from measured amplitude and phase relationships. This determination will be made in a future report.

It is concluded that Propulsion Units 1 and 4 have natural frequencies of longitudinal vibration near 880 CPM, first mode, and about 1230 CPM, second mode. The second-mode critical of Propulsion Units 2 and 3 occurs near 880 CPM.

MAIN PROPULSION UNITS 1, 2, 3, AND 4

The primary purpose of measuring the vibration of the main propulsion machinery was to determine the effectiveness of the flexible couplings in their function of isolating the propeller-excited longitudinal vibration from the turbines.

The Main Propulsion Units 1 and 4 are physically similar; they are connected to the shortest propeller shafts. Propulsion Unit 2 is geared to the longest propeller shaft and Unit 3 to the shaft of intermediate length. Measurements of the vibration of the main propulsion units were made by the New York Naval Shipyard at Unit 2 and by the Westinghouse Corporation at Units 1 and 3.

The maximum single amplitudes of longitudinal relative motion between the turbine rotor and the turbine casing are given in Table 4, together with the measured turbine thrust-bearing clearances. Analysis of the tabulated data shows that all turbine thrust bearings, except the thrust bearing

TABLE 4

Longitudinal Relative Vibratory Motion between Turbine Rotor and Turbine Casing Measured at the Turbine Thrust Bearing

Propulsion Unit	Number of Propeller Blades	Turbine	Maximum Vibration*		Turbine-Bearing Clearance**	
			Single Amplitude mils	Corresponding Propeller RPM	mils	Date Measured July 1947
1	3	HP	2.0	204	15	15
	3	LP	1.0	204	12	29
2	3	HP	4.1	194	8	14
	3	LP	5.0	194	15	31
3	3	HP	2.0	194	14	29
	3	LP	3.0	194	14	29
1	4	HP	2	200	15	15
	4	LP	2	200	12	29
2	4	HP	5.0	200	8	14
	4	LP	10.0	200	15	31
3	4	HP	30.0	200	14	29
	4	LP	11.0	200	14	29
4					12	9
					16	9

* Longitudinal relative vibratory motion between turbine rotor and turbine casing was measured at the turbine thrust bearing.

** These readings were taken by means of dial indicators with the shaft jacked hard forward and hard aft. All clearances check within 0.001 to 0.002 inch of those taken during the overhaul period ending 4 April 1947. The design clearance is 0.007 inch at all bearings.

of Number 2 high-pressure turbine, have appreciably greater clearances than the design value of 0.007 inch. Thrust reversal is indicated at all turbine thrust bearings. Wherever the double amplitude of relative motion exceeds the turbine thrust-bearing clearance, the difference between the relative motion and the clearance must be absorbed by deflection of the bearing surfaces, the bearing housing, or the thrust collar. Under such circumstances severe pounding is probably taking place. This was the case at the turbine thrust bearing in Engine Rooms 2 and 3 during the high-speed four-bladed-propeller operation.

The vibration of the main machinery units was greatly reduced when three-bladed propellers were installed. The machinery was, in general, subject to less vibration than the corresponding units on the CVB42, if the ships are compared on a basis of three-bladed-propeller operation. The most marked improvement was that observed in Main Propulsion Unit 2, when a comparison is made with the CVB42 or with the four-bladed-propeller operation of the CVB41.

Critical frequencies of longitudinal vibrations of the machinery items, as determined from the steady-speed runs, are given in Table 5. These criticals were also in evidence at the main thrust bearings, as discussed in the Section "MAIN THRUST BEARINGS 1, 2, 3, AND 4." These modes of longitudinal vibration were shock-excited during the crash-astern and crash-ahead operation.

The conclusions given in the Section "MAIN THRUST BEARINGS 1, 2, 3, AND 4" apply also to this section. It is further concluded that the turbine thrust bearings in Engine Rooms 2 and 3 are subjected to pounding at the higher propeller RPM when the vessel is equipped with four-bladed propellers. Thrust is transmitted through quill shafts and the flexible couplings to the turbine rotors and therefore these couplings do not fully perform their function. The vibration amplitudes of the machinery units are considerably less with three-bladed propellers than with four-bladed propellers.

The flexible couplings should provide more efficient isolation of the turbine rotors from the main shafts; to this end methods of decreasing friction forces between the mating members of these couplings should be investigated. A frequent check of turbine thrust-bearing clearances should be made. The speed of Machinery Units 1 and 4 should be kept below 210 propeller RPM when operating with four-bladed propellers, in order to avoid a dangerous longitudinal resonance which will occur near 220 propeller RPM. At one time during the four-bladed-propeller operation the outboard shafts were turning at 217 RPM; observations of thrust variation at the main thrust bearings indicated large variations of thrust and consequent proximity to a longitudinal resonance of the propulsion system.

TABLE 5

Experimental Critical Frequencies of Longitudinal Vibration of the Main Propulsion Units, As Determined during the Steady-Speed Runs

Propulsion Unit	Number of Propeller Blades	Single Amplitude of Longitudinal Vibration mils		Propeller RPM	Frequency CPM	Mode of Longitudinal Vibration
		Main Thrust Bearing	Bull Gear			
1*	4	No evidence of critical				
4*	4					
1	3	Negligible	2	204	1230	2
2	4	1.0	2.5	110	880	2
2	3	3.0	8.0	140	840	2
3	4	0.8	3.0	110	880	2
3	3	2.5	4.0	146	880	2

* Propulsion Units 1 and 4 are physically similar.

MAIN-BATTERY DIRECTOR 3, MARK 37

The vibration characteristics of Main-Battery Director 3 were determined by means of rather extensive instrumentation. The director, on which the several stations are indicated, is shown in Figure 14.

The instrumentation comprised several velocity pickups manufactured by the Consolidated Engineering Company. The output of these pickups was recorded by means of a Consolidated Engineering Company oscillograph. The electrical connections were made so as to permit determination of the phase relations between the several motions. The director was trained aft during all measurements. The measurements were made at the stations and in the directions listed:

a. At the base of the director foundation, in the vertical and the transverse directions.

b. At the top of the director foundation, in the transverse direction.

c. On the deck of the director carriage, in the vertical and transverse directions.

d. At the center and the ends of the rangefinder tube, in the vertical direction only.

e. Near the rangefinder-tube bearing, in a direction along the axis of the rangefinder tube.

f. At the outboard end of the radar supporting bracket, in the vertical direction.

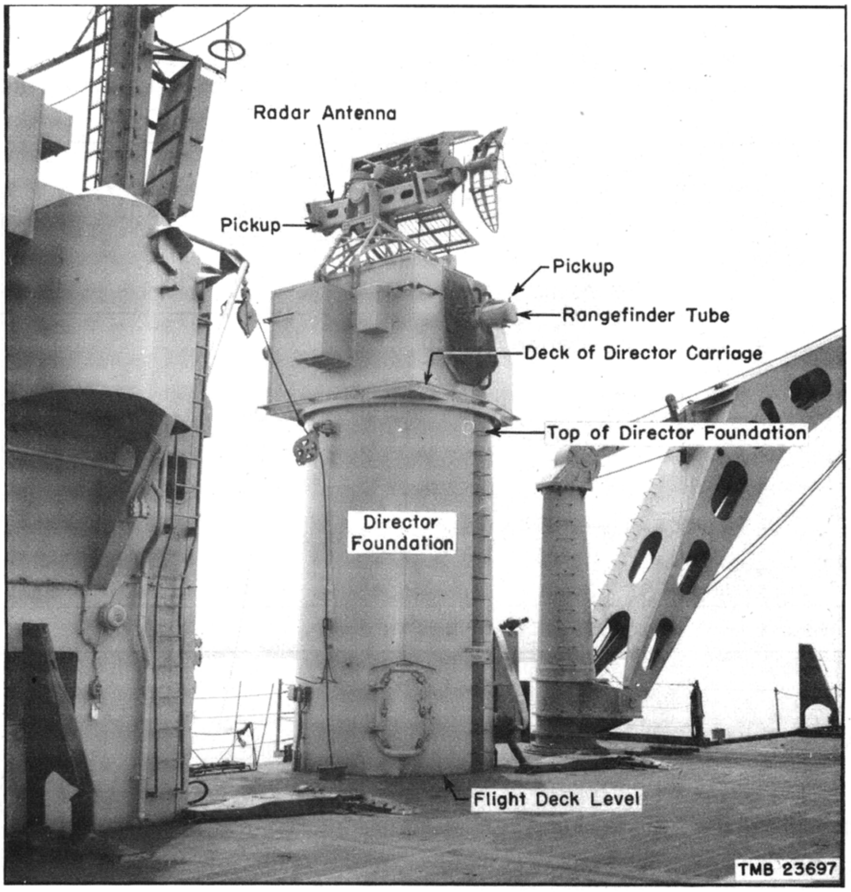


Figure 14 - Main-Battery Director 3 of the USS MIDWAY (CVB41)

Three-Bladed-Propeller Operation

The vertical-vibration amplitudes measured at the several stations are plotted on a basis of RPM in Figure 15. The phase of the vibration at the several stations is referred to the flight-deck motion at the base of the director. Figure 15 shows that all stations move in phase with the exception of the ends of the rangefinder tube. The ends of the rangefinder tube vibrate in opposite phase to each other at all times.

Two distinct severe resonances are in evidence; the first one occurs at 150 RPM and the second at 170 RPM, corresponding to 450 CPM and 510 CPM respectively. An attempt is made here to account for the presence of these critical frequencies. The resonance experienced at 170 RPM, which prevails throughout the director, is evidently a reflection of the flight-deck critical frequency.

The 450-CPM resonance, in evidence at 150 RPM, is believed to be the lowest mode of vibration of the two-body system, which consists of the Mark 12 radar antenna linked by an elastic spring, the leveling rod, to the

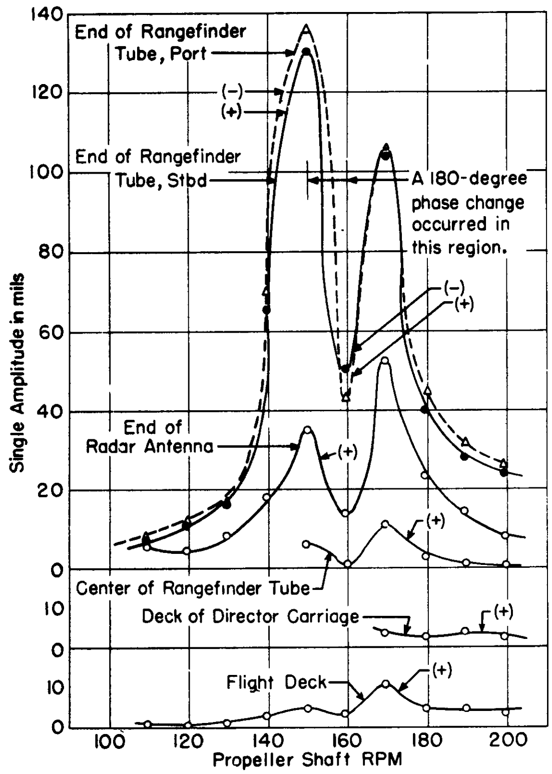


Figure 15 - Amplitudes of Vertical Vibration Measured on Main-Battery Director 3 (CVB41) during Trials with Three-Bladed Propellers

The vibration is of propeller-blade frequency. The phase relationship of the motions is indicated by (+) or (-).

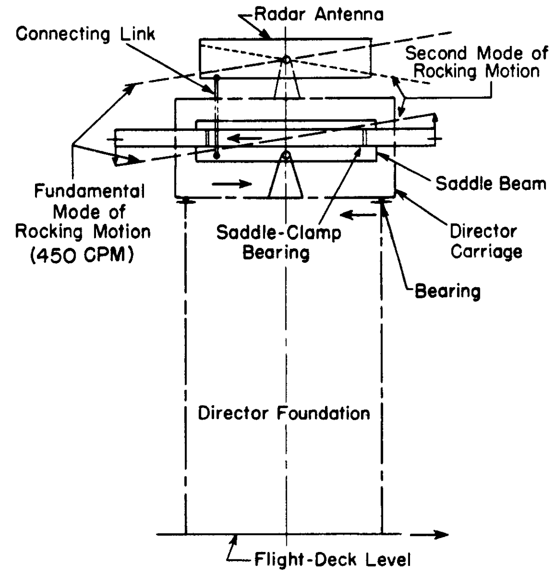


Figure 16 - Schematic Sketch of Main-Battery Director 3 (CVB41) Showing the Relative Motions of the Component Parts

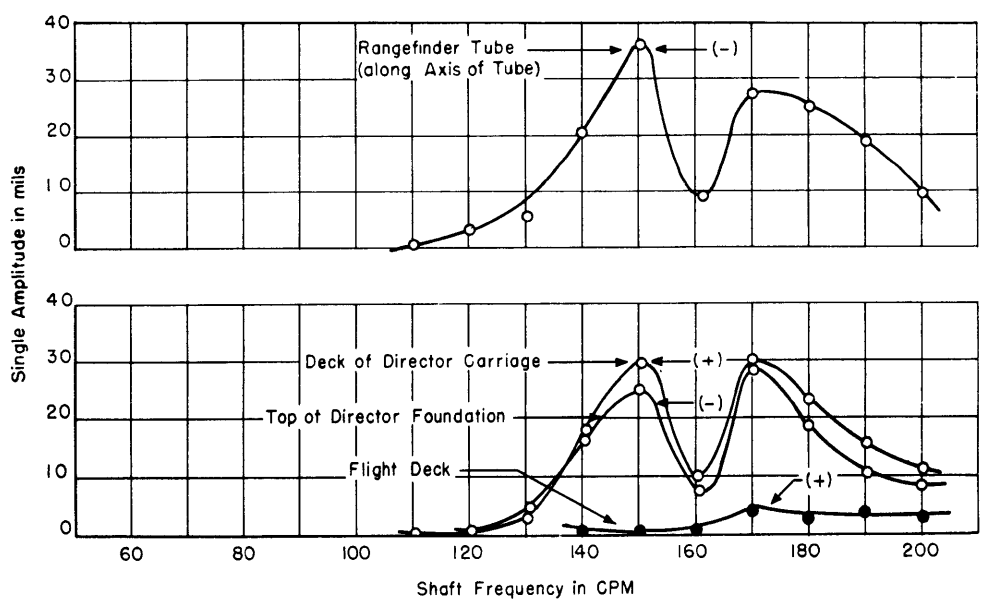


Figure 17 - Amplitudes of Transverse Vibration Measured on the Main-Battery Director 3 (CVB41) during Trials with Three-Bladed Propellers

The vibration is of propeller-blade frequency. The phase relationship of the motions is indicated by (+) or (-).

second body, which comprises the saddle beam and the rangefinder. The rangefinder pivots about a shaft in the stationary part of the rangefinder stand. This stand is geared to the cross-level motor. The arrangement is shown schematically in Figure 16. The fundamental mode of flexural vibration of the rangefinder tube lies outside the range of propeller-blade frequencies.

The transverse-vibration amplitudes measured at the several stations are plotted on a basis of RPM in Figure 17. This figure shows that the top of the director foundation moved out of phase with the flight deck, whereas the director carriage itself moved in phase with the flight deck. This phase relationship tends to indicate excessive play in the bearing between the carriage and the foundation. The rangefinder tube and the director carriage moved in opposite phase. The amplitude of this motion, which was considerable, may be due to excessive clearance in the rangefinder saddle bearings or the pivot bearing. The transverse vibration of the flight deck is considerably amplified by the cantilever vibration of the director foundation. Such amplification is to be expected with so slender a director foundation.

The fore-and-aft vibration at the center of the rangefinder tube was less than 10 mils single amplitude.

In order to obtain a correlation between the mechanical vibration of the rangefinder and the optical vibration of the image, the director was manned with operating personnel. The operators made notes as to the effect of the vibration on their ability to operate the rangefinder. These operators reported that the pointer's and trainer's scopes were not appreciably affected by the vibration but that at 150 and at 170 RPM it was difficult or impossible to take ranges. These observations show that the measured critical frequencies of vibration interfere seriously with rangefinder operation and that the difficulty lies in the rocking motion of the rangefinder.

This rocking motion may be due to excessive flexibility in the gear-and-shafting system which connects the pivot shaft with the cross-level motor. It is possible that this system has an excessive amount of backlash. Also, the connecting link between the saddle beam and the radar antenna is off center and introduces a vibratory couple. This moment may be counterbalanced and the frequency of this mode of vibration may be raised by symmetrically adding a similar connecting link on the other side of the pivot point. A vibration-generator survey of this director would definitely establish the weak point in this design.

Four-Bladed-Propeller Operation

The vertical-vibration amplitudes measured at the several stations are plotted on a basis of RPM in Figure 18. Unfortunately no data were

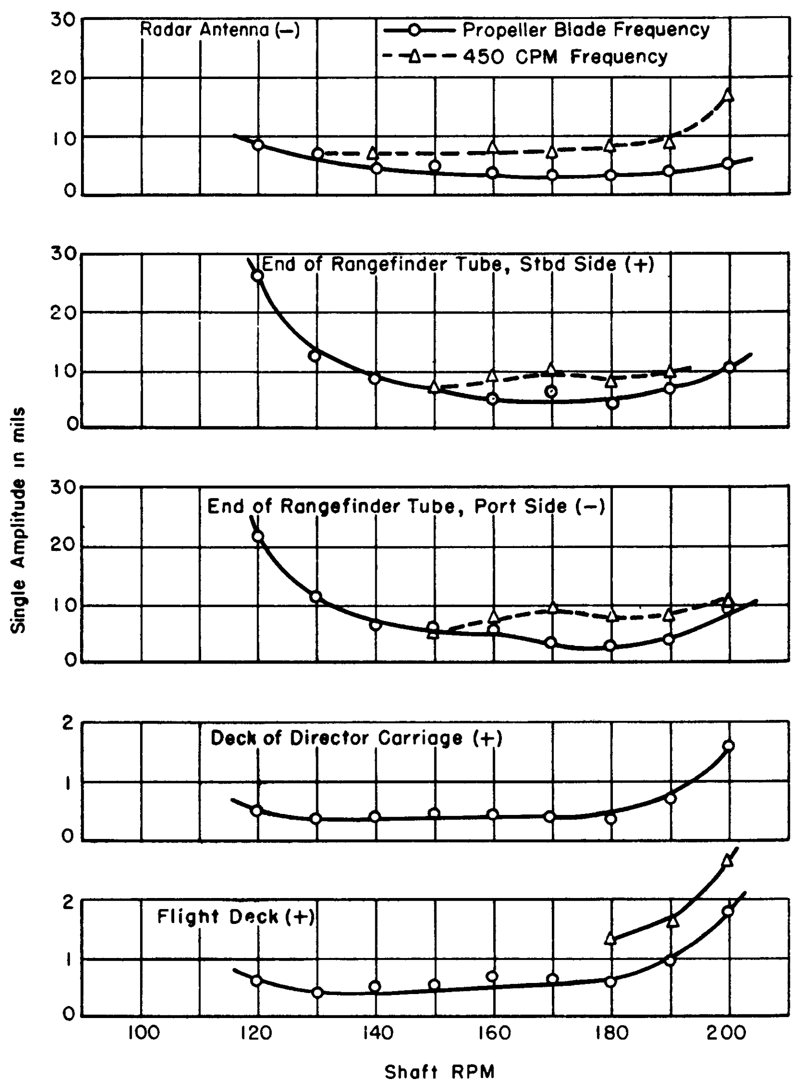


Figure 18 - Amplitudes of Vertical Vibration Measured on the Main-Battery Director 3 (CVB41) during the Vessel's Trials with Four-Bladed Propellers

The vibration was negligible at the center of the rangefinder tube. The phase relationship of the motions is indicated by (+) or (-).

obtained for propeller speeds below 120 RPM. The 450-CPM resonance which predominated during three-bladed-propeller operation would have occurred near 110 RPM. Figure 18 shows that the amplitudes approach a resonance near the lowest speed at which measurements were obtained. Also a vibration of 450-CPM frequency corresponding to this critical frequency was recorded sporadically throughout the speed range. It is believed that the amplitudes at the resonance which would occur near 110 RPM would be very much smaller than those measured at 150 RPM during the previously discussed three-bladed-propeller operation. The general discussion given in this section for the three-bladed-propeller operation applies here.

The single amplitudes of transverse vibration measured during the speed range covered were less than 5 mils. The fore-and-aft vibration measured at the center of the rangefinder tube was less than 3 mils throughout the speed range.

MARK-57 GUN DIRECTOR AT BOW

The vibration amplitudes of the two forward Mark-57 gun directors were measured at several points as indicated on the photograph, Figure 19. The measurements were made with a Cordero vibrometer.

Three-Bladed-Propeller Operation

The amplitudes of vibration measured at the stations indicated in Figure 19 are plotted on a basis of propeller RPM in Figures 20 and 21. An

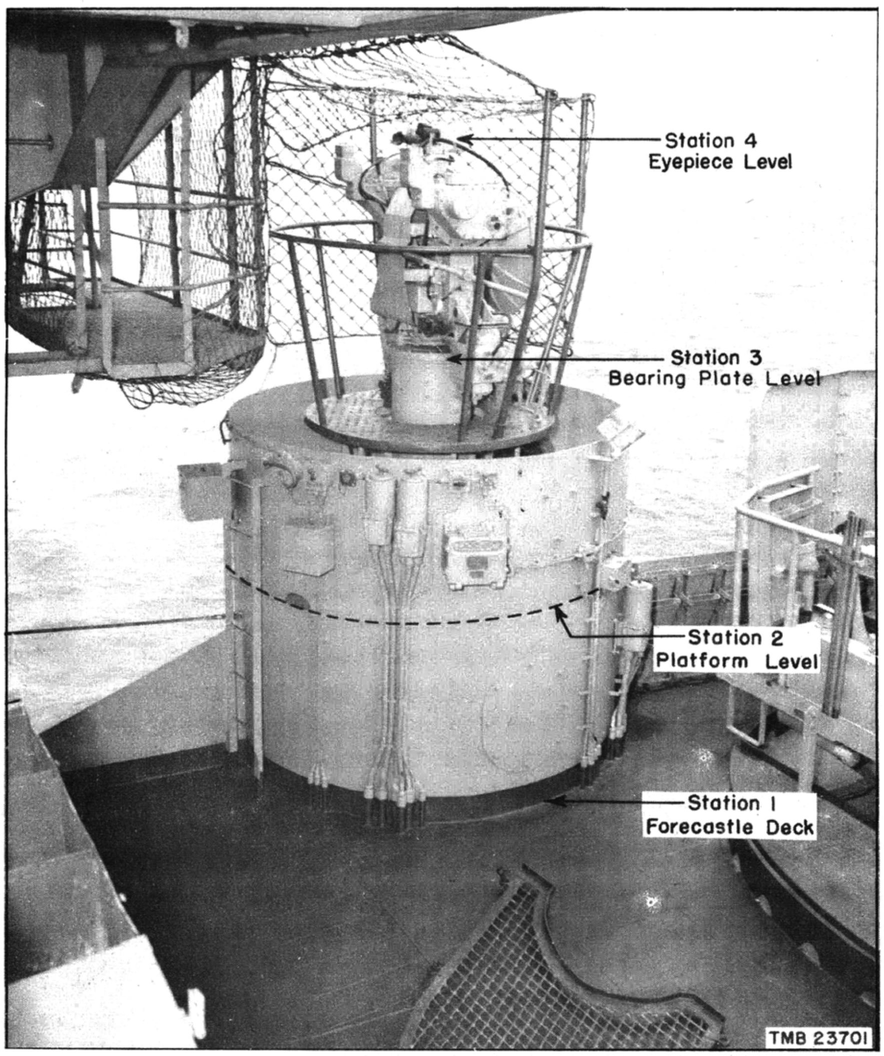


Figure 19 - Port Mark-57 Gun Director on Forecastle Deck of USS MIDWAY (CVB41)

inspection of these figures shows that a resonance exists near 145 RPM corresponding to 435 CPM. In order to obtain a correlation between the mechanical vibration of the gun director and the optical vibration of the image, it was decided to man the director with operating personnel. The operators made notes as to the effect of the vibration on their ability to operate the rangefinder. The operators reported that it was difficult to sight at propeller speeds of 140 and 150 RPM. Since the mechanical resonance also occurred within this speed range, it may be concluded that the measured resonance interferes seriously with the operation of the director. The difficulty lies principally in the excessive vibration of the eyepiece in the vertical and the transverse directions. The vibration of the deck, Station 1, is considerably amplified in the director structure.

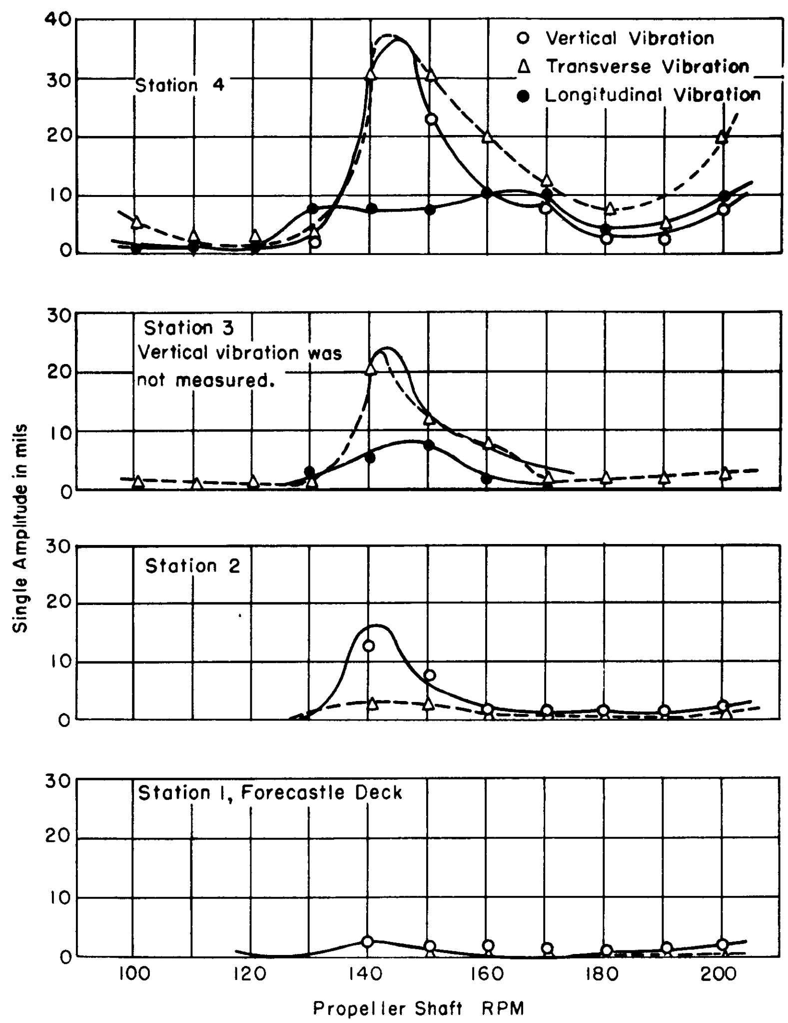


Figure 20 - Amplitudes of Vibration Measured on the Forward Mark-57 Director, Starboard Side, during Three-Bladed-Propeller Operation of USS MIDWAY (CVB41)

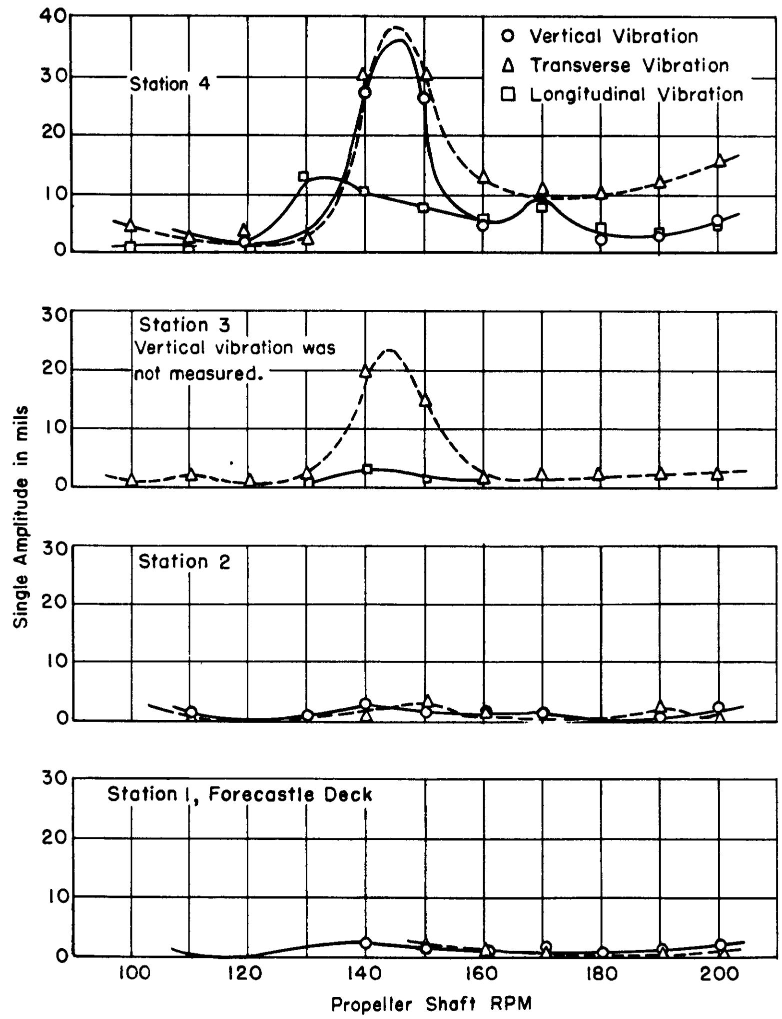


Figure 21 - Amplitudes of Vibration Measured on the Forward Mark-57 Director, Port Side, during Three-Bladed-Propeller Operation of the USS MIDWAY (CVB41)

Four-Bladed-Propeller Operation

The amplitudes during the steady-speed runs did not exceed 2.5 mils single amplitude at any station at any speed. The vibration therefore is negligible when four-bladed propellers are used. The critical frequency observed during three-bladed-propeller operation corresponding to 435 CPM occurs near 110 RPM when four-bladed propellers are fitted; at this speed the exciting forces are small and the damping is sufficient to limit the vibration to a negligible value.

AFTER MARK-51 GUN DIRECTORS

The vibration amplitudes of the two after Mark-51 gun directors were measured at the several stations indicated on the photograph, Figure 22. The measurements were made with a Cordero vibrometer.

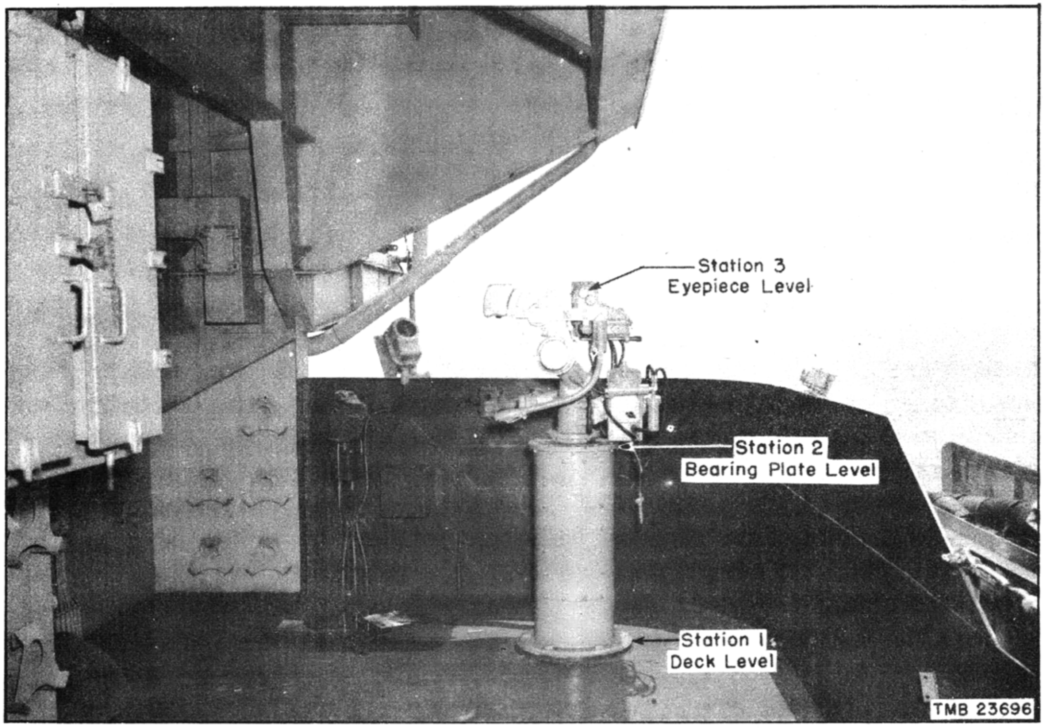


Figure 22 - After Mark-51 Gun Director at Gallery-Deck Level, USS MIDWAY (CVB41)

Vibration Measurements were made in the vertical, transverse, and longitudinal directions.

The vibration amplitudes, although large during operation with both three-bladed and four-bladed propellers, were larger during the four-bladed-propeller operation. Double amplitudes of vertical vibration of the deck, Station 1, were in excess of 30 mils at top speed. The vertical amplitudes at the eyepiece, Station 3, were of somewhat greater magnitude. The amplitudes of transverse vibration were about equal to the amplitudes of vertical vibration.

The gun director was manned by a fire-control man who stated that he could track at all speeds and that the reticle movement was small at all speeds. For this particular gun director the image vibration is not appreciably affected by mechanical vibration, principally because of the type of director system used. However, the mechanical vibration of the structure and the rangefinder was excessive, principally because of the fact that the director is mounted on a cantilever structure, which is inherently more flexible than the more rigid truss type of structure.

In cantilever structures, strut reinforcements, restraining the free end of the cantilever, are much more effective than attempts to increase the rigidity at the base and are economical in the use of labor and material.

RADIO ROOMS III AND VI

In order to determine the advisability of relocating Radio Room III from Frames 155 to 158, starboard, to Frames 204 to 208, starboard, gallery deck, naval vibration measurements were taken by the Research Laboratory at the stations indicated in Figure 23. The measurements at Frames 155 to 158 were made with an Askania vibrograph, and those at Frames 204 to 208 were made with a Consolidated Type 4-102 velocity pickup.

The amplitudes of vibration at the former and at the present locations of Radio Room III are plotted in Figure 23 on a basis of RPM for both the three-bladed- and four-bladed-propeller operation. An inspection of Figure 23 clearly shows that the former location of Radio Room III is much to be preferred to the present location. Also, three-bladed propellers, in general, induce greater vibration than four-bladed propellers. This conclusion was also reached by an analysis of the flight-deck vibration data.

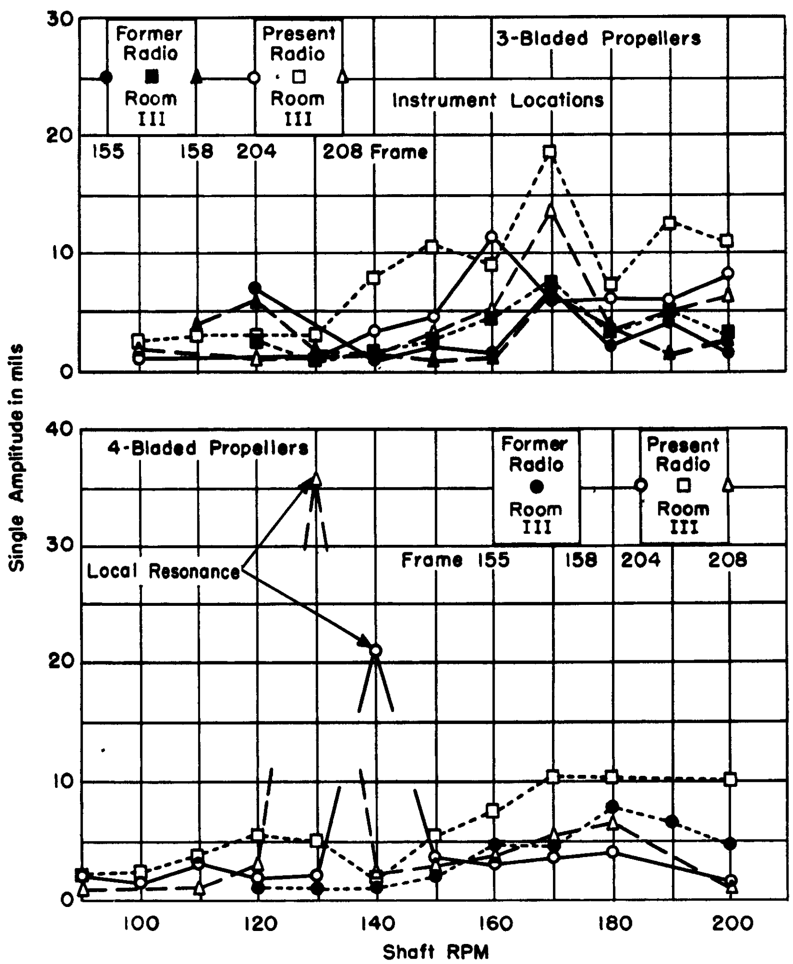


Figure 23 - Amplitudes of Vertical Vibration of the Gallery Deck Measured at the Former and Present Locations of Radio Room III of the CVB41

The amplitudes of vibration measured in Radio Room VI at Frame 225 are plotted in Figure 24 on a basis of propeller RPM. This figure shows that larger amplitudes were encountered when the vessel was equipped with three-bladed propellers than when equipped with four-bladed propellers.

Severe damage to radio equipment located in Radio Room VI, Frames 223 to 227, starboard, occurred during the standardization trials of CVB42. The opinion was expressed (6) that this damage may have been due to resonance of the elastically mounted equipment in response to the hull vibration. According to Navy specifications, shock-mounted radio and radar equipment is required to be mounted so as to have a natural frequency on its mountings in excess of 1500 CPM (14). If equipment is mounted according to these specifications, resonance cannot occur during the speed range of this vessel. The radio equipment in Radio Room III and Radio Room VI of the CVB41 was inspected and tested to determine the natural frequency of the equipment on its elastic mounts. Not one item of shock-mounted equipment met these Navy specifications. Table 6 gives the natural frequencies of equipment mounted in Radio Room III. An examination of this table shows that several of the units are in resonance near top speed.

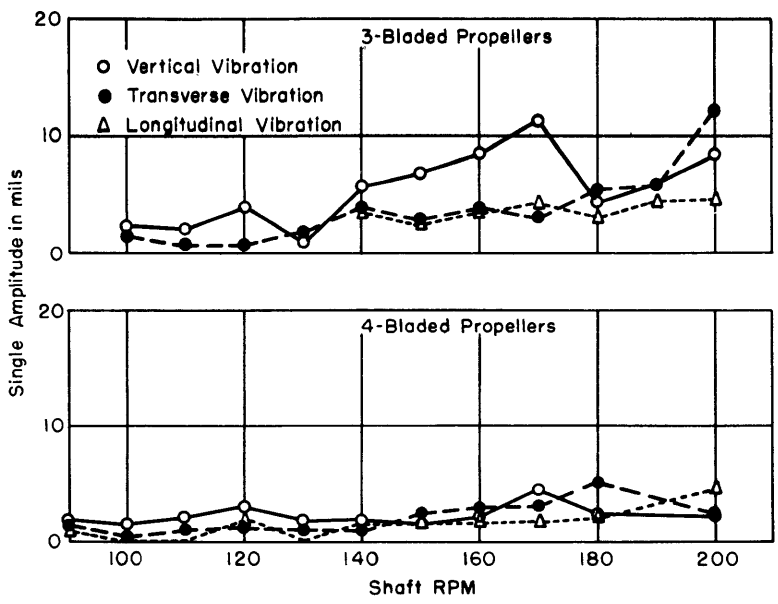


Figure 24 - Vibration Amplitudes of Gallery Deck Measured in Radio Room VI of the CVB41

TABLE 6

Natural Frequencies of Elastically Mounted Radio Equipment in Radio Room III of USS MIDWAY (CVB41)

Description of Equipment	Measured Natural Frequency CPM	Mode of Motion	Propeller RPM at Which Equipment Will Resonate	
			Three-Bladed Propellers	Four-Bladed Propellers
TCS-12 Serial 5580	600	Transverse	200	150
Model TCS12	606	Rotation about a fore-and-aft axis	202	151
TCZ-1 Motor Generator Type COL 211322 Serial 92 Rectifier	240	Rotation about a longitudinal axis	80	60
CRU 46147 Radio Receiver Serial 1494 Model RBB-1	420	Rotation about a longitudinal axis	140	105
FSA Radio Equipment Model OCT Frequency Shifter Serial 36	540	Rotation about a transverse axis	180	135
Radio Receiver CRU 46147 Serial 1494 MOD RBB-1	420	Rotation about a longitudinal axis	140	105
CFT 46154 RBA-2 Serial 427	420	Rotation about a longitudinal axis	140	105
Radio Transmitting Equipment TCK-3 Serial 160	480	Rotation about a transverse axis	160	120
Radio Transmitter Model RBM-11 Serial 96	750	Rotation about a transverse axis	250	188
RCK-3 Serial 192 CG52216-A	510	Rotation about a transverse axis	170	128

The frequent failures of radio equipment should not be attributed to excessive vibration of the structure unless the equipment is properly mounted. It is emphasized that the radio equipment, if properly mounted, should withstand the existing vibratory forces. It is recommended that the existing specifications according to which the manufacturers shock-mount their equipment be changed to agree with the recent specifications for shock-mounting equipment for naval shipboard use. It is furthermore recommended that the naval shipyards be made responsible for proper shock-mounting of radio and radar material passing through the yard for installation aboard ship. The necessary design information for accomplishing this is contained in Reference (15).

RADAR MASTS

Measurements of the vertical, longitudinal, and transverse vibrations of the SR-2, SX, and SR-3 radar antenna masts were made by means of vibration pickups secured to the platforms directly below the antenna pedestals. A rather complete tabulation of the data obtained at the radar masts is given in a report by the Naval Research Laboratory, Reference (16).

The maximum vibration amplitudes measured during the steady-speed operations are given in Table 7. An examination of this table and of the complete data (16) leads to several conclusions.

1. Substantially greater vibration was in evidence when the vessel was equipped with three-bladed propellers than when equipped with four-bladed propellers.

2. The transverse and the longitudinal vibrations of the masts were of the same order of magnitude, whereas the vertical vibration was considerably less than either the longitudinal or transverse vibration.

3. The SR-3 antenna mast was subjected to the largest vibrations; the SX antenna mast, in general, had the smallest vibration amplitudes.

TABLE 7

Maximum Vibrations Measured on Radar Masts during Steady-Speed Operation of the USS MIDWAY (CVB41)

Propeller	Radar Mast	Vertical Vibration			Transverse Vibration			Longitudinal Vibration		
		Shaft RPM	Frequency CPM	Amplitudes* mils	Shaft RPM	Frequency CPM	Amplitudes* mils	Shaft RPM	Frequency CPM	Amplitudes* mils
4-bladed	SR-2	140	340	1.8	160	360	13.3	190	270	24.5
	SR-3	200	1500	0.2	200	200	45.5	180	170	75.0
	SX	170	680	5.6	170	180	5.5	180	180	15.0
3-bladed	SR-2	190	570	30.0	200	360	32.0	200	300	29.5
	SR-3	190	570	2.1	200	200	134.0	200	150	134.0
	SX	200	600	1.5	150	160	42.8	150	150	56.4

* Single amplitudes are indicated.

Shock-excited vibration of the antenna masts at their natural frequencies was measured during the high-speed turns and crash operations. The same frequencies also recurred frequently during the steady-speed runs. These shock-excited vibrations were as follows:

Antenna Mast	Frequency of Vibration, CPM	
	In Transverse Direction	In Longitudinal Direction
SR-2	350	270
SR-3	200	170
SX	About 180	About 180

The vibrations measured on the CVB41 and CVB42 are not directly comparable, since the island structures at the time of the tests were not identical.

The maximum amplitudes occurred during the high-speed turns and the crash operations.

MAIN SWITCHBOARD ROOM 4

Vibration measurements in Switchboard Room 4, Frames 139 to 147, were made with an Askania vibrograph by a representative of the Naval Research Laboratory. The vibration of the 4A and 4B switchboard and of the 4A control panel was measured and the measurements are summarized here.

1. Vibration in the horizontal planes was negligible, less than 1 mil single amplitude.

2. All vibrations were of propeller-blade frequency.

3. The maximum single amplitude measured during the steady-speed runs was 9 mils. The maximum single amplitude measured during the crash-back operation was less than 20 mils.

4. The shock-mounts appeared to be rather stiff.

The Bureau of Ships (Code 660) considers switchboard vibration of more than 40 mils double amplitude to be excessive (17). Since the largest double amplitudes recorded were below this value, the vibrational characteristics of the switchboard are considered satisfactory.

PANEL VIBRATION

Numerous complaints regarding excessive noise throughout the ship were justifiable. Observations showed that most of this noise was due to drumming of bulkheads and deck panels. It is recommended that particular attention be given, in the design and the early construction stages, to resonant vibration of panels. The panels should be designed so as to be free of objectionable resonances within the ship's operating range; that is, the natural frequencies of the panels should be either well above the top propeller-blade frequency or they should occur at relatively low power. It is further recommended that experiments be made on a series of panels to determine empirical relations between the physical parameters of the panels and their resonance frequencies.

CONCLUSIONS AND RECOMMENDATIONS

This section recapitulates the conclusions drawn in the preceding sections and recommends improvement of existing unsatisfactory conditions as well as suggests further tests if such tests appear justified.

1. The vibration amplitudes of the main deck were of tolerable magnitude with the exception of the deck panel extending from Frame 159 to Frame 176, 12 feet to port and to starboard of the centerline, which was subjected to excessive vibration, especially at the higher speeds during four-bladed-propeller operation. These large vibrations not only generated noise but also reduced the comfort and operating efficiency of personnel. The vibration could probably be greatly reduced by adding a stanchion at the centerline of the deck, Frame 169, and by carrying this stanchion down into the inner bottom structure; such an addition is strongly recommended. An alternate method of solving the problem would be to install a deep transverse beam at Frame 169 similar to that at Frame 167.

2. Considerably greater vertical and transverse vibrations of the fantail were produced by three-bladed-propeller operation than by four-bladed. Multinoded critical frequencies of vertical flexure of the hull at approximately 300 CPM and 540 CPM were in evidence.

3. This test did not give definite data for the determination of the fundamental natural frequency of vertical and transverse flexure of the hull girder. Such data may easily be obtained by means of shock excitation by dropping and snubbing the anchor. It is suggested that such tests be made as a matter of routine on each newly commissioned vessel. It would be even more informative and desirable to determine the natural modes of vibration of a representative vessel of each class of ships by means of vibration-generator tests.

4. Shock-excited longitudinal vibrations of 800-CPM frequency were measured at the bow during the crash-back operation. This frequency is believed to be a natural frequency of longitudinal vibration of the hull.

5. The amplitudes of vertical vibration measured on the flight deck were of considerably greater magnitude during three-bladed-propeller operation than during four-bladed operation, and the level of vibration was more severe on the CVB42 than on the CVB41. Transverse vibrations were of small magnitude.

6. The major flight-deck section subjected to the most severe vibration is the aftermost one. A resonance of the aftermost flight-deck section occurs at a propeller speed of about 170 RPM, whether three- or four-bladed propellers are fitted. The resonance at 680 CPM, four-bladed-propeller operation, represents that mode of vibration of the entire after flight-deck section in which the armor-plate panels are vibrating in their fundamental modes as plates. The 510-CPM critical frequency observed with three-bladed propellers is believed to be the fundamental vertical flexural resonance of the armor-bent combination. The latter frequency presents no difficulties when four-bladed propellers are fitted.

7. The vibratory stresses existing in the after major flight-deck section are of small magnitude except during high-speed turns and crash-back operations, at which time dangerously high stresses may be attained.

8. The flight deck and the gallery deck act as flanges of a box girder. It is concluded therefore that data such as plotted in Figures 4 through 6 may be used to determine the relative severity of vibration to be expected at any location on the gallery deck.

9. The vertical vibration of a major flight-deck section, which extends the entire length between expansion joints, is a maximum near the center of the section and a minimum near the expansion joints. Consequently installations on the gallery deck that require relative freedom from vibration, such as radio rooms, should be located near the expansion joints, or forward of Frame 135.

10. It is recommended that Radio Room III on the CVB42 not be relocated but that the equipment installed in Radio Room III be properly shock-mounted. Radio stores should be located in an area relatively free of vibration.

11. Most of the equipment failures occurring in Radio Room III and Radio Room VI are believed to be due to resonance of the elastically mounted equipment in response to the hull vibration. It was found that not one item of supposedly shock-mounted equipment was mounted properly. Failures of equipment should not be attributed to excessive vibration unless the equipment is properly installed.

12. It is recommended that the existing specifications, according to which manufacturers shock-mount shipboard equipment, be changed, if necessary, to agree with recent developments in shock-mounting of equipment for naval shipboard use (15). It is furthermore recommended that the naval shipyards be made responsible for proper shock-mounting of radio and radar material passing through the yard for installation aboard ship.

13. The motion across the flight-deck expansion joint at Frame 46 1/2 was 3/8 inch in the longitudinal direction. This motion is small. Considerably greater displacements may be expected to occur during a heavy sea. The flight-deck section between expansion joints is believed to have a fundamental natural frequency of longitudinal vibration near 45 CPM.

14. The rangefinder of Main-Battery Director 3 has a natural rocking mode of vibration near 450 CPM. This vibration makes ranging difficult or impossible at a propeller speed of 150 RPM when three-bladed propellers are fitted. It is believed that this type of vibration is due to excessive flexibility in the gear and shafting system which connects the pivot shaft with the cross-level motor. It is recommended that this point be investigated and the condition be relieved by means of a redesign if necessary.

15. The flight-deck resonance is reflected as a severe rocking vibration of the rangefinder during three-bladed-propeller operation. This vibration makes ranging impossible. The vibration amplitudes were greatly reduced when four-bladed propellers were fitted.

16. There are indications of excessive clearances in the rangefinder saddle bearings, the rangefinder pivot bearing, and the bearing between the carriage and the director foundation. The only serious vibrations are those in the vertical direction.

17. The vibration of the Mark-57 gun director was objectionable to the extent that it made sighting difficult at propeller speeds of 140 and 150 RPM during three-bladed-propeller operation. The vibration was negligible when four-bladed propellers were fitted. It is recommended that some means be evolved for vertical stiffening of the platform to which the director foundation is secured.

18. The mechanical vibration of the after Mark-51 gun directors and of the cantilever structure to which these directors are secured was excessive, although the operation of the directors was not affected.

In cantilever structures, strut reinforcements, restraining the free end of the cantilever, are much more effective than attempts to increase the rigidity of the base and are economical in the use of labor and material.

19. It is recommended that particular attention be given, in the design and early construction stages, to attenuation of resonant vibration of panels. It is further recommended that experiments be made on a series of panels to determine empirical relations and, if possible, analytical relations between the physical parameters of the panels and their resonance frequencies.

20. Considerable change in the rigidity of the main thrust bearing will have but little effect on the frequency of the second mode of longitudinal vibration of the main propulsion system; on the other hand, such a change will affect the fundamental mode to a greater extent.

21. The first mode of longitudinal vibration of Propulsion Units 1 and 4 has a resonance frequency of about 880 CPM, and the second mode a resonance frequency of about 1230 CPM. The second mode of longitudinal vibration of Propulsion Units 2 and 3 occurs near 880 CPM.

22. All turbine thrust bearings are subjected to thrust reversal. The turbine thrust bearings in Engine Rooms 2 and 3 are subjected to pounding at the higher RPM when four-bladed propellers are fitted. The flexible couplings do not fully perform their function of isolating the turbine from the propeller-shaft thrust. It is recommended that means of decreasing the friction forces between the mating members of the flexible coupling be investigated.

23. It is recommended that propeller revolutions be kept below 210 RPM when four-bladed propellers are fitted in order to avoid a dangerous longitudinal resonance.

24. The main switchboards showed very little vibration. The cantilever design of these boards appears to be successful as regards freedom from resonances within the vessel's operating speed range.

25. As a general conclusion it may be stated that three-bladed propellers are preferred in relation to their effect on machinery vibration but that four-bladed propellers are more desirable when hull vibrations are considered.

26. Since the vibration amplitudes of Main Propulsion Units 1 and 4 are of acceptable magnitude when either type of propeller is installed, it may be of benefit to operate the vessel with three-bladed propellers on the inboard shafts and four-bladed propellers on the outboard shafts. Such an installation may be expected to reduce the hull vibration appreciably without increasing the machinery vibration appreciably. Also, since the three-bladed propellers would be located behind the inboard skegs, only one blade at a time would pass the skeg; this arrangement minimizes the longitudinal impulse transmitted to the shaft system. The three-bladed propellers should be modified to

increase the clearances between the propeller and the skeg. It is recommended, in addition, that the propellers be redesigned to develop approximately equal power near top speed on all four shafts. This will help to reduce both the hull and the machinery vibrations.

27. Hull vibration would be considerably reduced by fitting five-bladed propellers on the inboard shafts. This approach is not recommended, however, since it would probably produce severe machinery vibrations on Main Propulsive Units 2 and 3 whose second-mode resonance frequencies of longitudinal vibration would occur at a propeller speed near 176 RPM.

REFERENCES

(1) Joint RESTRICTED letter CVB41(436), InSurv CVB41/S8(604-S), Serial 195P45, of 9 May 1947, from BuShips to TMB and others.

(2) "USS FRANKLIN D. ROOSEVELT (CVB42) Vibration Survey Conducted during Tactical, Standardization and Miscellaneous Trials of July 1946," by N.H. Jasper, RESTRICTED TMB Enclosure Report, January 1947; TMB File S87-19/A11-(1).

(3) Letter CVB41/S8 of 22 December 1945, Preliminary Report of Shipboard Vibrations Experienced during Shakedown Cruise, from Commanding Officer of MIDWAY to Chief of BuShips.

(4) Letter CVB41/S67/S8 Serial 513, Vibration Tests in Radio Three and Six, USS MIDWAY (CVB41): Request for Conduct of, 12 May 1947, from Commanding Officer of MIDWAY to Chief of BuShips.

(5) "Trip Aboard USS MIDWAY, CVB41, February 8 and 9, 1946," Westinghouse Electric Corporation trip report presenting preliminary vibration readings on main machinery.

(6) TMB letter S87-19/A11-(1) of 4 March 1947 to Chief of BuShips and others, discussing the relocation of Radio Room III.

(7) "Vibration Trials Conducted Aboard USS MIDWAY (CVB41) 19 to 23 July 1947 - Conducted with Four-Bladed Propellers - Preliminary Report on," memorandum from N.H. Jasper, TMB, and E.F. Noonan, BuShips, to Trail Board, USS MIDWAY (CVB41).

(8) "Vibration Trials Conducted Aboard the USS MIDWAY (CVB41) 6 August 1947 - Conducted with Three-Bladed Propellers - Preliminary Report on," dated 8 August 1947, memorandum from N.H. Jasper, TMB, to Trial Board, USS MIDWAY (CVB41).

(9) "Structural Design of Warships," by William Hovgaard, U.S. Naval Institute, Annapolis, Maryland, 1940.

(10) TMB CONFIDENTIAL letter C-S87-19/A11-(1) of 13 March 1945 to Chief of BuShips.

(11) U.S. Atlantic Fleet Air Force letter FF13-2/L9-3, Serial 479, of 18 January 1947 to Chief of BuShips and others.

(12) "Strain and Deflection Measurements on the Flight Deck of the USS FRANKLIN D. ROOSEVELT (CVB42) during Landing Tests of 31 October - 4 November 1946," by E.O. Berdahl and L.D. Anderson, TMB Enclosure Report, May 1947; TMB File F1-2/EN28.

(13) TMB CONFIDENTIAL letter C-S87-19/A11-(2) of 14 August 1945 to Chief of BuShips.

(14) Inclination, Shock and Vibration Test Specifications for Shipborne Naval Radio, Radar, and Sonar Equipment. Navy Department Specification RE9284B, of 1 August 1944.

(15) "Shock Mounts for Naval Shipboard Service," RESTRICTED NAVSHIPS 250-600, June 1944.

(16) "Measurements Aboard USS MIDWAY during 13-25 July and 1-9 August 1947, Report on Problem 40S06-02," NRL Report; NRL File 401-495/47(473), 22 October 1947.

(17) "Design of Switchboards and Switchboard Foundations to Prevent Excessive Vibration," by S.S. Browne and W.P. Welch, memorandum to Captain R.E. Cronin of BuShips, Code 660, 28 September 1945.

PRNC-4965-8-16-48-100