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SEAKEEPING TRIALS ON TWO MODIFIED LIBERTY SHIPS

[redacted]

by

Margaret D. Bledsoe, Paul Plaia,
and
Sigmund S. Hagara

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NOTATION

E	Area under the spectrum curve
g	Acceleration due to gravity
KIPS	Kilopounds
Z	This symbol following a number indicates Greenwich Civil Time
$\Delta \omega_e$	Increment of ω_e
ω_e	Frequency of encounter

ABSTRACT

This report discusses the Liberty ship seaworthiness trials conducted under the joint sponsorship of the U. S. Maritime Commission and the U. S. Navy. The prime objective of the trials was to obtain sufficient data to evaluate the relative seakeeping ability of two types of modified Liberty ships. Motions, stresses, accelerations, speed and power, and limited slamming data were obtained during four Atlantic crossings of MV THOMAS NELSON and four of SS BENJAMIN CHEW. In addition, special maneuvers were conducted at several speeds for a series of ship headings relative to the oncoming sea. Although data were recorded daily during each trip, only the data taken during the special maneuvers are discussed in this report.

The plan of the tests, instrumentation, and variables measured during the trials are described. A statistical approach was used in the analysis of the motion, acceleration, and stress data, and the results were reduced to the form of power spectra and presented in terms of a parameter E which defines the statistical distribution of the double amplitudes. The two ships are compared by reducing the data for all nine maneuvers (four for BENJAMIN CHEW and five for THOMAS NELSON) to a ratio which is equivalent to motion or stress per unit wave height. The ships are also compared in regard to their ability to maintain speed in a seaway. The overall evaluation of the seaworthiness characteristics indicates that the NELSON is superior to the CHEW.

Since the sea condition for all special maneuvers was approximately the same (State 4-5 sea), spectral density curves for the waves, motions, and stresses are presented for a representative pair of maneuvers only.

INTRODUCTION

For many years naval architects have depended upon still water tests for prediction of ship speed-power relations; that is, little has been done toward the prediction of speed of a ship in a seaway. This was due not only to a lack of adequate test facilities and theories, but also to the absence of valid full-scale seakeeping data.

It is now recognized that seakeeping qualities have a significant effect on sustained sea speed. As these speeds tend to increase, the importance of designing hulls for optimum seaworthiness becomes apparent. Towards this end, the David Taylor Model Basin had, for some years prior to the trials herein reported, planned and engineered the installation of a new facility for evaluating the maneuvering and seaworthiness characteristics of hull forms from model tests.

Early in 1955, the Maritime Administration was engaged in the initial stage of a four-ship program of Liberty ship modernization and had underway the conversion of the first two ships, SS BENJAMIN CHEW and MV THOMAS NELSON. As part of this program the propulsion machinery for both ships was modernized and horsepower was greatly increased. Furthermore, THOMAS NELSON was lengthened by addition of a finer bow.

The objectives of these trials are summarized as follows: (1) to evaluate the relative seakeeping performance of these two Liberty ships; (2) to obtain full-scale seakeeping data for use in model correlation procedures for the new basin; and (3) to add to the general store of seakeeping information being gathered in many ways by various persons and organizations.

An agreement was reached in March 1955, whereby the David Taylor Model Basin would provide the instrumentation and collect and analyze the data, and the Maritime Administration would provide the ships, finance the installation and removal of this instrumentation, and arrange for the operation of the ships. Instruments were installed during the conversion period, and the ships were ready for sea in September and October 1956.

In planning the trials, it was decided that the ships should be operated in the North Atlantic and preferably in the service of one shipping company. Furthermore, it was considered advantageous to have the data obtained while the ships were in routine commercial service. The Maritime Administration was able to charter the vessels to the United States Lines for operation between South Atlantic ports of the United States, and northern European ports in France, the United Kingdom, Germany, and the Low Countries. The cooperation extended by the United States Lines was a significant contribution toward obtaining the desired data.

Seakeeping trials were conducted from the fall of 1956 through the spring of 1957 on BENJAMIN CHEW. Tests were also conducted on THOMAS NELSON during this period; however, insufficient data were accumulated and additional trials were run during the winter of 1957-1958. The trials consisted of eight voyages and resulted in the accumulation of data on nine special maneuvers and numerous slowdown runs.

This report describes the plan and instrumentation of the trials and contains a presentation of the data for the special maneuvers only. For each variable the data from all the maneuvers of each ship are averaged and compared. One maneuver for each ship for which the sea conditions were most nearly equal was selected for a detailed analysis of the spectral density curves. These results are also presented.

DATA ON SS BENJAMIN CHEW AND MV THOMAS NELSON

BENJAMIN CHEW and THOMAS NELSON are modifications of the Liberty ship and were operated by the United States Lines on similar Atlantic routes but on separate schedules. They differ from the prototype in that the rated horsepower of these ships has been increased from 2500 to 6000 shp. In addition, the hull of THOMAS NELSON has been lengthened by approximately 25 ft. This was accomplished by adding a new bow section beginning at Frame 38 of the original Liberty ship hull. The modifications of THOMAS NELSON were performed by the Bethlehem Steel Company of Baltimore, Maryland, and BENJAMIN CHEW was modified by the Ira S. Bushey Shipyard of New York.

The ships' characteristics are listed in Table 1, and the draft, trim, and displacement of the two ships at the time of the maneuvers are given in Table 2. The bow profiles are shown in Figure 1 and the body plans are shown in Figure 2. The curves of form appear in Figures 3 and 4 and the inboard profile and general arrangement of decks in Figures 5 and 6.

Shaft horsepower and rpm curves predicted from tests of a 20-ft model are shown in Figure 7 for the original Liberty ship (CHEW) at 12,000 tons displacement and in Figures 8 and 9 for the modified Liberty ship (NELSON) at 13,500 and 8,200 tons displacement, respectively.

DESCRIPTION OF THE TRIALS

To evaluate the seaworthiness characteristics of the two ships it was desirable to obtain ship responses including motions, hull stresses, slamming, shipping of green seas, and speed loss in a variety of conditions. Since the parameters which influence the motions of a particular ship are her forward velocity, oceanographic environment, and angle of encounter with the predominant sea, the plan for the trials encompassed several sea conditions with three forward speeds of advance and four to five headings for each sea condition. Furthermore, it was desirable that the seaway should remain statistically invarient (stationary) and unidirectional during the tests. It was realized that fulfillment of these requirements would necessitate considerable time and effort, especially since the ships were commercially operated and hence not at the complete disposal of the project at hand. It was therefore recognized that the trials would be conducted during many ocean crossings. Although the ships were operated on separate schedules, it was expected that they would eventually experience comparable sea conditions. The tests covered a period of 1 1/2 years. Sea conditions in which the trials were conducted ranged from State 4 to State 5. Although it was not possible to conduct the special maneuvers of the two ships in identical seas, they were conducted in seas that were approximately the same.

The performance of the two ships was evaluated by comparing amplitudes of oscillations, (motions, stresses, etc.) as well as frequencies which they contain. In the first case, the data from all maneuvers of each ship were averaged and compared. For the second case, a detailed spectral analysis of the waves, motions, accelerations, and stresses was made for a representative pair of maneuvers.

PLAN OF TESTS

The test schedule for each ship consisted of the following phases:

1. Once daily with the ship on course, ship motions, wave height, stresses, and powering were recorded for a 1/2-hour period at the propeller rpm determined for stillwater speeds of 5, 10, and 15 knots. In addition, a recording was made with the ship in hove-to condition heading into the sea.

2. Twice daily with the ship maintaining speed and course, the same data were recorded for 1/2-hour.

3. A 2-minute sampling of the same data, except powering, was recorded automatically every hour.

4. Special maneuvers: When the weather conditions were favorable, an extensive exploration of the seaworthiness characteristics of the ship was made. This was accomplished through the special maneuvers illustrated in Figure 10. The maneuvers started with the ship heading into the prevailing sea at point A with propeller rpm set for a stillwater speed of 15 knots. This rpm was maintained for runs at the various headings shown in this figure. At point B this first phase was completed, and the propeller rpm was reduced to that equivalent to a stillwater speed of 10 knots. From point C to point D the second phase was conducted at this intermediate speed. At point D the ship reduced rpm equivalent to a 5-knot stillwater speed, and at point E the final phase of the test was begun. At point F the special maneuvers were completed with a total of 15 trial runs. Each trial run was of 20- to 30-minute duration; thereby, requiring about 7 hours for the entire maneuver. Prior to and immediately following these runs the ship was placed in hove-to condition heading into the sea, and a record of the sea conditions and motions was obtained.

5. Slamming: At anytime that slamming was experienced during the voyage of the ship, it was intended that the phenomenon be recorded. This would include motions, stresses, accelerations, impact pressures, speed, and other pertinent data. Two serious difficulties were encountered, however, in obtaining the slamming data. First, when the ship experienced slamming, the captain was tempted to slow down or change course to lessen the severity. Second, since the transient nature of the slamming phenomena necessitates operation of the recording mechanism at very high speeds, the recorder was operated only when slams appeared imminent, and this was difficult to predict. The introduction of these human elements frequently resulted in failure to obtain data at the instant of impact. Because of these factors, few slamming data are available for analysis.

6. Standardization Trials: These trials were to be conducted for full load and ballast condition at some time during the trial period. However, data were actually obtained for two loading conditions for NELSON, but only one for CHEW. Propeller revolutions and torque at nominal speeds of 6, 8, 10, 12, and 14 knots and speed corresponding to full power were to be recorded over a measured mile.

This report does not include the results of phases 1, 2, and 3 but only those of 4 and 5. The results of phase 6 are presented in two other TMB reports.[1,2]

INSTRUMENTATION

The ships were instrumented to record motions, keel stress due to vertical bending, slamming pressure, power, speed, and wave height. For the location of the instruments on the ships, see Figure 11.

Pitch and roll were measured by Minneapolis Honeywell gyroscopes, designated by the manufacturer as type JG 7003A5. Heave acceleration was measured with ±1-g Shaevitz, VC-S type, accelerometers, located amidships at Frame 87, 15 ft above the inner bottom. The natural frequency of the accelerometers was 20 cps.

Longitudinal stresses due to vertical bending were measured by Baldwin, SR-4 type, AD-3 strain gages mounted in pairs on the keel girder at Frames 89-90. Static calibrations were made on the gyros, accelerometers, and strain-gage bridges before and after each crossing.

The recording of data on pitch, roll, heave acceleration, wave height, and keel strains was made on the TMB Automatic Statistical Recorder (ASR). The one exception occurred during the last crossing of NELSON where recordings were made on a portable 800 Ampex magnetic tape reel recorder at a tape speed of 1 7/8 ips. Since this was the first attempt to tape record data at DTMB, a simultaneous recording was also made on a Sanborn paper-tape recorder.

The ASR system consists of recorder and counter units. The recorder accommodates five channels of data on chart paper moving at various speeds depending on the resolution desired. In these tests, records were taken at a paper speed of 3 ipm. The recorder was set to automatically sample 2 minutes every hour except during the 1/2-hour runs when it was changed to manual control. These variables, in addition to being recorded on chart paper, were recorded by the ASR counter. This instrument indicates complete cycles of oscillations by means of banks of six counters per channel. These counters trip in succession when the phenomena reach a series of predetermined levels. The counters are actuated by a series of sliding bar contacts in the ASR mechanism, one set of six contacts per channel. To determine the effects of slamming, the ships were instrumented with four TMB diaphragm-type pressure gages which utilize a differential transformer as the sensitive element, and with two accelerometers at the bow. Both 5- and 10-g accelerometers were used, the 10-g accelerometer being mounted forward in No. 1 hold and the 5-g aft in No. 1 hold. The natural frequency of the 5-g accelerometer was 200 cps, and the 10-g accelerometer had a natural frequency of 280 cps.

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[1] References are listed on page 85.

The membrane-type pressure gages have a soft-iron core attached to the center of the diaphragm which moves an amount proportional to the pressure, thereby inducing voltage change in a differential transformer. The pressure range is determined by the thickness of the diaphragm. The capacity of the gages used in these tests ranged from 500 to 900 psi and the natural frequency was around 3000 cps. The gages were located in No. 1 hold on both ships. In NELSON, two gages were located at the keel at 9 and 14 percent of the length aft of the forward perpendicular, and an additional two had corresponding longitudinal locations but were located 6 and 9 ft, respectively, outboard on the portside. On CHEW, three gages were evenly spaced longitudinally in No. 1 hold on the portside and the fourth was located outboard, starboard.

The output of the pressure gages, strain gages, and accelerometers was fed to a 3-kc carrier amplifier system and was recorded on an 8-channel, Consolidated string oscillograph. Each oscillograph channel consists of a thermostatically stabilized sensitive galvanometer. Light rays reflecting from mirrors on the galvanometers produce the amplified signals on photographic paper. The oscillograph was operated only during slamming at which time a paper speed of 10 ips was used.

The waves were measured by a sea-condition meter developed by the British National Institute of Oceanography. The principles of operation and schematics for this equipment are given in Reference 3. The meter is shipborne and records the wave height by suitably combining the water pressure at some point on the ship hull and the vertical displacement of this point relative to some reference level. To offset the effects of wave reflections on pressure measurements, two pressure cells are used, one on each side of the ship and directly opposite each other, and the mean of their output is taken as a measure of the wave elevation above their respective locations on the ship. The ship vertical accelerations are double integrated to obtain fluctuations in wave measurements due to ship motion. This vertical displacement is then appropriately combined with the pressure measurements to indicate the actual height of the waves. A 10-percent accuracy can be expected in measuring waves with periods from 4 to 20 seconds; however, for periods from 4 to 8 seconds a correction factor should be applied because of the meter's relative insensitivity to short wave lengths.

The pressure transducers, port and starboard, were mounted to sea valves on the hull of the ship in the machinery space about Frame 106 at the 7-ft waterline. The output of the sea-condition meter was recorded on a special graphic recorder provided with the instrument as well as on the ASR recorder.

Ship speed was measured with impeller log equipment consisting of a rodmeter, sea valve, rodmeter amplifier, and a visual speed indicator. A torsion meter and shaft-rpm and horsepower meters were used to determine ship power. Ship speed, shaft torque, horsepower, and rpm were recorded on a 4-channel, Sanborn recorder. The Sanborn recorder consists of multiple galvanometers with electrically heated pens, a chart drive system, and a temperature sensitive chart paper.

VARIABLES MEASURED DURING TRIALS

The following data were obtained:

1. Roll angle
2. Pitch angle
3. Heave acceleration
4. Wave profile
5. Keel strain, amidships
6. Pressures in the ship bottom in the forebody
7. Vertical acceleration at the bow
8. Ship speed
9. Shaft rpm
10. Shaft torque

Items 1 through 5 were recorded by the ASR, items 5 through 7 on the string oscillograph, and items 8 through 10 on a Sanborn recorder.

In addition, other pertinent data such as visual observations of the wave periods, heights, and lengths and predominant direction of the sea were made. A description of the weather was usually obtained regarding wind velocity, direction, and character. Qualitative observations of the ship seakindliness such as shipping of green water and slamming were also made.

A sample of the ASR data is shown in Figure 12. Since, during the special slam runs, the oscillographs were run for short intermittent periods, there are no continuous records of accelerations, pressures, and stresses for these conditions. These records, then, are only suitable for detailed study of the slamming phenomena. Samples of such high-speed slam records are shown in Figure 13.

Ship speed and power were recorded along with the motions. However, a detailed analysis of the powering of the ship is not pertinent to the data of the present report. Speed is considered here only insofar as it is related to or affects the ship responses to the seaway in which she operates.

SEA CONDITIONS DURING THE SPECIAL MANEUVERS

In the initial planning of the test program it was intended that motion data should be obtained in several sea conditions ranging approximately from State 3 to State 6. It was further planned that special maneuvers would be conducted only under conditions when the seaway was unidirectional and remained statistically invariant. With these latter restrictions, it was expected that special maneuvers could be conducted in at least one sea condition for each ocean crossing. However, during the first two attempts made with CHEW, no special maneuvers were run because the requirements of unidirectionality and statistical invariance could not be met. It was therefore decided that although these prerequisites were desirable, sea conditions which approximated them would have to be accepted for conducting maneuvers.

During subsequent crossings, five maneuvers were conducted on NELSON and four on CHEW. During the maneuvers, as well as the hove-to tests, a continuous recording of the waves was obtained using a shipborne recorder.

The wave data were spectrum analyzed. The use of spectra to describe fluctuating quantities of the type such as wave height (also motions and stresses) provides not only the frequency distribution of the various components present but also provides a means for computing any statistical quantity derivable from the original record. For example, the area under the spectrum, designated by E, is equal to twice the mean square value of the signal, and the average peak-to-peak oscillations are related to E as follows:

1. The most frequent double amplitude of oscillation = $1.414\sqrt{E}$
2. Average double amplitude oscillation = $1.77\sqrt{E}$
3. Average of the highest one-third (significant) double amplitude oscillation = $2.83\sqrt{E}$
4. Average of the highest one-tenth double amplitude oscillations = $3.60\sqrt{E}$
5. Most probable maximum double amplitude for N oscillations = $2\sqrt{E \ln N}$

In the analysis of the sea-condition meter data, consideration was given to the effect of the depth of the meter below the free surface. The meter measures heights for long waves almost entirely by a vertical accelerometer; however, waves too short to cause appreciable heave motion of the ship are measured by pressure units. Since pressure variations due to waves decay rapidly with depth, an attenuation effect is introduced in these measurements. In the present trials on the Liberty ships the meters were located at depths of 17 and 18 ft; therefore, the error in measuring the heights of shorter waves can be appreciable. To determine this attenuation effect on evaluating E, corrections were made for several cases by application of the exponential relation of pressure to depth. Since pressure attenuation for constant depth depends only on wave frequency, frequencies of encounter were converted to wave frequencies when the ship had a forward speed of advance. Corrections corresponding to the true wave frequency were then applied. It was found that although the amplitudes of the higher frequency components may be in error by as much as 50 percent, the contributions of these components to the total area under the spectrum is so small that the resultant error in the estimation of E is only of the order of 10 percent. Since the characteristic properties of the waves are proportional to the $\sqrt{E}$, only a 5-percent error is introduced into these values. On the basis of these results it was decided that, for the present application, the additional effort required in correcting all the wave data for attentuation was not justified.

Spectra computed from data of the hove-to tests are shown in Figure 14 for all nine maneuvers. Some variation in the energy content of the sea is apparent for the various maneuvers. Of even greater significance is the variation observed at two different times during any one maneuver. For example, during CHEW tests on 2 Jan 1957 for the period required for maneuvers, a 50-percent variation in wave height was measured. This variation in the $\sqrt{E}$ obtained at two separate times during any one maneuver suggests the inadvisability of selecting either one as an adequate representation of the sea during the entire period required for the maneuver. It was therefore decided to investigate the $\sqrt{E}$ values obtained from the spectra of encounter. These values are shown in Figure 15. This approach assumes that the areas under the wave spectra are independent of ship speed and heading and that only the frequency distribution is affected by these parameters. Included also in this figure are the results from the hove-to tests. It can be seen that no systematic variation occurs that can be attributed to ship speed and heading and also that the variations in the $\sqrt{E}$ for the hove-to conditions are sometimes greater than the variations between any of the successively obtained values as heading and speed were changed.

It is therefore apparent that, if attention is restricted to amplitude alone, wave data obtained during the maneuvers are as meaningful as that from the hove-to tests. Thus the average of all $\sqrt{E}$ values obtained during any one maneuver (irrespective of ship speed and heading) was used to characterize the wave height appropriate for that test condition. The point spectra from the hove-to tests, however, were used to evaluate the range of frequencies present in the wave system.

It may be of interest to classify the sea conditions during the trials in terms of sea state as generally accepted by oceanographers. The properties of waves resulting from certain idealized wind conditions have been established by Neumann.[4] Oceanographers have utilized the data of Neumann's representation for a fully arisen unidirectional sea, and have classified sea states in terms of range of significant frequencies present, frequency of maximum energy, and the statistic E. The information from Figures 14 and 15 has been summarized in terms of these parameters in Table 3. Table 3 shows that the component frequencies present for all nine maneuvers of the Liberty ships cover approximately the same range; that is, the range lies between 0.2 and 1.4. The table also shows that the $\sqrt{E}$ for wave height lies between 2.3 and 3.7 ft. This indicates that the hydrographic conditions during the trial periods did not differ significantly, and therefore, to some extent, we may say that they are comparable.*

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*In the evaluation of motion data, the effect of variation in wave height is eliminated on the average by dividing $\sqrt{E}$ for motions by $\sqrt{E}$ for wave height.

An examination of data from the Neumann representation shows that these sea conditions correspond most closely to a State 4 to 5 sea. Characteristic data of these sea states are itemized in Table 4. A comparison of Tables 3 and 4 shows that the agreement is especially good insofar as the energy content is concerned. Discrepancies are observed, however, between the frequency ranges as indicated by the Neumann spectra and measured spectra. For example, if we group from Tables 3 and 4 the $\sqrt{E}$ values which most nearly correspond and compare the associated frequencies, we have the following:

	$\sqrt{E}$ for Wave Height ft	Significant Range of Frequencies radians/sec	Frequency of Maximum Energy of Spectrum
Neumann	2.4	0.59 to 2.2	0.82
Measured	2.47 2.33 2.40 2.38	0.2 to 1.2 0.3 to 1.2 0.4 to 1.2 0.2 to 1.1	0.54 to 0.48 0.46 to 0.52 0.72 to 0.58 0.72
Neumann	3.6	0.51 to 1.85	0.71
Measured	3.59 3.60 3.74 3.72	0.2 to 1.3 0.2 to 1.2 0.1 to 1.4 0.3 to 1.2	0.60 to 0.44 0.44 to 0.50 0.40 to 0.55 0.50
Neumann	2.8	0.57 to 2.1	0.78
Measured	3.0	0.3 to 1.3	0.52

The above tabulation provides only a qualitative comparison but it is apparent that the frequencies in the measured sea spectra are displaced toward the lower end of the frequency scale in comparison with that predicted by the Neumann spectra. It may be mentioned here that hindcasts* of the sea conditions based on weather charts in the operating areas during the trials almost always indicated the presence of significant swell components. Thus, this shift in frequency range may be attributed to the influence of swell which accentuates the lower frequencies in the spectrum band. As mentioned earlier, the Neumann highly idealized representation of the sea does not take swell components into consideration.

In summary, from a consideration of total energy content and other characteristic properties of the waves during the trial periods, the sea conditions can be classified as approximately equivalent and can be considered to correspond reasonably well to a fully developed high State 4 sea to intermediate 5.

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*Hindcast is a study of an event which has taken place in the past but, was not observed.

AMPLITUDES OF PITCH, ROLL, HEAVE ACCELERATION, AND STRESS

For a relative comparison of the two ships under the various test conditions the parameter E was determined from the spectra. These are tabulated in Tables 5 to 13. In these tables, an average value is used for wave height and speed while the ship is executing a 180-deg turn. Assuming that the motions are linearly related to wave height, a meaningful comparison of the ships can be made by expressing the data in the form of a ratio of $\sqrt{E}$ of the motion (or stress) to the $\sqrt{E}$ for wave height. This is equivalent to reducing the motions and stresses to a number which is a measure of the motion or stress per unit wave height. This has been done using the data of Tables 5 to 13, and the results are plotted in Figures 16 to 23. Though stresses are a function of the effective wave height (rather than actual wave height), which depends on ship form as well as speed, the ships were sufficiently similar to permit the assumption of equivalent body-wave interference effects at corresponding speeds.

Most of the curves in the figures show that the data have a fair degree of collapsibility when reduced in this fashion. This is apparent even though there was some variation in the displacement and trim of the ships at the time of the various maneuvers; see Table 2. The most outstanding exception to this tendency is demonstrated by the rolling motion of CHEW.

To facilitate a comparison of the ships based on the data from all nine maneuvers, the data of Figures 16 to 23 have been averaged and presented in Figures 24 to 27. From an examination of these figures, the following comments can be made concerning the effect of the various variables on the resulting motions.

EFFECT OF COURSE

1. Maximum pitch was obtained in head and bow seas with minimum pitch occurring in beam and quartering seas.

2. Maximum roll generally occurred in beam seas with minimum in head and following seas. As would be expected courses which tend to maximize roll minimize pitch and vice versa.

3. Heave acceleration was a maximum in bow and minimum in quartering or following seas except at the intermediate speed where it experienced a maximum in beam seas.

4. Little variation in stresses due to vertical bending appear with alteration in course although there is slight tendency for the stresses to be reduced when the seas are approaching from abeam.

EFFECT OF SPEED

1. The effect of speed was less significant than the effect of course. There was no discernible effect of speed on pitching for NELSON but there was a slight tendency for CHEW to pitch less at the low speed than at the intermediate and high speeds.

2. There was a slight tendency for the maximum heave acceleration to increase with speed for both ships.

3. The effect of speed on roll was not marked for either CHEW or NELSON. For CHEW at high speed, however, maximum roll occurred in quartering instead of beam seas.

4. The stresses show remarkably consistent uniformity. No effect can be attributed to speed for either of the ships.

EFFECT OF SHIP

1. Heaving accelerations were less for NELSON than for CHEW at all three speeds, although the trends with speed and heading were similar. The maximum heave acceleration for NELSON was only 70 percent of that for CHEW at the low and intermediate speeds and less than 60 percent at the high speed.

2. The pitching motion was about the same for NELSON at all three speeds and was always less than that of CHEW. At the low speed, the maximum pitch of NELSON was 75 percent of that for CHEW, and at the intermediate and high speeds it was less than 60 percent.

3. The longitudinal stress was less for NELSON at all three speeds even though she is the longer ship. Since the stress was virtually unaffected by speed or course, it can be said on an overall basis that the stress experienced by NELSON was only 50 percent of that for CHEW.

4. As mentioned previously, the roll motion of the two ships, especially that of CHEW, were the most difficult to reconcile for all of the maneuvers. From Figures 20 and 21, a comparison of roll for the CHEW maneuver on 2 Jan 1957 with that of the NELSON maneuver on 28 Mar 1958 indicates that NELSON rolls more than CHEW. However, if the average of the curves of Figure 20 is compared with the average of those of Figure 21 (see Figure 26), the opposite conclusion is reached.

It is known that rolling motion is generally more sharply tuned than other motions because of low damping in roll. This results in roll spectra usually having the form of a single sharp peak when the wave excitation is near the ship natural roll frequency because of large amplification at synchronism. When the wave excitation is apart from the natural frequency, secondary peaks may appear; however, the peaks associated with the natural frequency may still dominate the motion.

An examination of all roll spectra obtained during the nine maneuvers of the two ships (four on CHEW, and five on NELSON) showed that the roll behavior followed the foregoing trend. That is, the roll spectra were usually very narrow and characterized by a single peak at nearly the same frequency (at least for any one maneuver) irrespective of ship heading or speed.* The peak values, of course, varied with heading. This relative constancy in frequency of maximum roll energy, irrespective of heading, suggests that the ships were rolling at their natural period. The $\sqrt{E}$ obtained from the roll spectra as well as the corresponding frequencies for maximum energy in the spectra were tabulated, and these data are plotted in Figures 28 and 29 for CHEW and NELSON respectively. Figure 29 shows that NELSON during her maneuvers rolled at periods between 12 and 14 seconds, the most frequent period being about 12.5 seconds. CHEW, on the other hand, rolled at a somewhat different frequency for each of her maneuvers. In three of her four maneuvers this variation was between 10 and 14 seconds, with an average of about 12.5 seconds. During the maneuver of 2 Jan 1957, however, the roll spectra peaked at frequencies between 0.29 and 0.34 radians per second, the average frequency corresponding to a roll period of about 20 seconds. The reason for this discrepancy is not immediately apparent. To ensure that this value of 20 seconds was characteristic of the rolling motion for this maneuver, the roll spectra obtained during slow-down runs on the day prior to the maneuvers as well as the two following days were examined. These spectra all showed peaks at about 20 seconds though they were obtained at various speeds and relative headings to the predominant direction of the sea. This strongly suggests that the reason for this significantly different roll period may be due to the loading of the ship during this crossing. Though the total displacement at this time did not differ significantly from that during her maneuver of 1 May 1957 (see Table 2), it is possible that the distribution of loading was such that she had a smaller GM than usual.

An attempt was made to estimate its GM by examining the loading diagram for this particular voyage of CHEW and obtaining the KM from the curves of form. Unfortunately, the results were inconclusive in that the distribution of cargo in the loading diagram was not adequately identified.

It should be noted that during the maneuver of 2 Jan 1957, CHEW experienced her minimum rolling motion and during this maneuver only did she appear to be superior to NELSON in roll. This no doubt can be attributed to the fact that for this case her natural frequency of oscillation in this mode (0.31 radians per second) was quite far from the forcing frequency of the wave (0.52 radians per second); see Figure 34.

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*In the few cases where additional peaks occured, they were of a secondary nature.

COMPARISON OF SPEED LOSS OF THE TWO SHIPS

The average speed during each test condition was determined from the output of the impeller log. These data are listed in Tables 14 to 17 for CHEW and in Tables 18 to 21 for NELSON. Given also in the tables are the ships' heading relative to the oncoming seas, and the rpm and corresponding calm water speeds estimated from the standardization trials reported in References 1 and 2.

Standardization trials were conducted at two displacements for NELSON, 10,550 and 12,400 tons, but at only one displacement for CHEW, 10,400 tons. Therefore, for the various displacements given in Table 2, it was necessary to make an estimate of the calm water speeds for a given rpm based upon the percentage speed loss for the two displacements of NELSON. No correction was made for the differences in trim since no reliable critera were available for such a correction.

Cross plots of the data of Tables 14 to 21 were made, and the faired values were used to estimate the speed loss of the two ships for all headings at constant propeller revolutions of 96, 65, and 45 rpm. The percent loss in speed was calculated from the following formula:

$$\text{Percent speed loss} = \frac{V_{sw} - V_w}{V_{sw}} \times 100$$

where V_{sw} = still water speed at specified rpm

V_w = speed in waves at specified rpm

The results are shown in Figure 30 for CHEW and in Figure 31 for NELSON. The results from these two figures may be compared in two different ways; first, by averaging all data for a particular rpm of each ship irrespective of wave height, as shown in Figure 32; and second, by selecting from Figures 30 and 31 only those data obtained in equal or nearly equal wave height, as shown in Figure 33. From Figure 32, it can be seen that even though NELSON encountered higher waves at all three rpm's, her loss in speed is appreciably less than that for CHEW. In Figure 33, where the loss is compared when the ships are operating in equivalent wave heights, it is again apparent that NELSON is superior to CHEW. At 45 rpm there was an 80-percent speed loss for CHEW as compared to only 52 percent for NELSON.

In summary, both methods of comparison show that CHEW suffered the greatest speed loss. For both ships, the speed reduction was maximum in head seas and minimum in following seas. In some cases there was a slight increase in speed over that in still water for the same rpm in following seas. As would be expected, the speed loss for both ships increased as the rpm decreased.

ANALYSIS OF SLAMMING DATA

As mentioned earlier, few slam data are available for analysis. Although the occurrence of a slam may be detected by suddenly increased accelerations or large impact pressures, the existence of high vibratory stresses superimposed on the basic bending stress was used here as the basis for identification of a slam. Stresses were recorded on both the ASR or Sanborn and on a string oscillograph whereas pressures and accelerations were recorded only by the latter. The ASR provided a continuous record, but the string oscillograph was operated only when a slam appeared imminent. A comparison of the records from the two recorders showed that the string oscillograph was almost always activated too late to "catch" the phenomena. For example, during one test on NELSON, the ASR record showed that increased vibratory stresses occurred about 30 times, yet only five of these slams were obtained on the oscillograph. The three most severe of these slams are shown in Figures 13a, b, and c. Here, the largest pressures were measured at 15 percent of the length aft of the forward perpendicular, and were in the range of 35 to 40 psi. Maximum accelerations were of the order of 2 g. The high-frequency stress oscillations were of the order of 100 cpm. It was found by examining the ASR stress records for the 30 slams that the duration of the high-frequency oscillations varied from 30 to 50 seconds depending upon the severity of the slam. Their magnitude varied from 30 to 90 percent of the bending stress due to waves and ship motion.

ANALYSIS OF THE SPECTRAL DENSITY DATA FOR A REPRESENTATIVE PAIR OF MANEUVERS

OCEANOGRAPHIC CONDITIONS

Inasmuch as the oceanographic environment during the nine maneuvers did not differ significantly, a detailed presentation and discussion of spectra will not be made for all of the maneuvers. Instead, this will be done for a representative pair only. In examining the total mass of data collected during the trials, it was found that a comparison of the maneuvers undertaken by CHEW on 2 Jan 1957 and NELSON on 28 Mar 1958 may be most appropriate from a consideration of directionality, stability, and other characteristic properties of the waves. Therefore, the wave conditions for this set of maneuvers will be discussed in some detail.

The CHEW maneuvers of 2 Jan 1957 took place between 1300 and 1900 GMT at a location of 40.7°N latitude and 55.8°W longitude. An observer on board characterized the sea as consisting of waves having an average period of 10 seconds and an estimated height of 10 to 16 feet. A wind velocity of approximately 30 knots was recorded by the anemometer aboard ship.

The NELSON maneuver on 28 Mar 1958 was executed between 1130 and 1830 GMT at a position of 48.3°N latitude and 38.7°W longitude. During this period an observer described the sea as having a wave height ranging from 8 to 20 feet with an average period of 9 seconds. Wind velocities recorded aboard ship ranged from 21 to 26 knots.

A hindcast of the sea based on weather charts obtained in the respective operating areas was also made. These results are listed in Table 22. By using the results of this table an attempt was made to reconstruct the seaway. This was done by deriving the sea and swell spectra separately and combining the two by adding the respective components at corresponding frequencies. The sea spectra were computed using the wind velocities from Table 22 and following the procedure of Neumann for a fully developed sea. In arriving at the swell spectra the assumption was made that the known total swell energy was distributed throughout its bandwidth in a manner similar to the distribution of energy in the sea over its period band. The resulting wave spectra from the hindcast of conditions in the operating areas are plotted in Figure 34 for CHEW and Figure 35 for NELSON. Included also in the figures are the wave spectra obtained from analysis of the data obtained from the sea-state meter during hove-to conditions. These figures indicate that the period of maximum wave energy was about 12 seconds during both maneuvers with an average period of 10 seconds. The discrepancy in the statistic E between the sea-state-meter results and those of the hindcast is not considered too significant since, at best, the Neumann spectrum represents a highly idealized sea. Also, an error of only a few knots in estimating the wind force can produce a significant difference in the resulting spectrum.[5] However, the variation between the $\sqrt{E}$ values obtained at two separate times by the sea-state meter is significant – a factor of 1.4 and 1.5 in the $\sqrt{E}$ for NELSON and CHEW, respectively. It was for this reason, as explained earlier, that E values from spectra of encounter were also used in characterizing the sea conditions for the trials. A plot of the $\sqrt{E}$ as a function of time during the respective test periods is shown in Figures 36 and 37 for CHEW and NELSON, respectively, and the mean curve through all the data is taken to represent the wave height appropriate for the trial conditions. Figure 37 shows that the sea remained relatively constant during the NELSON maneuvers except during the last 1.5 hours, when there was an apparent decay. The overall agreement between the results of the hindcast and the sea-state-meter data is good from a consideration of energy content. The significant wave height varied from 8.5 to 11.5 feet as compared to 10 feet estimated from the hindcast.

Figure 36 shows that during the CHEW maneuvers there was a slight tendency for the severity of the sea to increase. The significant height varied from 7 to 10 feet. The hindcast would have predicted 16 feet. Here, however, the hindcast is doubtful because of the inherent inaccuracies mentioned earlier which are associated with such an approach. For instance, though the hindcast of Table 22 gives a wind force of 25 knots with an effective duration of 24 hours, a study of actual wind velocities measured intermittently during this 24-hour period revealed wind forces of 10 to 36 knots.

The spectra of encounter from which the E values in Figures 36 and 37 were obtained are shown in Figures 38, 39, and 40. These are included for convenience in analysis and interpretation of the motion data for this pair of maneuvers.

MOTION, ACCELERATION, AND STRESS SPECTRA

The motion and stress data obtained during the special maneuvers were analyzed by computing energy spectra. Where data were recorded on chart paper, digital computations of the spectra were made following the autocovariance transform method outlined in Reference 6. The spectra obtained during the CHEW maneuvers of 2 Jan 1957 and the NELSON maneuvers of 28 Mar 1958 will be discussed here.

During the NELSON maneuvers on 28 Mar 1958 the data were recorded on magnetic tape. These data were then analyzed by an analog method using the SEADAC system at the Model Basin.[7] Since the tape recording system comprised a somewhat new technique at the time of its use in these trials, the data were simultaneously recorded on Sanborn paper tape and these records were analyzed digitally. Sample spectra obtained by the two methods of analysis are plotted in Figures 41 and 42 for comparison purposes. The shapes show good agreement and the largest discrepancy in $\sqrt{E}$ is 15 percent.

The spectra for the various headings and speeds are plotted in Figures 43, 44, and 45 for heave accelerations; Figures 46, 47, and 48 for pitch; Figures 49, 50, and 51 for roll; Figures 52, 53, and 54 for longitudinal stress due to vertical bending.

As described under Plan of Tests, runs were made at several headings relative to the predominant wave direction as determined visually. After spectral analysis another more accurate determination of wave direction could be made. This process[8] identifies the wave direction by observing the frequency shift of a particular component in the spectra of encounter as heading angle is varied and speed is held constant. Since the most readily identifiable component is that corresponding to the period of maximum energy (i.e., peak of the spectral curve), this component was used in the present analysis. Where several independent components exist because of swell and/or wind-generated waves, multiple peaks may appear in the spectra.

As a consequence of this type of analysis, it was found that the visually determined relative headings were in some cases in error. Corrections were therefore applied and all data are presented as functions of the corrected headings.* The corrections resulted sometimes in apparent duplication of the test runs. For example, during the low-speed maneuver of CHEW, runs were made at headings of 20 and 25 deg – one port and one starboard. This was also done during the high-speed maneuver of NELSON at the 45-deg heading. These results are included in the figures as an indication of the repeatability of the measurements.

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*This correction was applied to data from all maneuvers listed in Table 2. It was not limited to the two maneuvers discussed in this section.

The roll spectra are quite uniform in their general character in that they are usually characterized by a single peak occurring at or near the natural frequencies of the respective ships. Rolling for both ships in head and bow seas is relatively small and is generally largest in beam seas. NELSON experienced larger rolling in beam seas than CHEW except at high speed where the magnitudes were comparable when compared on the basis of equivalent wave height. This may be attributed to the fact that NELSON was subjected to greater excitation near her natural period in roll.

An examination of the roll spectra show that in general when rolling is significant, and especially in beam seas, the spectra are narrow with well defined sharp peaks. For NELSON, these peaks occur at a frequency of encounter of approximately 0.50 radians/sec. In beam seas the frequency of encounter should be almost identical to the wave frequency. A comparison of the peaks in the wave spectra for the NELSON maneuvers shown in Figure 35 (point spectra) and in Figures 38, 39, and 40 (motion spectra) for beam or near beam seas indicates that this is indeed true, and moreover, this frequency is around 0.50. The peaks of the roll spectra for CHEW, on the other hand, occur at a frequency of about 0.31 radians/sec. Figure 34 (point spectra) and Figures 39 and 40 (motion spectra) for beam seas show that the frequency of maximum energy of the wave spectra for CHEW was again around 0.50 radians/sec. Thus, judging from the well-defined character of the roll spectra and the fact that the spectra peak at about the same frequency irrespective of heading, it appears that both ships were responding in their natural periods. For NELSON the exciting frequency was near the natural frequency for the ship, whereas for CHEW the exciting and natural frequencies were generally not synchronous.

In quartering and following seas, rolling was moderate to small, and the spectra in some instances show irregularities and become more broad. A striking exception to this is the following-sea run for CHEW at high speed (Figure 49) where she experienced the largest rolling during her entire maneuver. Maximum roll is not usually to be expected in following seas. However, here, because of the unusually long roll period (20 seconds), CHEW apparently approached resonance as the spectrum of encounter shifted toward the low frequencies.

The pitch spectra are much broader than the roll spectra and, in general, are characterized by multiple peaks. With few exceptions major peaks followed the peak of the spectra of encounter instead of the estimated natural periods of the ships (6.85 and 6.70 for CHEW and NELSON respectively). This indicates that the oscillation is almost completely forced. A few cases can be observed where secondary peaks in the pitch spectra correspond to the natural frequencies. One interesting example of the occurrence of both forced and synchronous oscillation is the spectrum obtained for NELSON at a 35-deg heading during the intermediate speed maneuver (Figure 47). Here, double peaks of equal magnitude exist. Both peaks correspond to peaks in the spectrum of encounter; however, the peak at $w_e = 0.9$ in the spectrum of encounter was definitely secondary. Because it corresponded to the natural pitching period, however, the pitch response spectrum was amplified at this frequency.

Spectra for heave acceleration are again broad even to a greater extent than pitch and are of a rather irregular form with multiple peaks. This is probably attributable to the greater high-frequency content in acceleration spectra than in the displacement spectra. Selected cases of the acceleration spectra were converted to displacement spectra by multiplying the ordinates of the acceleration spectra at any particular frequency, w_e, by $1/w_e^4$. (These are shown in the figures by the dashed line.) The frequency transformation results in shift of the peaks to the lower frequencies in the displacement spectra. The displacement spectra, in general, show a greater tendency to have a singular clearly defined peak. Where additional peaks are exhibited, they are usually secondary. The peaks follow very closely the peaks of the spectra of encounter, and there is no peak clearly associated with the estimated heave natural frequency of the ships (0.85 radians/sec). At the 5- and 50-deg headings for CHEW at the high speed, (Figure 43), the spectra are not as sharply peaked, and secondary peaks occur near the natural frequency, however, examination of the encounter spectra (Figure 38) showed that in these cases the encounter spectras were also quite irregular and secondary peaks were discernible at this frequency.

The stress spectra show a resemblance to the pitch spectra for a given condition. Some variations in the frequency distribution and location of peaks are discernible, because of the differences in the response amplitude operators of the two quantities. Pitching was a maximum in head seas and a minimum in following; however, stresses were equally as large in following as in head seas. A determination of the amplitude operators for these two quantities for CHEW at the 14-knot speed in following seas showed that the response characteristics in stress were relatively larger than those of pitch at the lower frequencies. Since the wave energy in following seas is concentrated in a narrow band at the lower frequencies, the stress experiences accentuated response in this region.

SUMMARY

Analyses of the data obtained from four special maneuvers of BENJAMIN CHEW and five of THOMAS NELSON lead to the following conclusions:

1. Maximum pitch occurred in head or bow seas. The pitching motion (considering the average for all maneuvers) was less for NELSON at all three speeds. At the low speed, the maximum pitch of NELSON was only 75 percent of that for CHEW, whereas at the intermediate and high speeds, it was less than 60 percent.

2. Maximum heave acceleration usually occurred in head or bow seas. The maximum heave acceleration for NELSON was only 70 percent of that for CHEW at the low and intermediate speeds, and less than 60 percent at the high speed.

3. There was little variation in longitudinal stress for either ship due to alteration in course. The stress was less for NELSON at all three speeds even though NELSON is the longer ship. The stress experienced by NELSON was only 50 percent that of CHEW.

4. Maximum roll generally occurred in beam seas. A comparison of the roll for the two ships was made difficult because of some inconsistencies in the roll data for CHEW. It is especially difficult to account for the large change in the rolling period of CHEW at the time of her maneuver on 2 Jan 1957. Subject to this reservation, a comparison of the average roll amplitudes for all the maneuvers (Figure 26) shows that NELSON has less rolling motion than CHEW.

5. Slamming accelerations and impact pressures were obtained only on NELSON. Maximum accelerations were of the order of 2 g's. Maximum slam pressures were measured at 15 percent of the length of the ship aft of the forward perpendicular, and were in the range of 35 to 40 psi. The frequency of the stress oscillations induced by the slams was about 100 cpm, and the magnitudes varied from 30 to 90 percent of the bending stress due to the waves and ship motion.

6. Loss of speed was a maximum in head seas and a minimum in following seas for both ships. At all three rpm's, the loss of speed was greater for CHEW than for NELSON. At 45 rpm, the loss of speed was 80 percent for CHEW as compared to only 52 percent for NELSON.

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TABLE 1

Ship Characteristics

	THOMAS NELSON	BENJAMIN CHEW
LOA, ft	466.8	441.5
LWL, ft	450.9	427.4
LBP, ft	441.0	416.0
Beam, ft	56.9	56.9
Depth, ft	42.7	42.7
Draft, ft	26.0	27.0
Displacement, tons	13,500	13,950
C_b	0.713	0.733
C_w	0.800	0.835
C_x	0.984	0.982
C_p	0.720	0.747
C_{pv}	0.890	0.879
SHP	6,000	6,000
Propulsion	Diesel	Steam turbine
Cargo capacity, ft^3	500,000	506,000

Note: Coefficients are based upon LWL.

TABLE 2

Draft, Trim, and Displacement for Nine Special Maneuvers

Note: Assume fresh or brackish water.

Ship	Date of Test	Draft Aft	Draft Forward	Trim by Stern	Mean Draft	Displacement tons
CHEW	2 Jan 57	26 ft 2 in.	24 ft 3 in.	1 ft 11 in.	25 ft 2.5 in.	12,400
CHEW	10 Mar 57	24 ft 11 in.	19 ft 3 in.	5 ft 8 in.	22 ft 1 in.	10,700
CHEW	8 Apr 57	24 ft 8 in.	16 ft 1 in.	8 ft 7 in.	20 ft 4.5 in.	9,750
CHEW	1 May 57	27 ft	22 ft 2 in.	4 ft 10 in.	24 ft 7 in.	12,100
NELSON	7 Oct 56	26 ft 6.5 in.	22 ft 11 in.	3 ft 7.5 in.	24 ft 8.5 in.	12,350
NELSON	14 Feb 57	27 ft 6 in.	23 ft 5 in.	4 ft 1 in.	25 ft 5.5 in.	12,800
NELSON	26 Apr 57	21 ft 6 in.	14 ft 7 in.	6 ft 11 in.	18 ft 0.5 in.	8,700
NELSON	25 Mar 58	26 ft	23 ft 3 in.	2 ft 9 in.	24 ft 7.5 in.	12,600
NELSON	28 Mar 58	26 ft	23 ft 3 in.	2 ft 9 in.	24 ft 7.5 in.	12,600

TABLE 3

Summary of Frequency and Wave Height Data during Maneuvers

Ship	Date	Significant Range of Frequencies radians/sec	Frequency of Maximum Energy of Spectrum	Average $\sqrt{E}$ for Wave Height ft
CHEW	2 Jan 57	0.3 to 1.3	0.52 to 0.52	3.02
CHEW	10 Mar 57	0.2 to 1.2	0.54 to 0.48	2.47
CHEW	8 Apr 57	0.3 to 1.2	0.46 to 0.52	2.33
CHEW	1 May 57	0.4 to 1.2	0.72 to 0.58	2.40
NELSON	7 Oct 56	0.2 to 1.3	0.60 to 0.44	3.59
NELSON	14 Feb 57	0.2 to 1.2	0.44 to 0.50	3.60
NELSON	26 Apr 57	0.1 to 1.4	0.40 to 0.55	3.74
NELSON	25 Mar 58	0.2 to 1.1	--- to 0.72	2.38
NELSON	28 Mar 58	0.3 to 1.2	0.50 to 0.50	3.72

TABLE 4

Sea Scale for a Fully Arisen Neumann Sea

Sea State	Significant Range of Frequencies radians/sec	Frequency of Maximum Energy of Spectrum	Average $\sqrt{E}$ for Wave Height ft
Low 4	0.63 to 2.5	0.87	2.1
High 4	0.59 to 2.2	0.82	2.4
Low 5	0.57 to 2.1	0.78	2.8
Intermediate 5	0.51 to 1.85	0.71	3.6
High 5	0.47 to 1.7	0.65	4.4

TABLE 5

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; BENJAMIN CHEW, 2 Jan 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
15	14	5	2.65	2.00	1.53	0.097	1.18
16	↓	50	↓	2.21	1.46	0.097	1.00
17	↓	95	↓	3.95	1.26	0.062	1.10
18	↓	140	↓	4.22	1.19	0.037	1.34
19	14	175	2.65	5.10	1.22	0.069	1.26
20	7.8	175	3.00	1.94	1.26	0.048	1.10
21	↓	130	↓	2.65	1.35	0.091	0.94
22	↓	85	↓	2.15	1.87	0.096	1.04
23	7.8	40	3.00	2.54	2.13	0.074	1.33
24	4.8	20	3.42	3.56	2.28	0.073	1.61
25	↓	25	↓	2.80	1.55	0.084	1.16
26	↓	70	↓	3.28	1.49	0.091	1.13
27	↓	115	↓	3.49	1.72	0.055	1.50
28	4.8	160	3.42	2.58	1.65	0.051	1.49

TABLE 6

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; BENJAMIN CHEW, 10 Mar 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
34	13.25	58	2.61	2.24	2.25	0.0605	1.626
35	↓	13	↓	1.96	2.11	0.0534	1.467
36	↓	32	↓	2.96	1.85	0.0576	1.466
37	↓	77	↓	3.79	1.75	0.0472	1.372
38	13.25	122	2.61	3.28	1.75	0.0470	1.508
39	8.8	142	2.49	4.11	1.61	0.0558	1.843
40	↓	173	↓	3.21	1.76	0.0495	1.494
41	↓	128	↓	4.71	1.91	0.0761	1.906
42	↓	83	↓	3.34	2.30	0.0739	1.459
43	8.8	38	2.49	2.23	2.39	0.0693	1.619
44	5.45	141	2.38	5.08	1.87		
45	↓	174	↓	3.00	1.72	0.0540	1.732
46	↓	129	↓	3.78	1.54	0.0479	1.350
47	↓	96	↓	3.17	1.85	0.0860	1.292
48	5.45	51	2.38	2.27	2.43	0.0894	1.361

TABLE 7

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress;
BENJAMIN CHEW, 8 Apr 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
98	5.5	0	2.43	4.04	2.46	----	---
99	↓	45	↓	---	2.13	0.0702	1.211
100	↓	90	↓	6.67	1.32	0.0632	1.165
101	↓	135	↓	4.21	1.64	----	1.624
102	5.5	180	2.43	3.11	1.86	0.0250	1.584
103	8.5	180	2.24	2.24	1.89	0.0261	1.626
104	↓	135	↓	4.73	1.73	0.0568	1.385
105	↓	90	↓	7.40	---	0.0808	1.296
106	↓	45	↓	4.95	2.53	0.0739	1.577
107	8.5	0	2.24	3.57	---	----	1.573

TABLE 8

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress;
BENJAMIN CHEW, 1 May 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
19	12.5	5	1.92	0.87	1.95	0.0534	0.979
20	↓	40	↓	2.70	1.32	0.0258	1.159
21	↓	180	↓	2.20	1.31	0.0358	1.140
22	↓	135	↓	3.95	1.42	0.0376	0.845
23	↓	90	↓	4.19	1.24	0.0644	0.703
24	12.5	45	1.92	3.21	2.20	0.0948	0.960
25	7.4	45	2.89	3.31	1.86	0.0681	0.873
26	↓	0	↓	1.87	2.41	0.0475	1.025
27	↓	90	↓	7.75	1.91	0.0876	0.894
28	↓	135	↓	7.42	1.98	0.0644	1.218
29	7.4	180	2.89	3.27	2.54	0.0303	1.594

TABLE 9

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; THOMAS NELSON, 7 Oct 1956

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
14 b	13.1	20	3.44	1.14	1.47	0.1074	0.8932
c	↓	25	↓	1.44	1.42	0.1225	0.7675
d	↓	75	↓	---	1.02	0.0980	----
e	↓	120	↓	---	0.74	0.0582	1.938
f	13.1	165	3.44	1.55	---	0.0422	0.848
14 g	8.3	165	3.35	2.24	1.00	0.0368	0.829
h	↓	150	↓	2.88	---	0.0643	0.783
i	↓	105	↓	---	1.28	0.1184	----
j	↓	60	↓	---	1.70	----	----
k	8.3	15	3.35	1.20	1.53	0.0714	0.869
14 l	5.0	15	3.98	---	---	0.0577	0.783
m	↓	30	↓	2.40	1.35	0.0721	0.499
n	↓	75	↓	7.57*	---	----	0.543
o	↓	130	↓	3.88	---	0.0546	0.567
p	5.0	175	3.98	1.86	1.16	0.0411	0.705

*Synchronous rolling.

TABLE 10

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; THOMAS NELSON, 14 Feb 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
14	14.6	5	3.81	0.95	1.86	0.0682	0.959
15	↓	40	↓	1.12	1.90	0.0764	0.909
16	↓	85	↓	4.55	1.02	0.0630	0.606
17	↓	130	↓	3.44	1.22	0.0397	1.302
18	14.6	175	3.81	1.42	1.07	0.0273	0.937
20	7.6	175	3.38	1.41	1.09	0.0263	0.899
21	↓	130	↓	4.30	1.32	0.0451	0.943
22	↓	85	↓	4.85	0.66	0.0498	---
23	↓	40	↓	2.52	1.18	----	---
24	7.6	5	3.38	---	1.56	----	0.949

TABLE 11

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; THOMAS NELSON, 26 Apr 1957

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
2	6.8	165	3.69	3.51	1.08	0.0317	0.74
3	↓	150	↓	3.12	1.13	0.0397	0.74
4	↓	105	↓	5.91	1.14	0.0538	0.53
5	↓	60	↓	5.47	1.05	0.0550	0.56
6	6.8	15	3.69	2.34	1.72	0.0481	0.93
7	8.8	15	3.91	2.73	1.84	0.0636	1.00
8	↓	60	↓	6.61	1.37	0.0749	0.65
9	↓	105	↓	5.68	0.99	0.0602	0.49
10	↓	150	↓	3.47	1.17	0.0402	0.77
11	8.8	165	3.91	3.43	0.97	0.0195	0.72
12	14.8	175	3.61	2.94	1.03	0.0182	0.70
13	↓	130	↓	3.46	0.96	0.0396	0.68
14	↓	85	↓	5.29	1.01	0.0596	0.48
15	↓	40	↓	5.22	1.26	0.0727	0.63
16	14.8	10	3.61	3.69	1.66	0.0713	0.91

TABLE 12

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; THOMAS NELSON, 25 Mar 1958

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
16	14.8	5	2.62	---	1.89	0.0785	---
17	↓	50	↓	---	1.68	0.0697	---
18	↓	85	↓	3.02	1.27	0.0691	---
19	↓	130	↓	3.66	0.94	0.0350	---
20	14.8	175	2.62	2.02	1.78	0.0434	---
21	10.3	170	2.44	2.31	1.20	0.0371	---
22	↓	145	↓	2.87	1.48	0.0457	0.953
23	↓	100	↓	2.60	1.36	0.0557	0.814
24	↓	55	↓	2.28	1.26	0.0607	0.729
25	10.3	0	2.44	1.67	1.47	0.0420	0.758
26	5.5	0	2.09	2.35	1.38	0.0320	0.852
27	↓	45	↓	---	1.21	0.0353	0.801
28	↓	90	↓	---	1.20	0.0373	0.680
29	↓	135	↓	2.96	0.89	0.0339	0.644
30	5.5	180	2.09	1.55	1.03	0.0271	0.736

TABLE 13

$\sqrt{E}$ for Wave Height, Roll, Pitch, Heave Acceleration, and Stress; THOMAS NELSON, 28 Mar 1958

Run Number	Average Speed knots	Heading deg	Wave Height Average ft	Roll deg	Pitch deg	Heave Acceleration g's	Stress kips/in.^{2}
43	13.4	45	4.08	3.94	2.42	0.0954	1.634
44	↓	0	↓	1.87	2.74	0.0825	1.667
45	↓	45	↓	3.43	2.34	0.0921	1.367
46	↓	90	↓	6.43	1.24	0.0734	1.166
47	13.4	145	4.08	2.89	1.60	0.0332	1.330
48	10.4	145	3.71	3.86	1.36	0.0300	1.349
49	↓	170	↓	3.77	1.48	0.0387	1.403
50	↓	125	↓	5.34	1.53	0.0583	1.646
51	↓	80	↓	6.80	1.51	0.0728	1.204
52	10.4	35	3.71	2.81	2.30	0.0616	1.572
53	5.2	35	3.36	3.71	2.24	0.0490	1.729
54	↓	10	↓	1.67	2.06	0.0400	1.593
55	↓	60	↓	4.85	1.73	0.0566	1.241
56	↓	105	↓	5.34	1.03	0.0424	0.959
57	5.2	150	3.36	2.69	1.32	0.0332	1.077

TABLE 14

Average Speed obtained at Various Headings for Constant RPM; BENJAMIN CHEW, 2 Jan 1957

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
15	99	14.80	11.5	5	2.65
16	↓	↓	12.7	50	↓
17	↓	↓	14.3	95	↓
18	↓	↓	15.0	140	↓
19	99	14.80	15.3	175	2.65
20	65	10.55	10.8	175	3.00
21	↓	↓	8.8	130	↓
22	↓	↓	6.8	85	↓
23	65	10.55	4.8	40	3.00
24	45	7.35	1.8	20	3.42
25	↓	↓	3.5	25	↓
26	↓	↓	5.1	70	↓
27	↓	↓	7.0	115	↓
28	45	7.35	6.8	160	3.42

TABLE 15

Average Speed obtained at Various Headings for Constant RPM; BENJAMIN CHEW, 10 Mar 1957

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
34	45	7.35	4.0	58	2.61
35	45	7.35	6.0	13	↓
36	45	7.35	5.0	32	↓
37	46	7.50	5.7	77	↓
38	45	7.35	6.5	122	2.61
39	66	10.80	9.7	142	2.49
40	66	10.80	9.0	173	↓
41	65	10.70	8.75	128	↓
42	65	10.70	8.50	83	↓
43	65	10.70	8.00	38	2.49
44	99	15.25	12.7	141	2.38
45	99	15.25	13.5	174	↓
46	100	15.35	14.0	129	↓
47	100	15.35	13.2	96	↓
48	99	15.25	12.7	51	2.38

TABLE 16

Average Speed obtained at Various Headings for Constant RPM; BENJAMIN CHEW, 8 Apr 1957

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
98	45	7.35	4.2	0	2.43
99	45	7.35	4.5	45	↓
100	46	7.50	5.8	90	↓
101	45	7.35	6.5	135	↓
102	45	7.35	7.0	180	2.43
103	66	10.90	10.0	180	2.24
104	67	11.00	9.5	135	↓
105	64	10.70	9.0	90	↓
106	65	10.80	7.5	45	↓
107	65	10.80	7.0	0	2.24

TABLE 17

Average Speed obtained at Various Headings for Constant RPM; BENJAMIN CHEW, 1 May 1957

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
19	85	13.20	---	5	1.92
20	86	13.30	---	40	
21	94	14.25	13.8	180	
22	94	14.25	13.0	135	
23	92	14.05	12.8	90	
24	89	13.70	10.5	45	1.92
25	65	10.50	7.0	45	2.89
26	60	9.70	4.7	0	
27	61	9.85	6.5	90	
28	63	10.15	8.3	135	
29	62	10.00	10.4	180	2.89

TABLE 18

Average Speed obtained at Various Headings for Constant RPM; THOMAS NELSON, 7 Oct 1956

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
14 b	92	14.80	12.5	20	3.44
c	90	14.45	12.5	25	
d	90	14.45	13.0	75	
e	90	14.45	13.7	120	
f	90	14.45	14.0	165	3.44
14 g	58	9.55	9.8	165	3.35
h	58	9.55	9.0	150	
i	59	9.75	8.8	105	
j	59	9.75	7.8	60	
k	59	9.75	7.9	15	3.35
14 l	38	6.30	3.8	15	3.98
m	38	6.30	4.0	30	
n	38	6.30	5.0	75	
o	39	6.55	5.8	130	
p	39	6.55	6.2	175	3.98

TABLE 19

Average Speed obtained at Various Headings for Constant RPM; THOMAS NELSON, 14 Feb 1957

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
14	93	14.90	14.5	5	3.81
15	95	15.10	14.5	40	↓
16	95	15.10	14.7	85	↓
17	95	15.10	14.5	130	↓
18	95	15.10	15.0	175	3.81
20	50	8.30	8.0	5	3.38
21	↓	↓	8.0	50	↓
22	↓	↓	8.5	95	↓
23	↓	↓	7.0	140	↓
24	50	8.30	6.25	175	3.38

TABLE 20

Average Speed obtained at Various Headings at Constant RPM; THOMAS NELSON, 25 Mar 1958

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
16	96	15.25	12.5	5	2.62
17	↓	↓	13.0	50	↓
18	↓	↓	14.0	85	↓
19	↓	↓	15.0	130	↓
20	96	15.25	15.5	175	2.62
21	70	11.50	11.5	170	2.44
22	↓	↓	11.5	145	↓
23	↓	↓	10.5	100	↓
24	↓	↓	9.0	55	↓
25	70	11.50	9.0	0	2.44
26	40	6.60	4.2	0	2.09
27	↓	↓	4.5	45	↓
28	↓	↓	5.5	90	↓
29	↓	↓	6.5	135	↓
30	40	6.60	7.0	180	2.09

TABLE 21

Average Speed obtained at Various Headings at Constant RPM; THOMAS NELSON, 28 Mar 1958

Run Number	RPM	Calm Water Speed knots	Measured Speed knots	Heading deg	Average $\sqrt{E}$ for Wave ft
43	96	15.25	12.2	45	4.08
44	↓	↓	12.0	0	↓
45	↓	↓	13.2	45	↓
46	↓	↓	14.4	90	↓
47	96	15.25	15.0	145	4.08
48	72	11.85	11.6	145	3.71
49	↓	↓	11.6	170	↓
50	↓	↓	10.2	125	↓
51	↓	↓	10.0	80	↓
52	72	11.85	8.4	35	3.71
53	40	6.60	3.4	35	3.36
54	↓	↓	3.3	10	↓
55	↓	↓	4.9	60	↓
56	↓	↓	6.0	105	↓
57	40	6.60	6.4	150	3.36

TABLE 22

Sea and Swell Hindcasts in Operating Areas of Liberty Ship Trials

	BENJAMIN CHEW	THOMAS NELSON
Date	2 Jan 1957	28 Mar 1958
Time	1305 – 1912	1105 – 1830
Ship Position	40.7°N 55.8°W	48.3°N 38.7°W
Sea		
Location of fetch	43.1°N 58.8°W	55.8°N 43.6°W
Fetch width, NM	350	210
Fetch length, NM	230	990
Wind speed, knots	25	20
Effective duration, hours	24	108
Wave direction	NNW	NNW
Total energy, E (ft^2)	26	8
Period band, sec	3.8 – 13.6	3.0 – 11.1
Significant height, ft	14	8
Swell		
Location of generating area	40.0°N 60.9°W	55.0°N 49.3°W
Fetch width, NM	240	360
Fetch length, NM	420	900
Swell direction	NW	NW
Total energy of contributing swell, E (ft^2)	5	4.5
Period band of contributing swell, sec	9 – 13	5 – 13.5
Significant height, ft	6	6

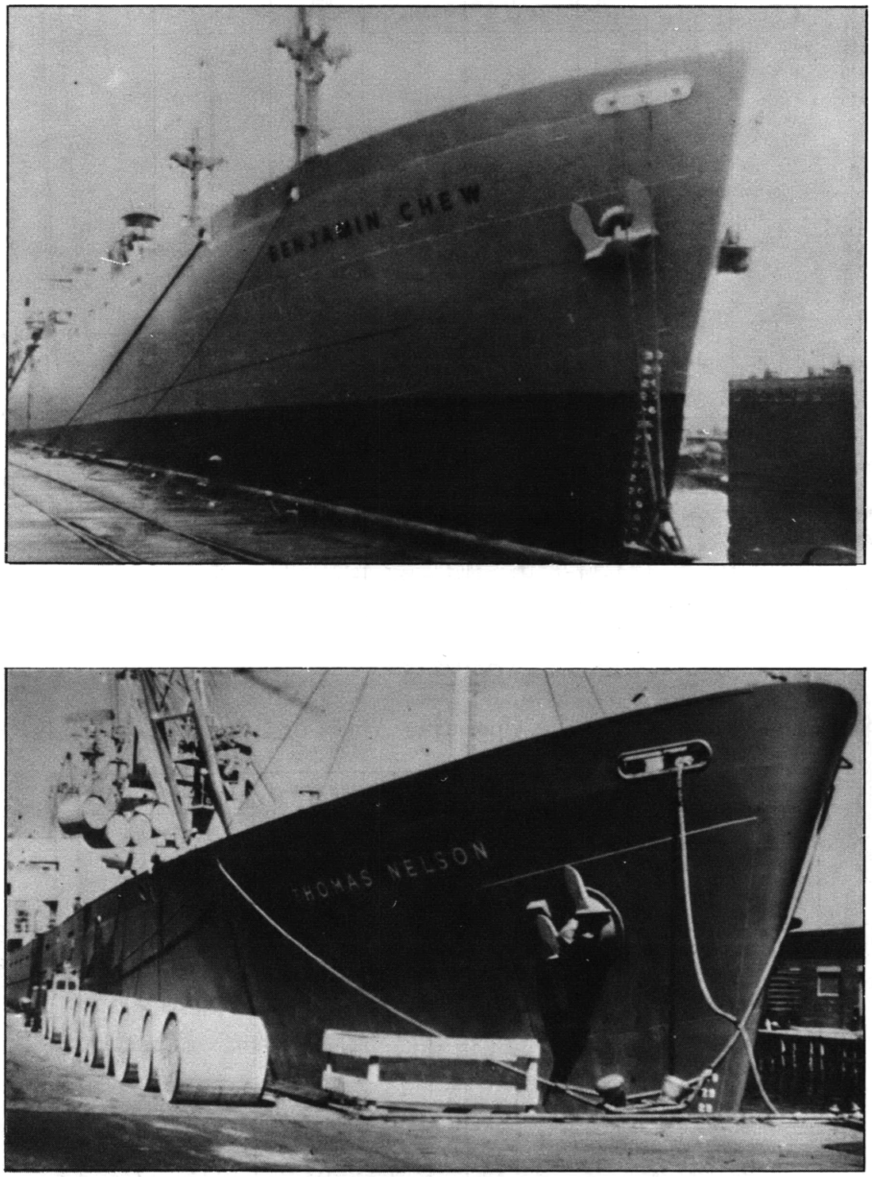


Figure 1 – Bow Profile of BENJAMIN CHEW and THOMAS NELSON

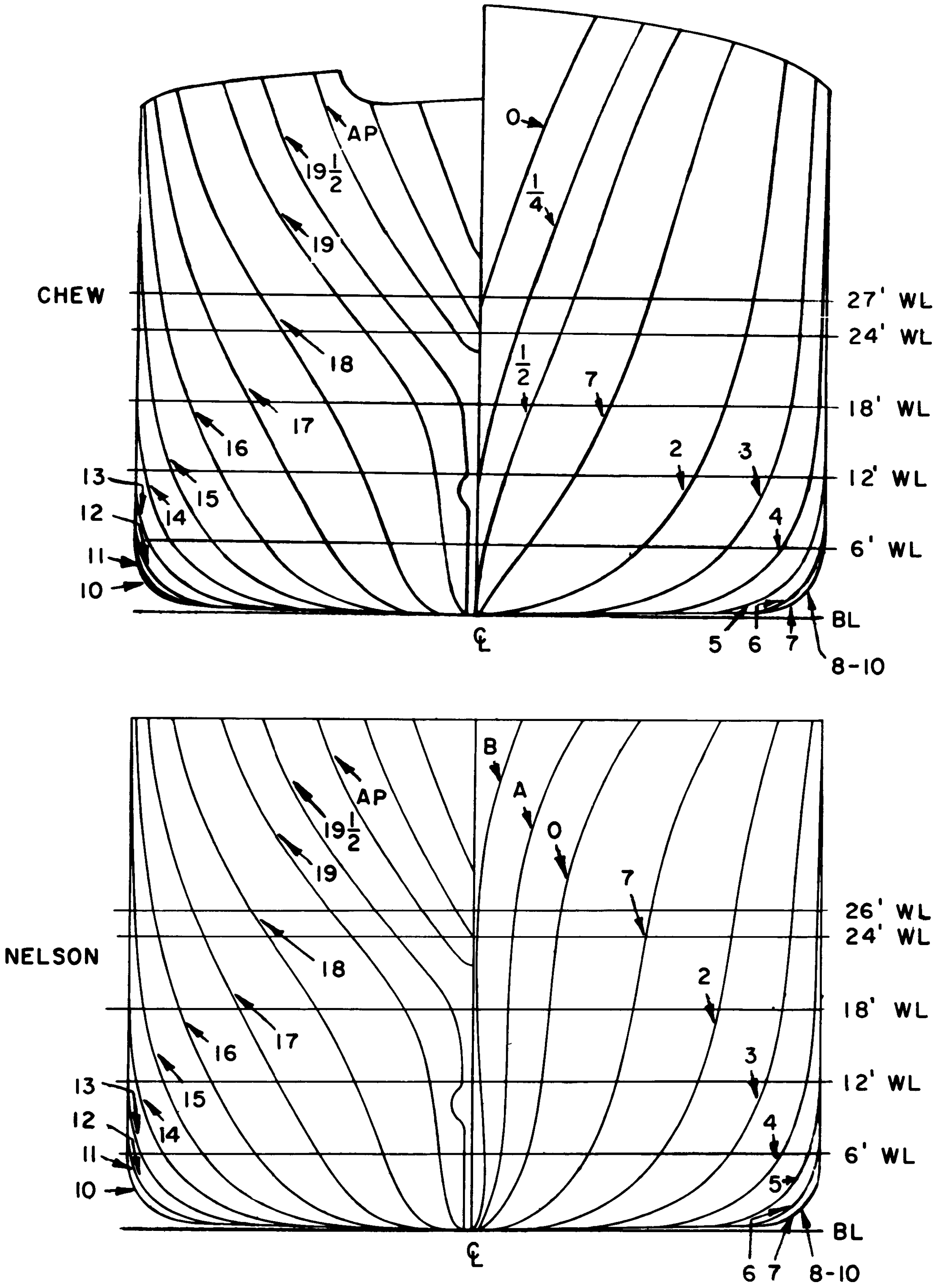


Figure 2 – Comparison of Body Plans of CHEW and NELSON

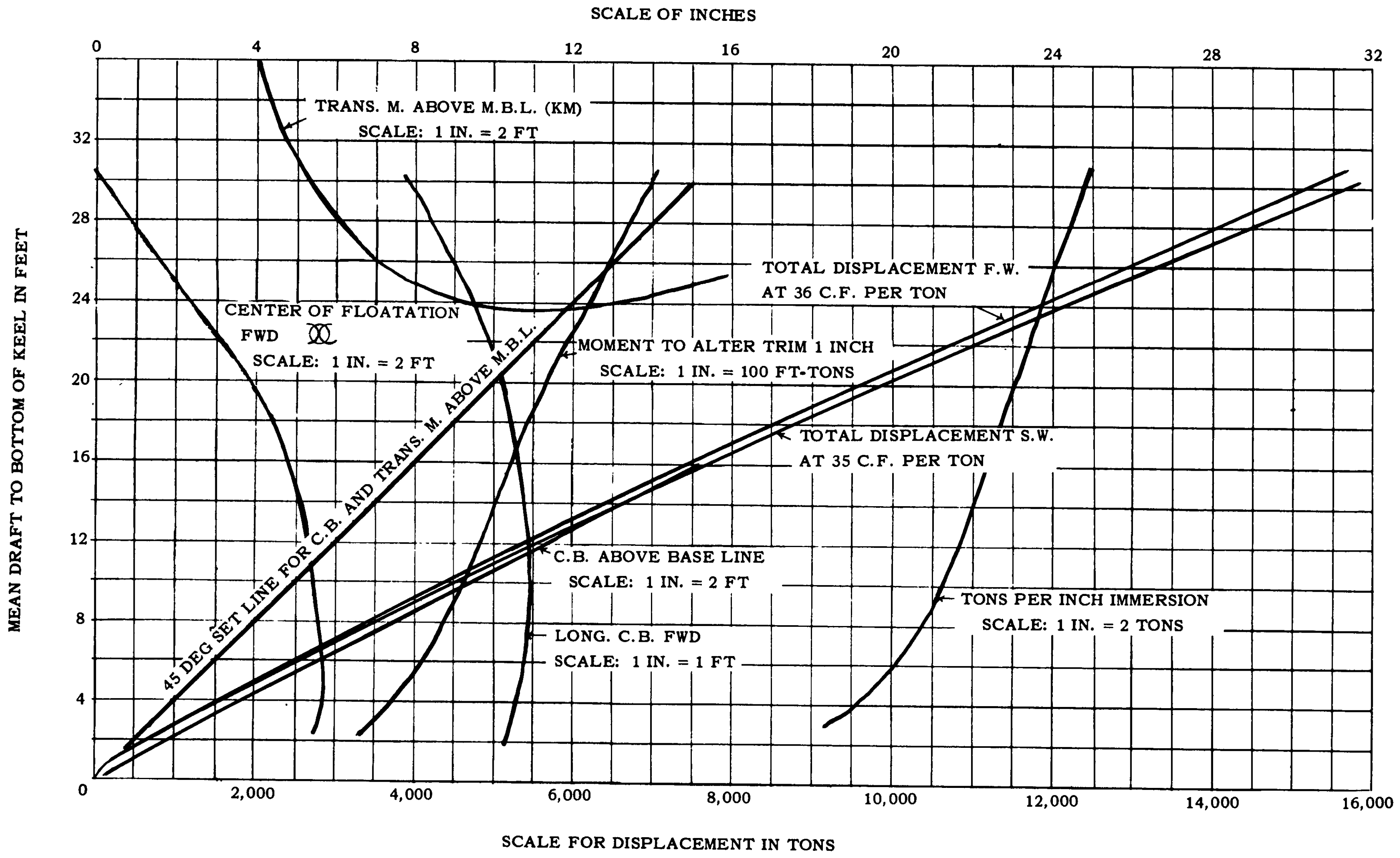


Figure 3 – Curves of Form for BENJAMIN CHEW

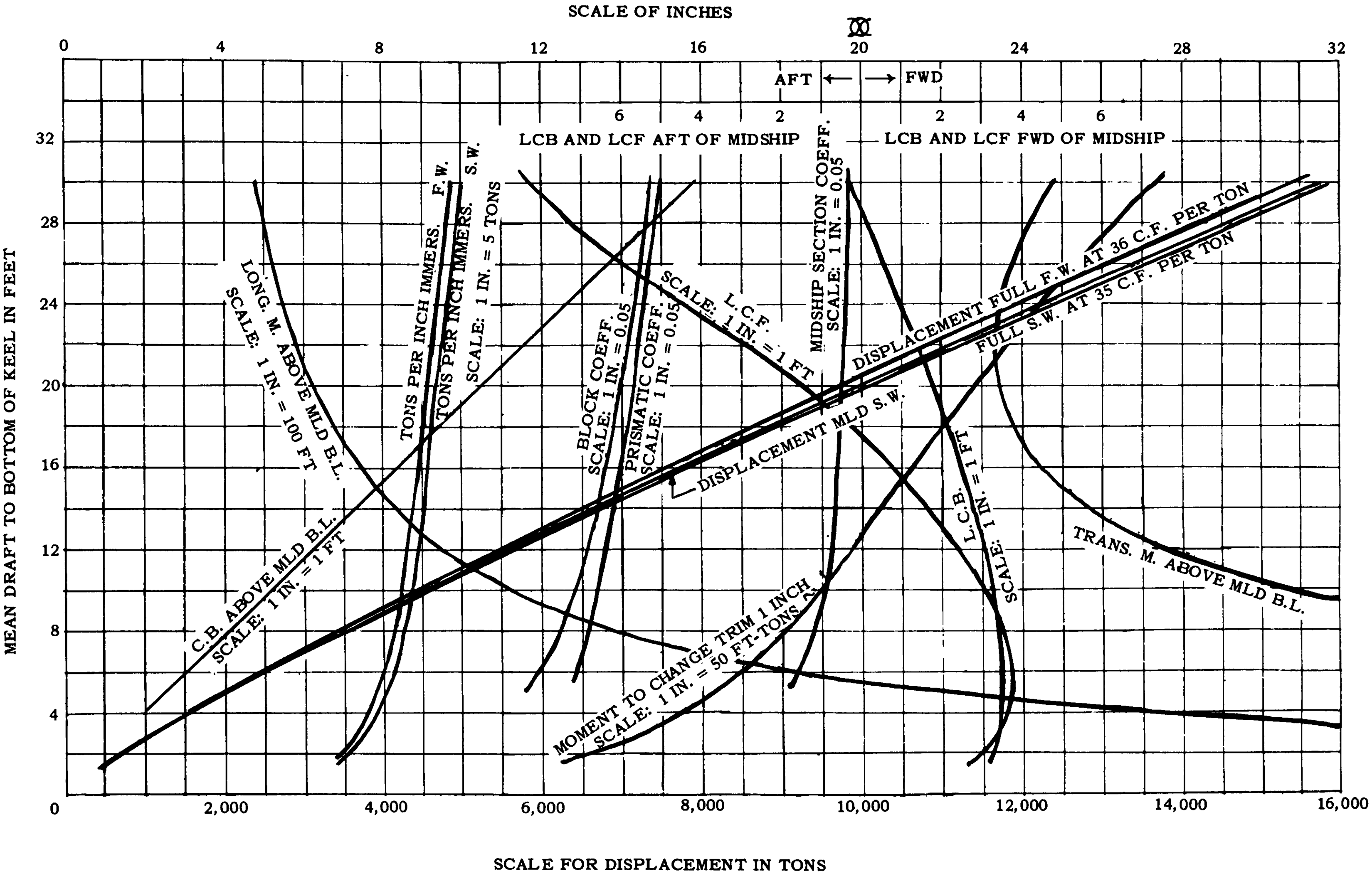


Figure 4 – Curves of Form for THOMAS NELSON

PRINCIPAL DIMENSIONS

L.O.A.	466′–10″
L.B.P.	441′–0″
BEAM MLD.	56′–10 3/4″
BEAM EXTREME	57′–0″
DEPTH MOLDED TO UPPER DECK	37′–4″
DEPTH MOLDED TO 2ND DECK	28′–7″
DRAFT LOADED MLD.	26′–0″

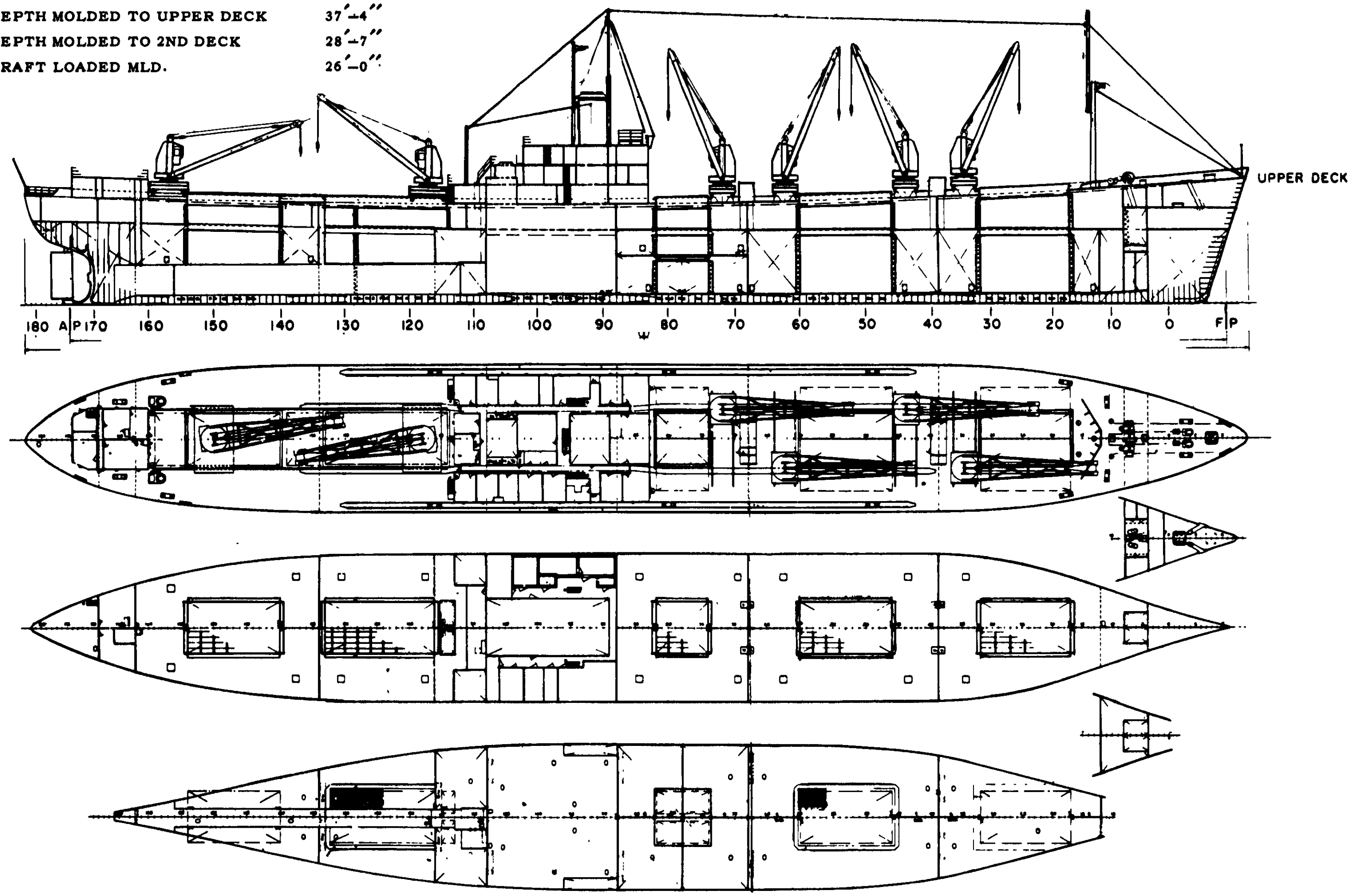


Figure 5 – Inboard Profile and General Arrangement of Decks for CHEW

PRINCIPAL DIMENSIONS

L.O.A.	441′–6″
L.B.P.	416′–0″
BEAM MLD.	36′–10 3/4″
BEAM EXTREME	37′–0″
DEPTH MOLDED TO UPPER DECK	37′–4″
DEPTH MOLDED TO 2ND DECK	28′–7″
DRAFT LOADED MLD.	23′–10 3/4″

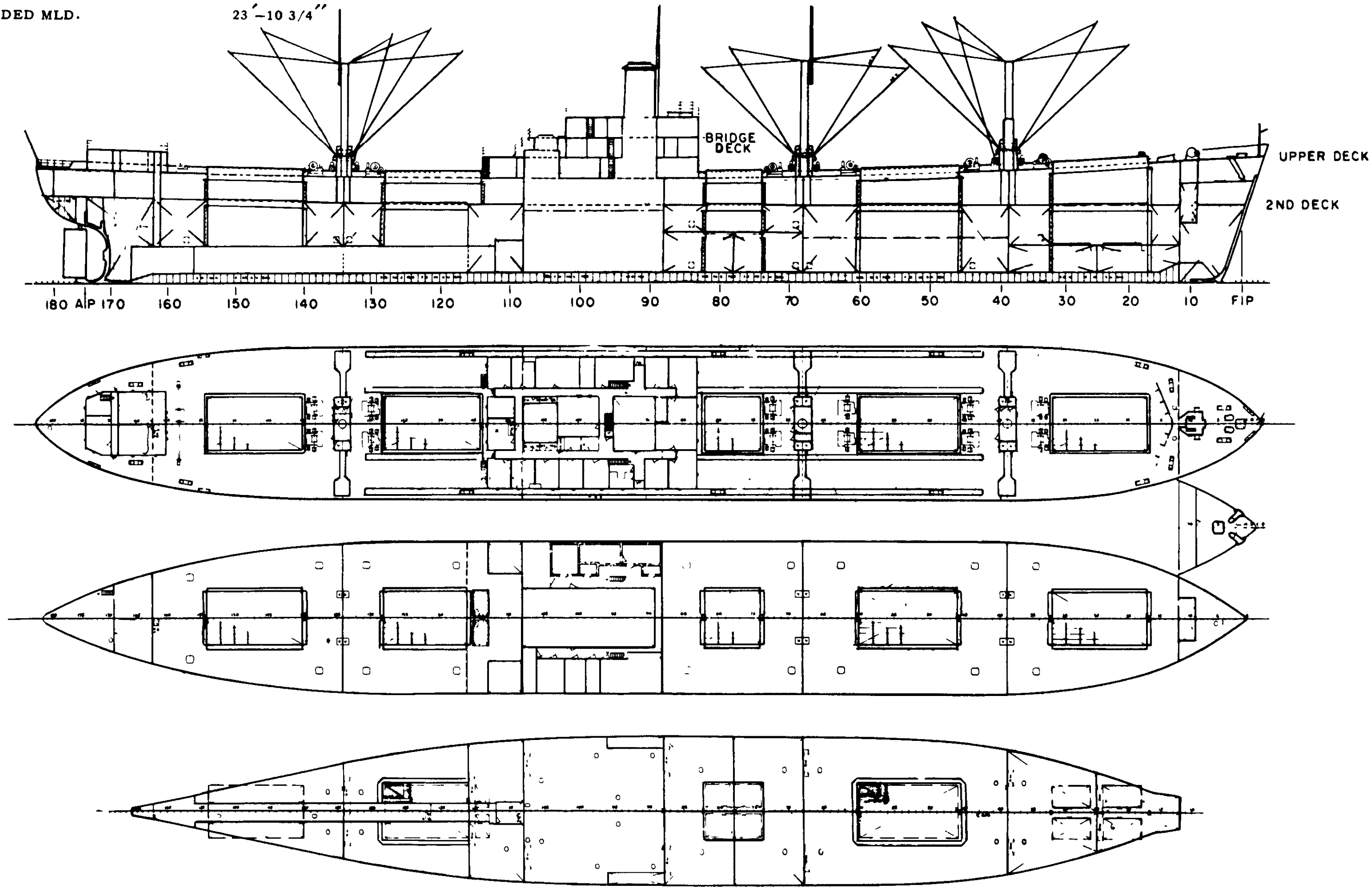
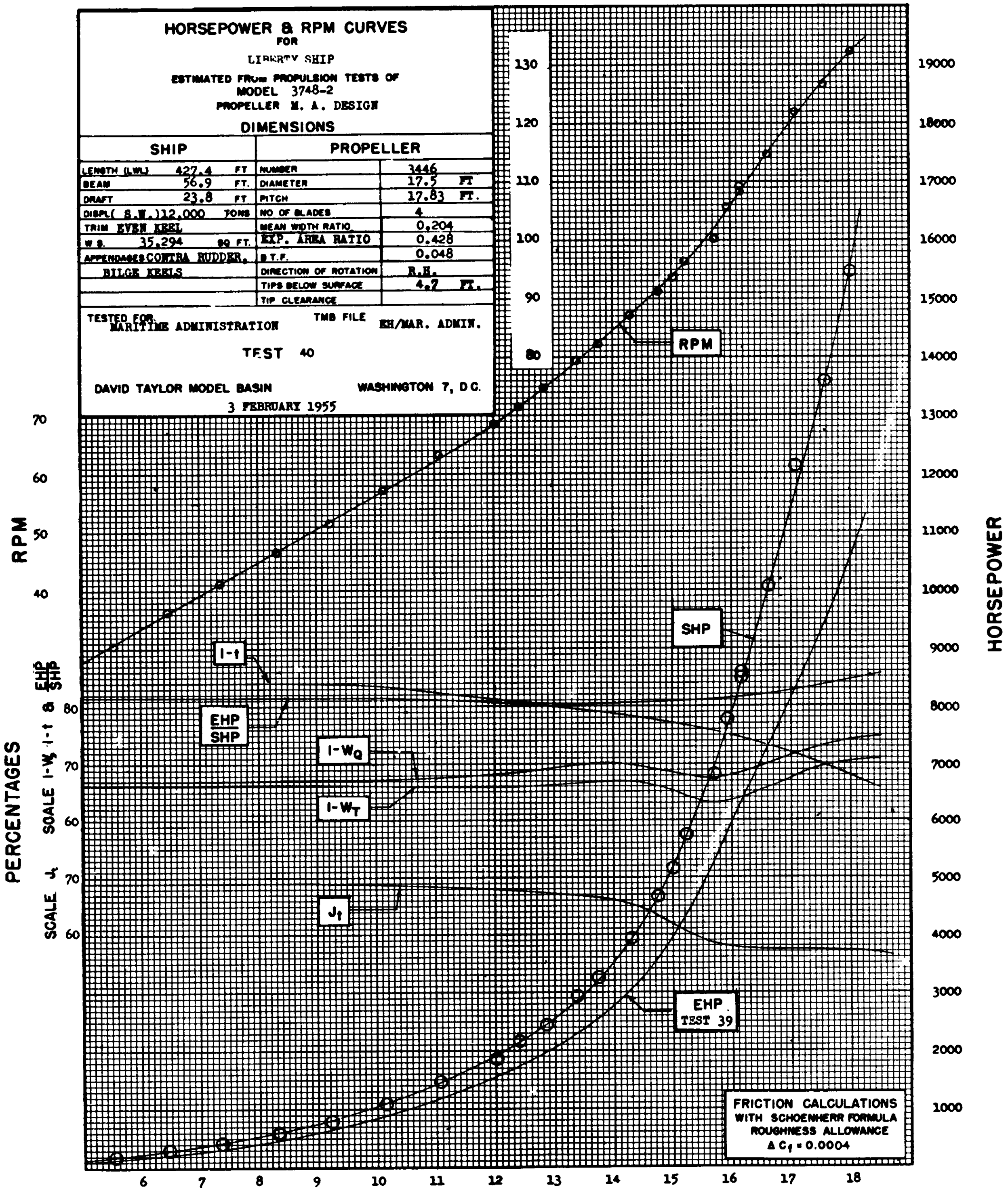


Figure 6 – Inboard Profile and General Arrangement of Decks for NELSON



HORSEPOWER & RPM CURVES
FOR
LIBERTY SHIP
ESTIMATED FROM PROPULSION TESTS OF
MODEL 3748-2
PROPELLER M. A. DESIGN

DIMENSIONS

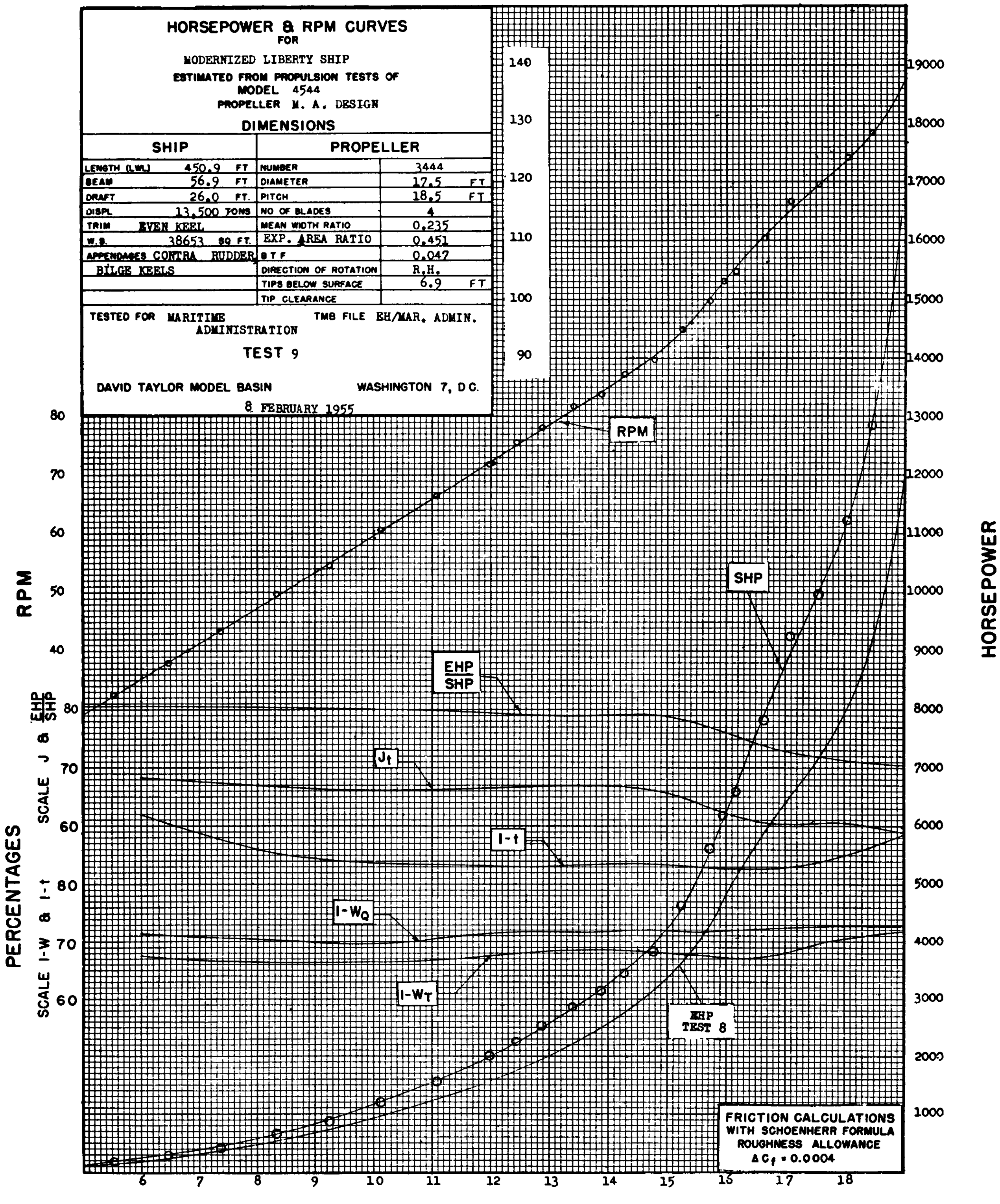
SHIP			PROPELLER	
LENGTH (LWL)	427.4	FT	NUMBER	3446
BEAM	56.9	FT.	DIAMETER	17.5 FT
DRAFT	23.8	FT	PITCH	17.83 FT.
DISPL(S.W.)	12,000	TONS	NO OF BLADES	4
TRIM EVEN KEEL			MEAN WIDTH RATIO	0.204
W S.	35,294	SQ FT.	EXP. AREA RATIO	0.428
APPENDAGES CONTRA RUDDER,			B T.F.	0.048
BILGE KEELS			DIRECTION OF ROTATION	R.H.
			TIPS BELOW SURFACE	4.7 FT.
			TIP CLEARANCE	

TESTED FOR MARITIME ADMINISTRATION
TMB FILE EH/MAR. ADMIN.

TEST 40

DAVID TAYLOR MODEL BASIN
WASHINGTON 7, D C.
3 FEBRUARY 1955

Figure 7 – Horsepower and RPM Curves for BENJAMIN CHEW at 12,000 Tons Displacement



HORSEPOWER & RPM CURVES
FOR
MODERNIZED LIBERTY SHIP
ESTIMATED FROM PROPULSION TESTS OF
MODEL 4544
PROPELLER M. A. DESIGN

DIMENSIONS

SHIP			PROPELLER		
LENGTH (LWL)	450.9	FT	NUMBER	3444	
BEAM	56.9	FT	DIAMETER	17.5	FT
DRAFT	26.0	FT.	PITCH	18.5	FT
DISPL	13,500	TONS	NO OF BLADES	4	
TRIM	EVEN KEEL		MEAN WIDTH RATIO	0.235	
W.S.	38653	SQ FT.	EXP. AREA RATIO	0.451	
APPENDAGES	CONTRA RUDDER		B T F	0.047	
BILGE KEELS			DIRECTION OF ROTATION	R.H.	
			TIPS BELOW SURFACE	6.9	FT
			TIP CLEARANCE		

TESTED FOR MARITIME ADMINISTRATION
TMB FILE EH/MAR. ADMIN.

TEST 9

DAVID TAYLOR MODEL BASIN
WASHINGTON 7, D C.

8 FEBRUARY 1955

Figure 8 – Horsepower and RPM Curves for THOMAS NELSON at Design Displacement

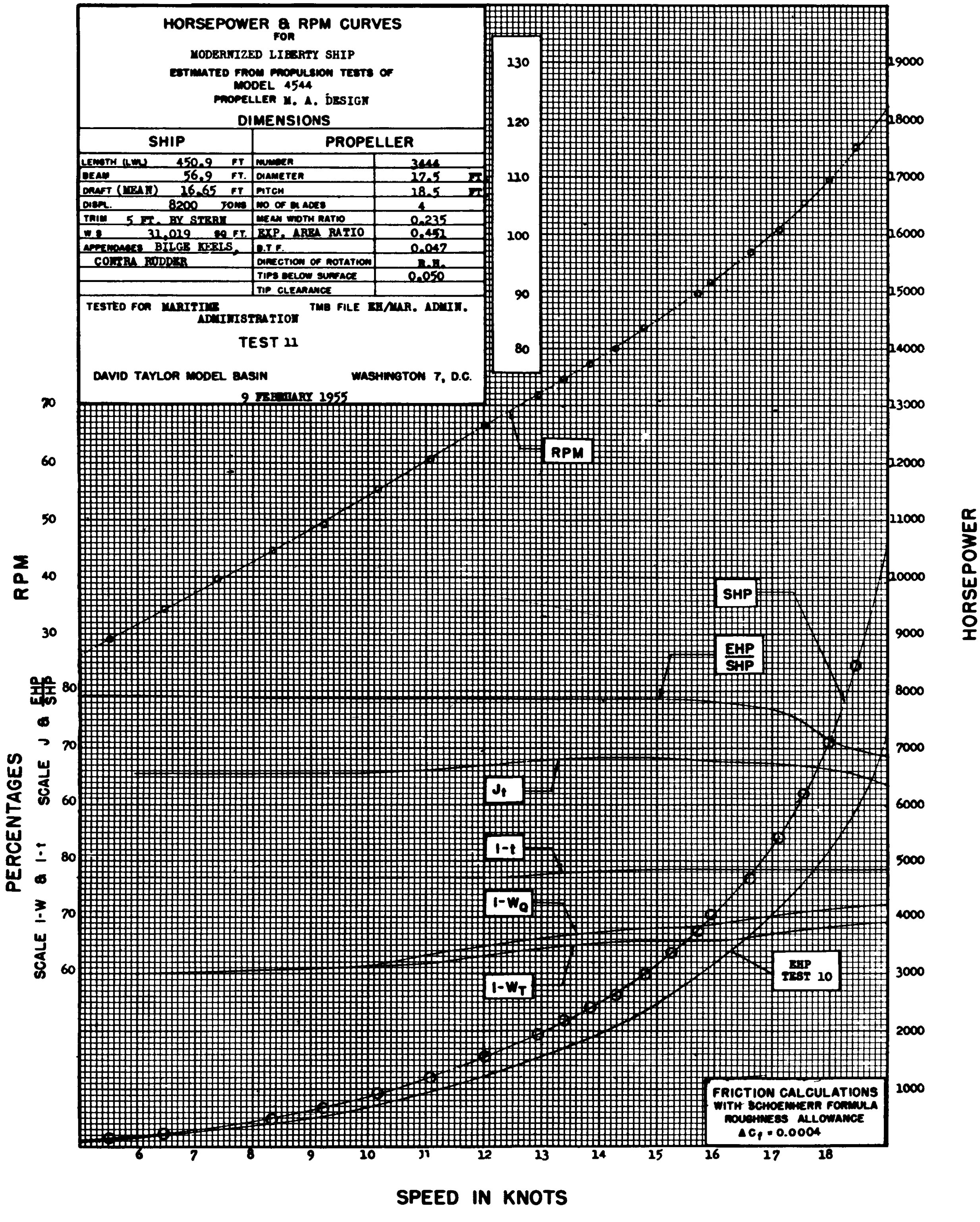


Figure 9 – Horsepower and RPM Curves for THOMAS NELSON at Light Displacement

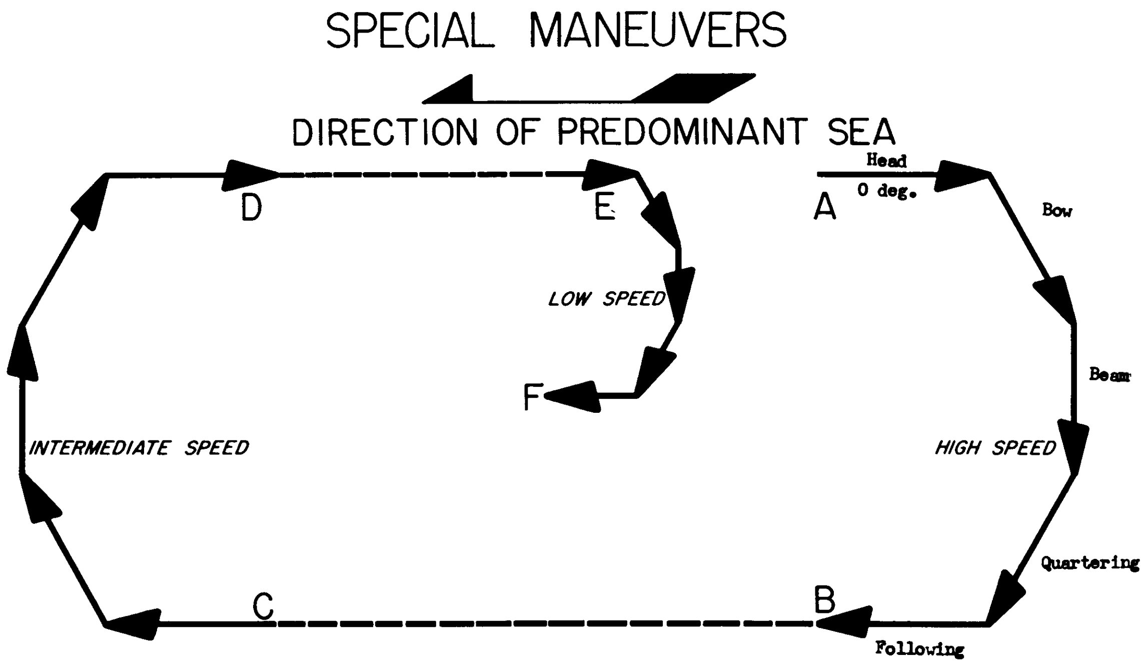


Figure 10 – Maneuvers Used in Conducting Full-Scale Seaworthiness Trials on BENJAMIN CHEW and THOMAS NELSON

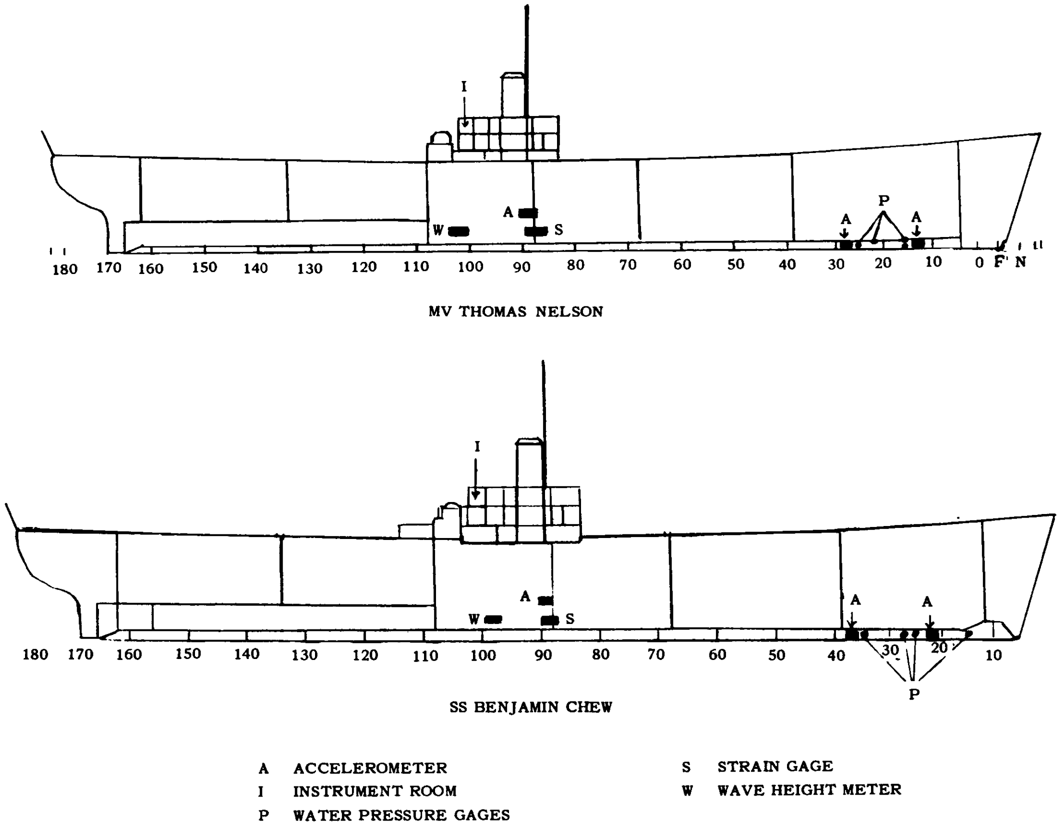


Figure 11 – Location of Instruments

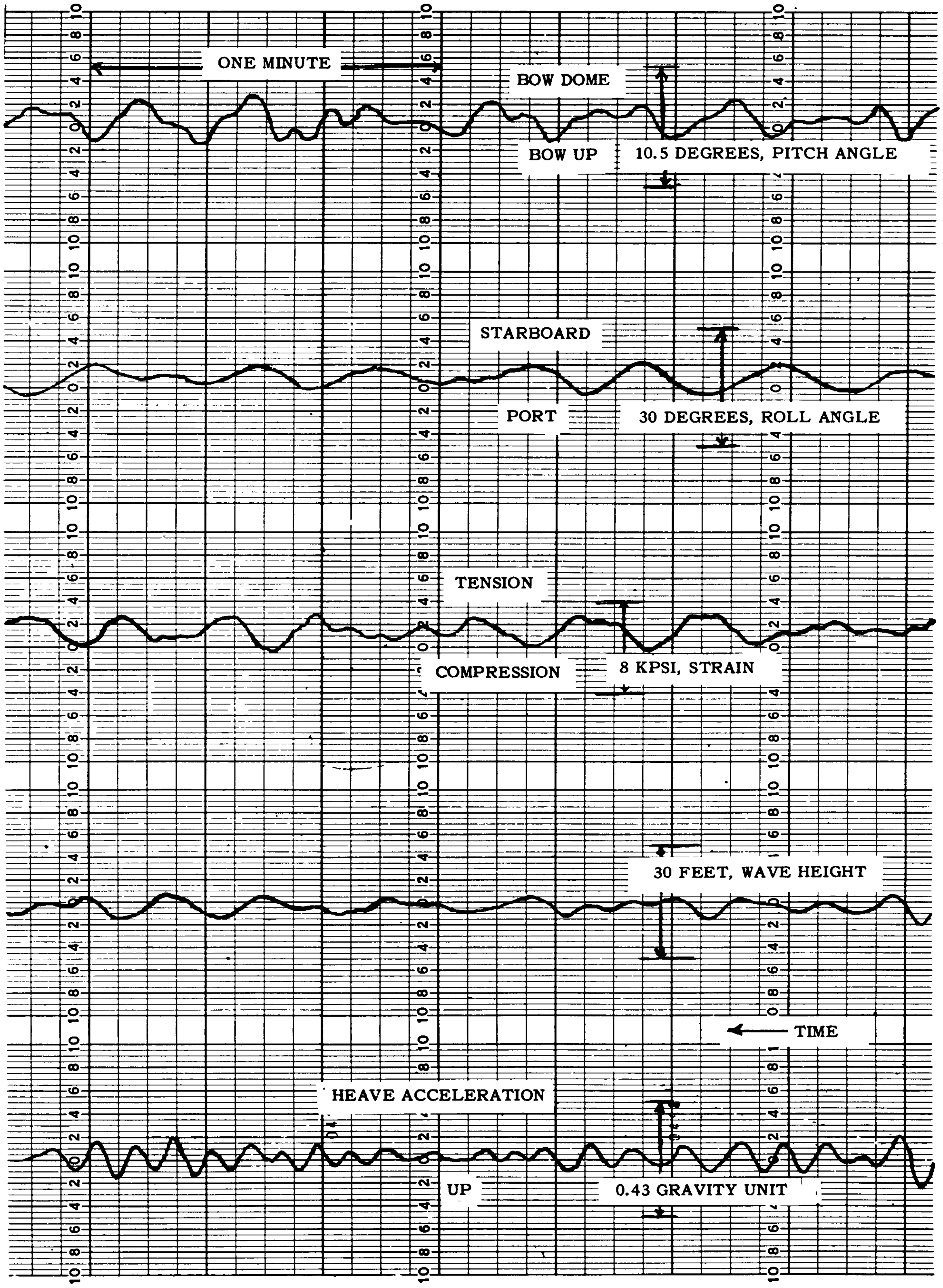


Figure 12 – Sample Trace from the Automatic Statistical Recorder

Figure 13 – Samples of Oscillograph Records

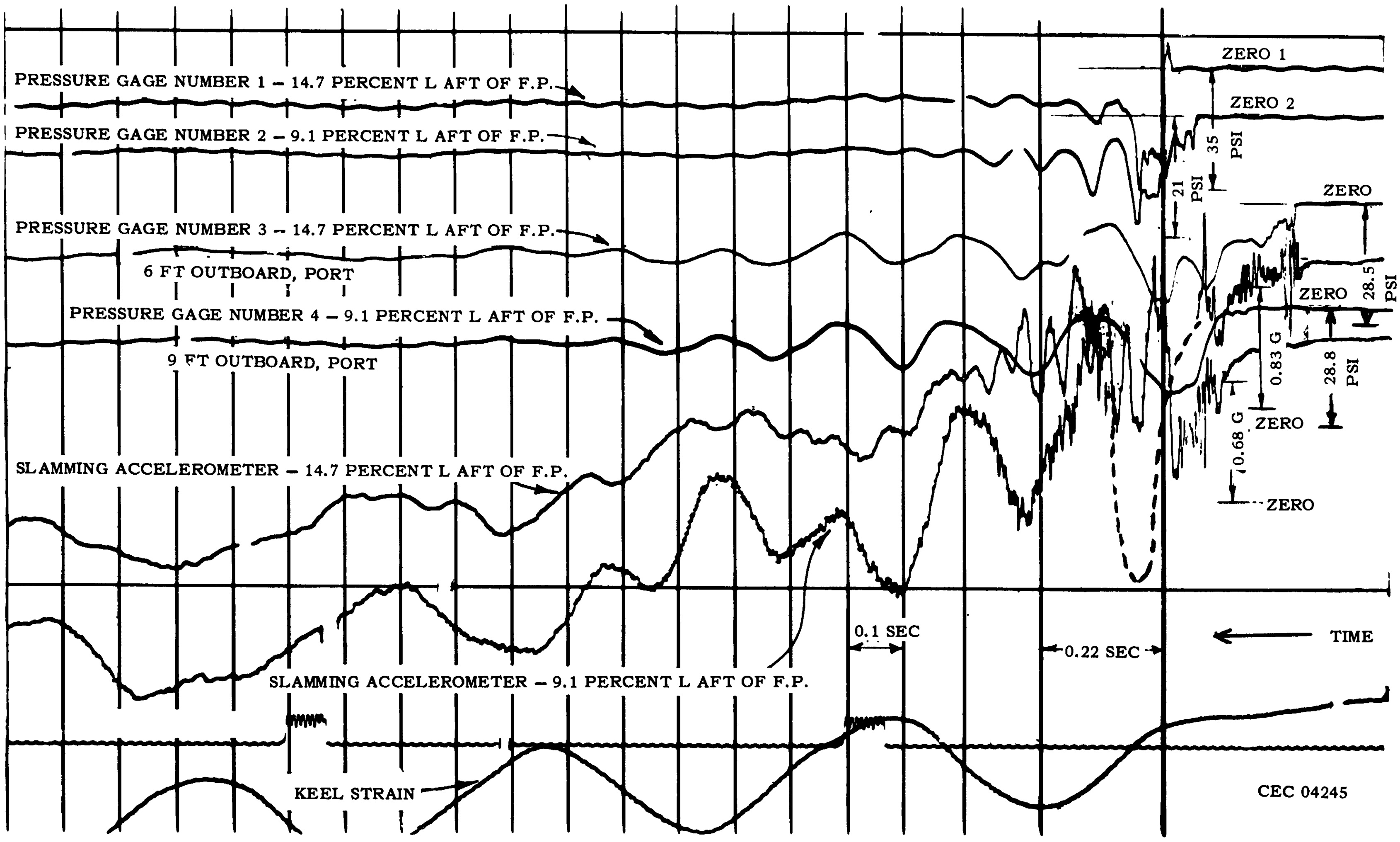


Figure 13a

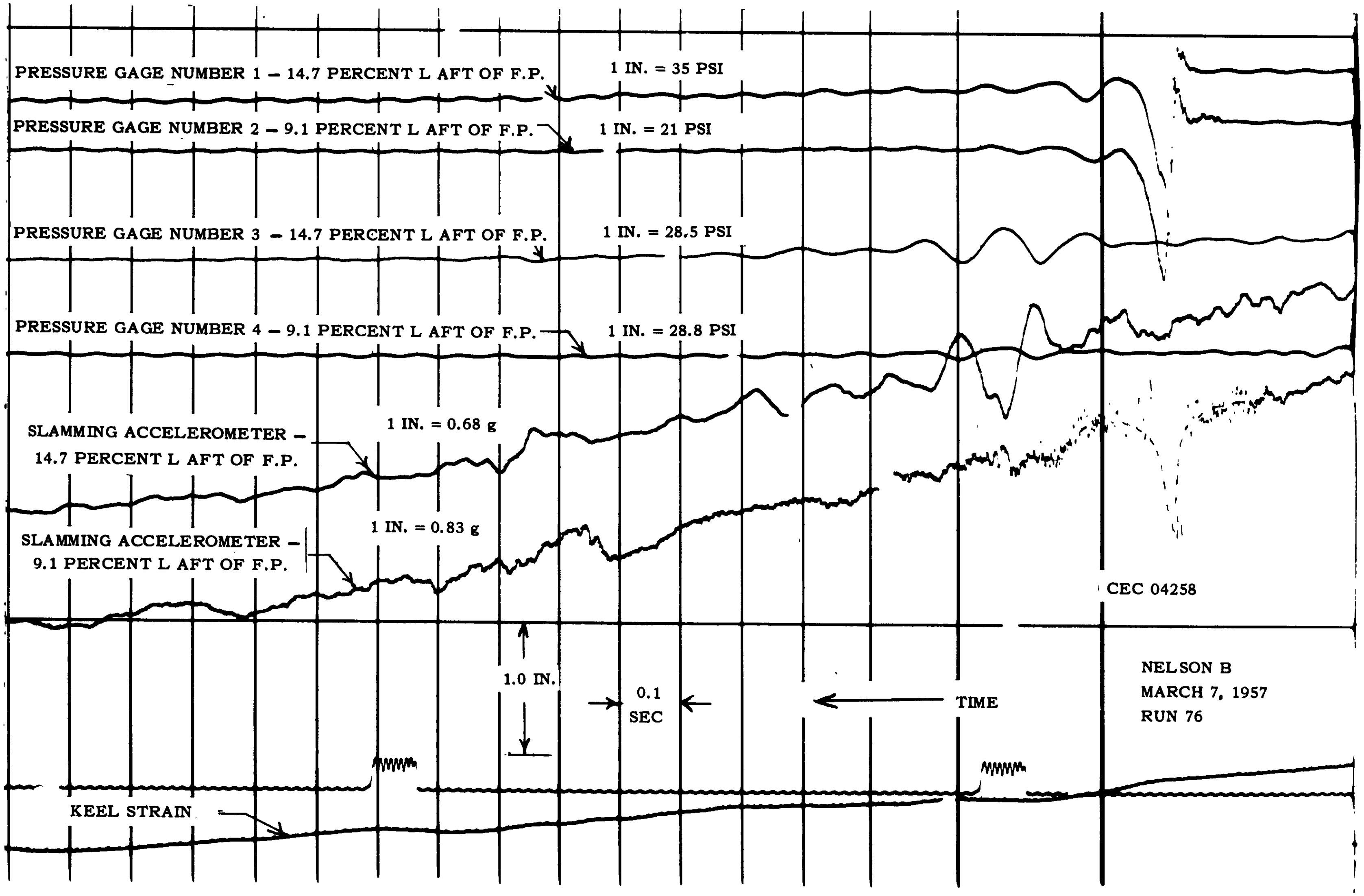

PRESSURE GAGE NUMBER 1 – 14.7 PERCENT L AFT OF F.P.
1 IN. = 35 PSI
PRESSURE GAGE NUMBER 2 – 9.1 PERCENT L AFT OF F.P.
1 IN. = 21 PSI
PRESSURE GAGE NUMBER 3 – 14.7 PERCENT L AFT OF F.P.
1 IN. = 28.5 PSI
PRESSURE GAGE NUMBER 4 – 9.1 PERCENT L AFT OF F.P.
1 IN. = 28.8 PSI
SLAMMING ACCELEROMETER – 14.7 PERCENT L AFT OF F.P.
1 IN. = 0.68 g
SLAMMING ACCELEROMETER – 9.1 PERCENT L AFT OF F.P.
1 IN. = 0.83 g
CEC 04258
1.0 IN.
0.1 SEC
TIME
NELSON B
MARCH 7, 1957
RUN 76
KEEL STRAIN

Figure 13b

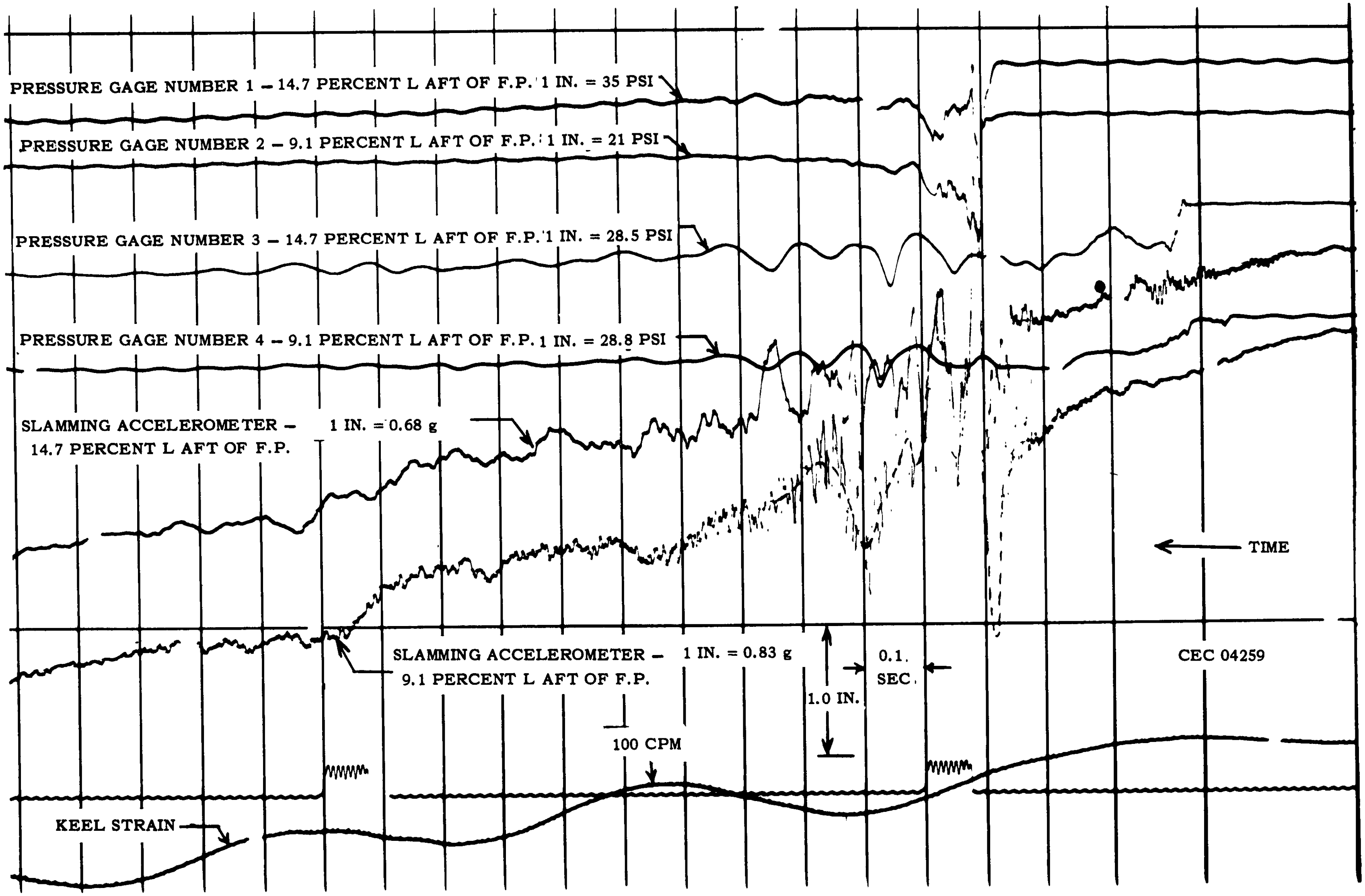

PRESSURE GAGE NUMBER 1 – 14.7 PERCENT L AFT OF F.P. 1 IN. = 35 PSI
PRESSURE GAGE NUMBER 2 – 9.1 PERCENT L AFT OF F.P. 1 IN. = 21 PSI
PRESSURE GAGE NUMBER 3 – 14.7 PERCENT L AFT OF F.P. 1 IN. = 28.5 PSI
PRESSURE GAGE NUMBER 4 – 9.1 PERCENT L AFT OF F.P. 1 IN. = 28.8 PSI
SLAMMING ACCELEROMETER – 14.7 PERCENT L AFT OF F.P.
1 IN. = 0.68 g
TIME
SLAMMING ACCELEROMETER – 9.1 PERCENT L AFT OF F.P.
1 IN. = 0.83 g
0.1. SEC.
1.0 IN.
CEC 04259
100 CPM
KEEL STRAIN

Figure 13c

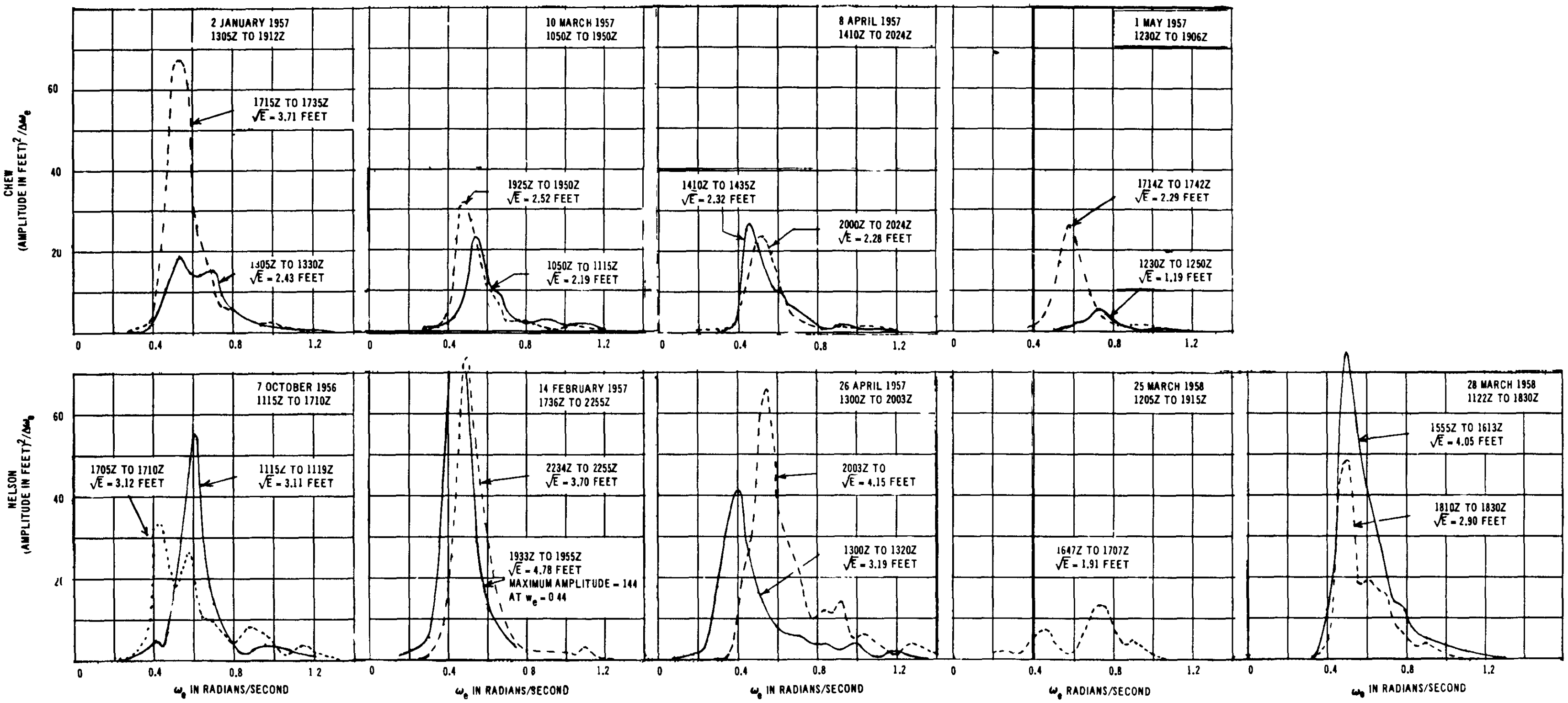


Figure 14 – Wave Spectra Encountered by the Two Ships at Zero Speed during the Special Maneuvers

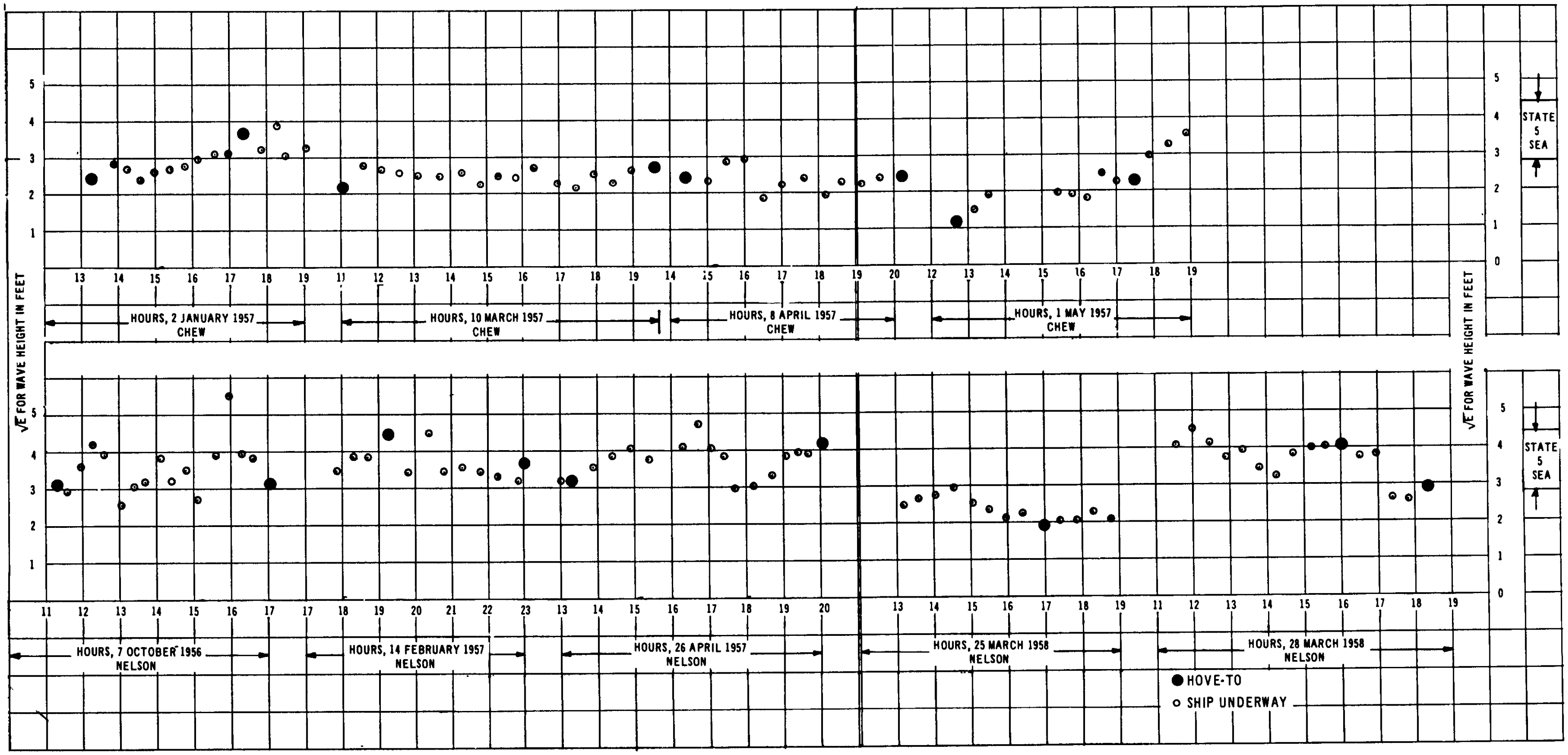


Figure 15 – Variations in the $\sqrt{E}$ for Wave Height for All Special Maneuvers for CHEW and NELSON

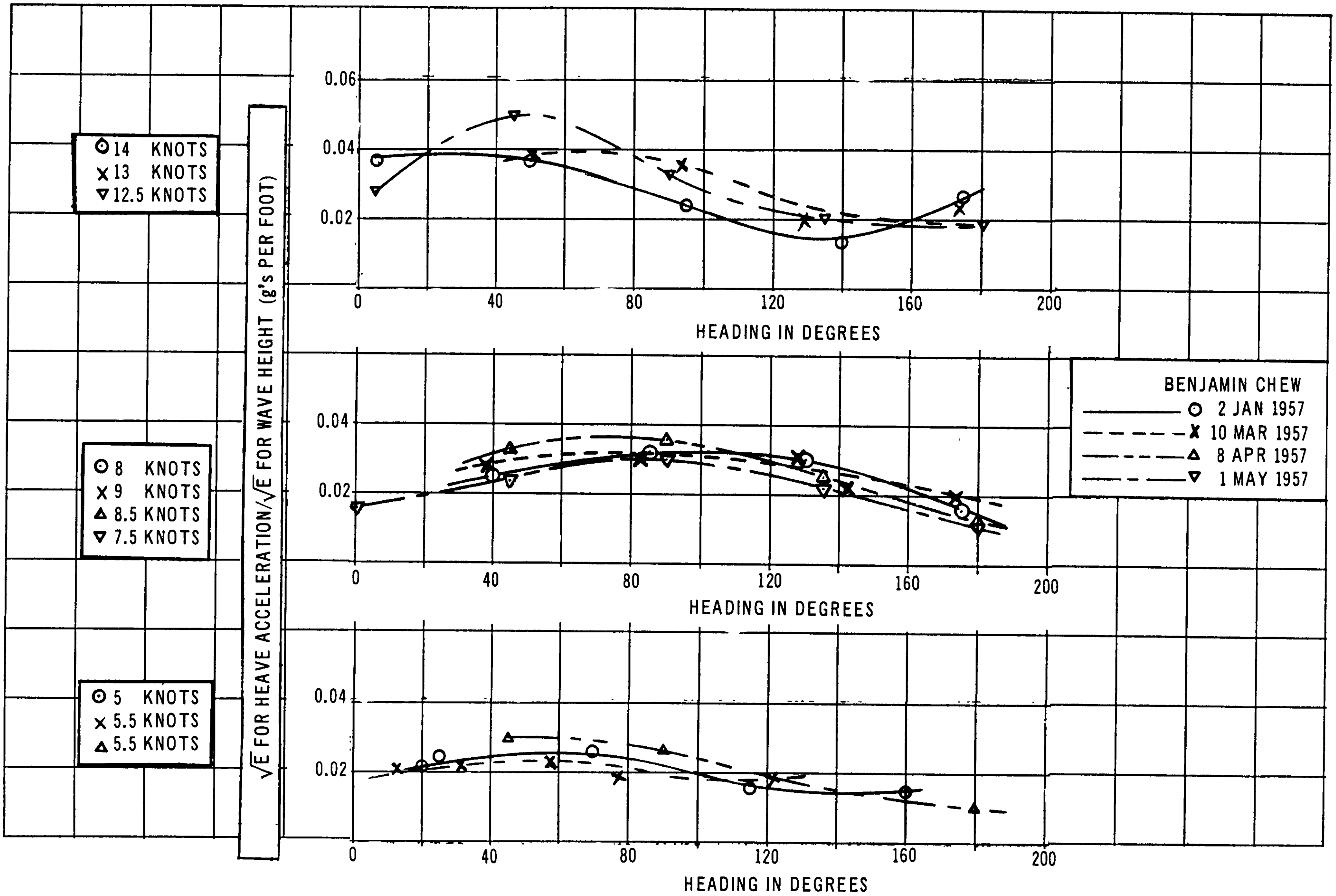


Figure 16 – Variation in Ratio of $\sqrt{E}$ for Heave Acceleration to the $\sqrt{E}$ for Wave Height with Respect to Heading – CHEW

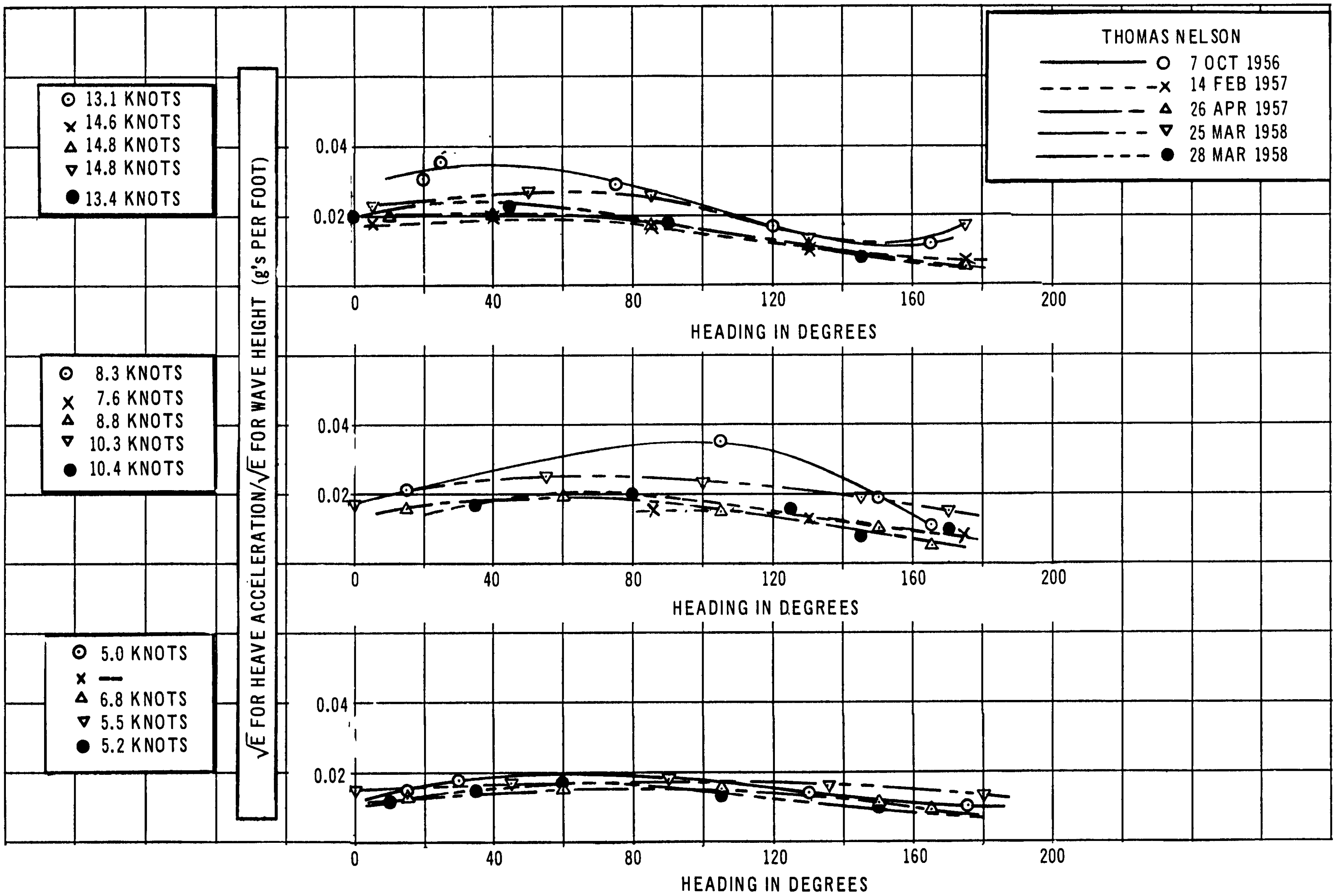


Figure 17 – Variation in the Ratio of $\sqrt{E}$ for Heave Acceleration to the $\sqrt{E}$ for Wave Height with Respect to Heading – NELSON

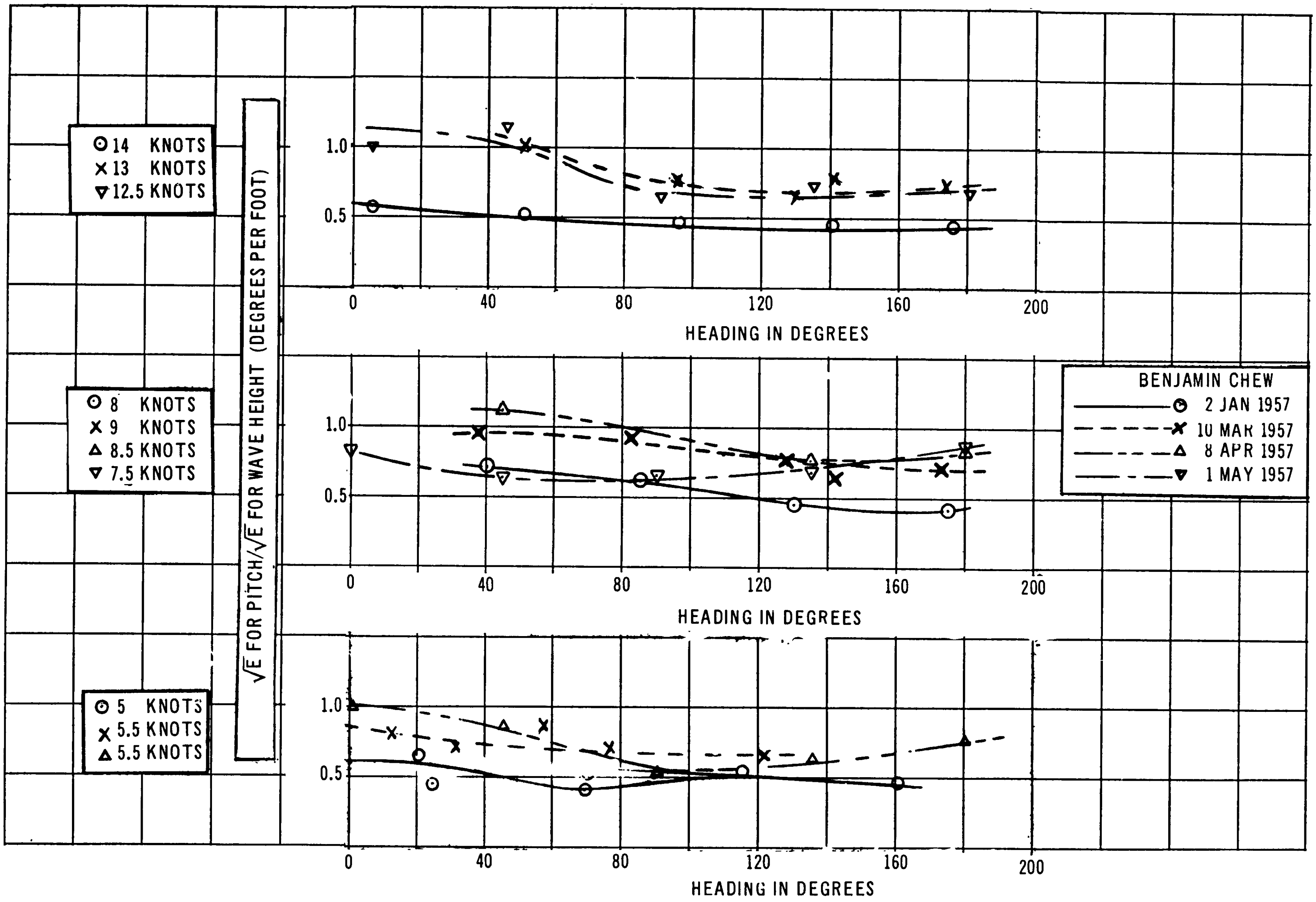


Figure 18 – Variation in the Ratio of $\sqrt{E}$ for Pitch to the $\sqrt{E}$ for Wave Height with Respect to Heading – CHEW

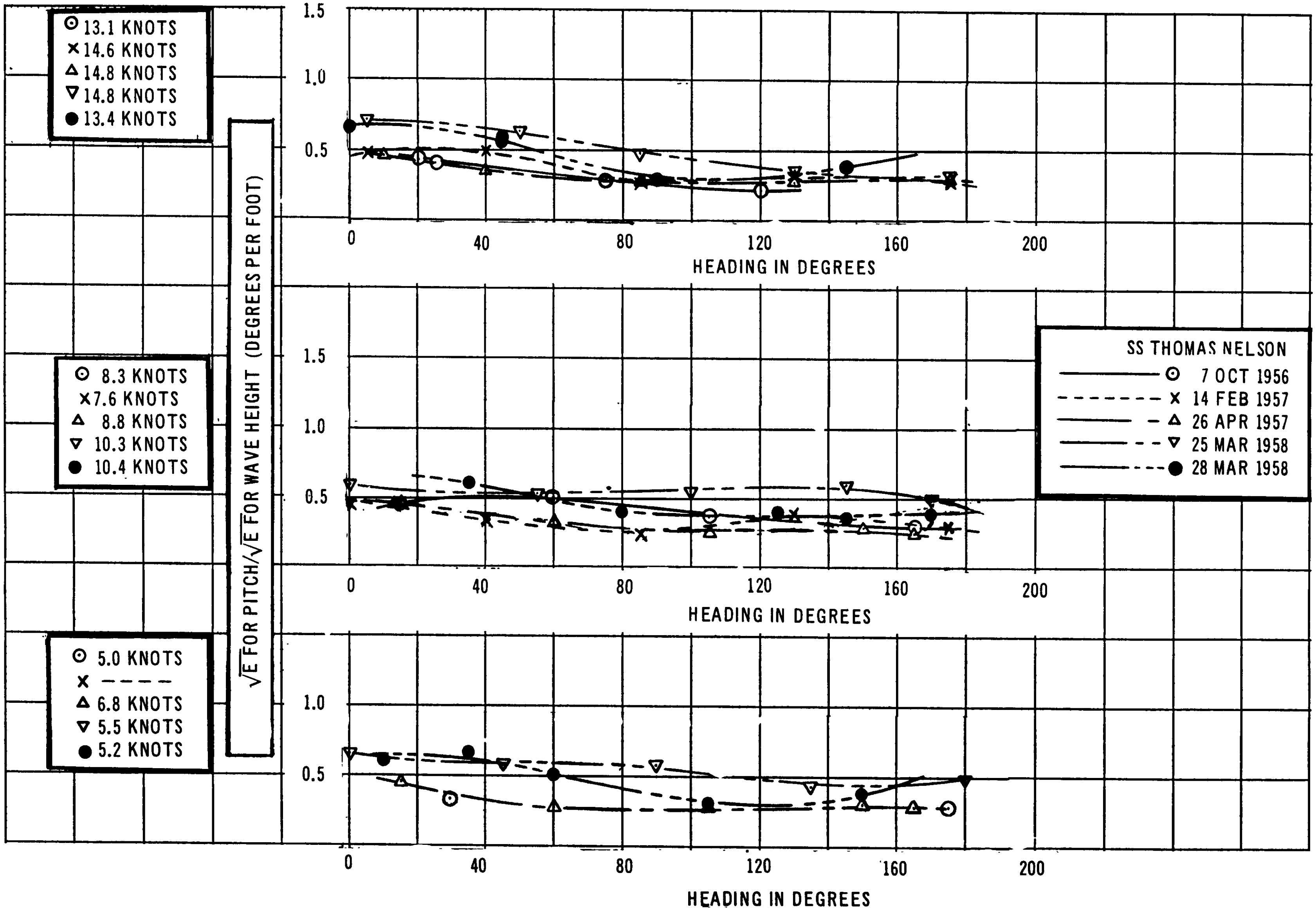


Figure 19 – Variation in the Ratio of $\sqrt{E}$ for Pitch to the $\sqrt{E}$ for Wave Height with Respect to Heading – NELSON

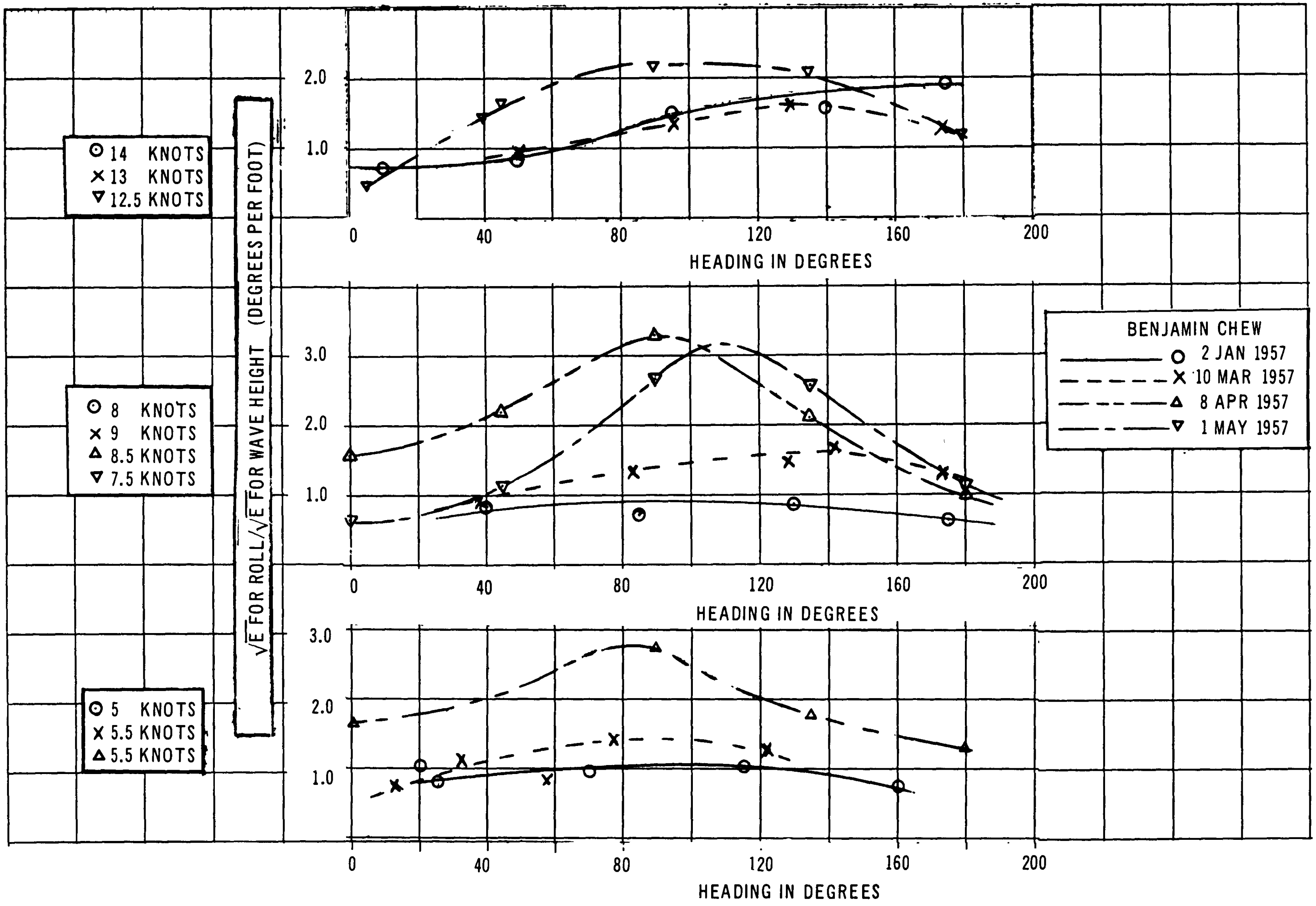


Figure 20 – Variation in the Ratio of $\sqrt{E}$ for Roll to the $\sqrt{E}$ for Wave Height with Respect to Heading – CHEW

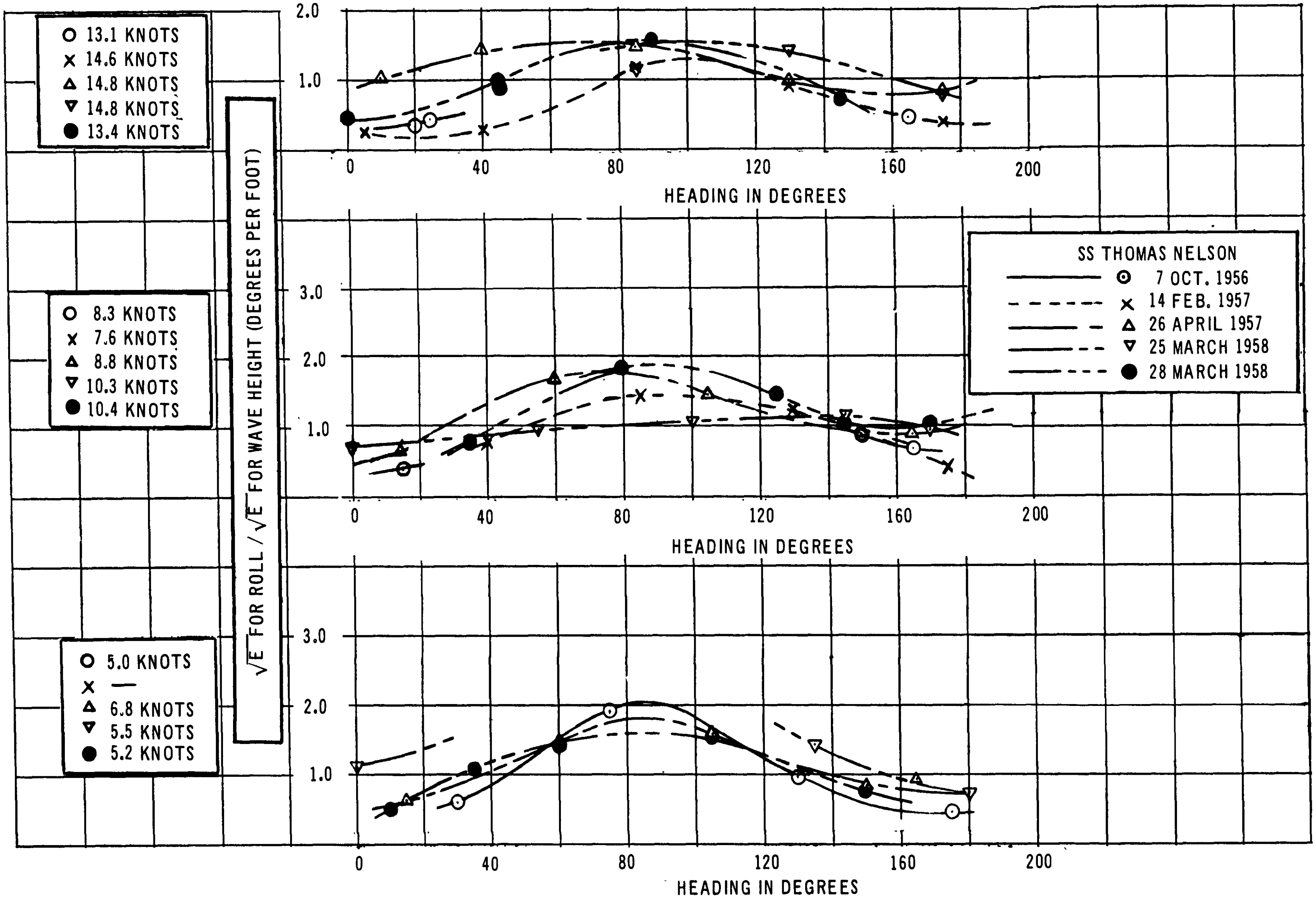


Figure 21 – Variation in the Ratio of $\sqrt{E}$ for Roll to the $\sqrt{E}$ for Wave Height with Respect to Heading – NELSON

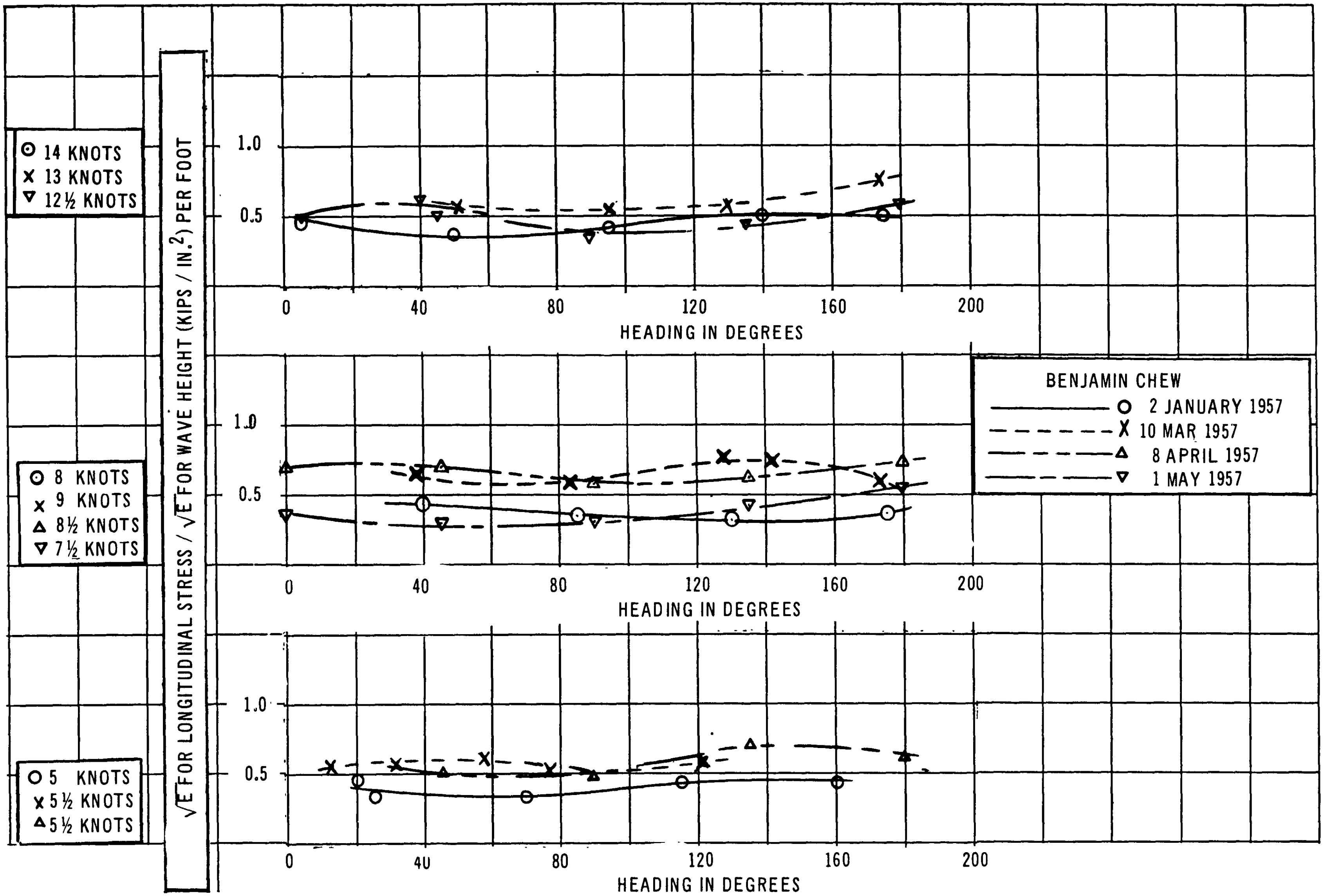


Figure 22 – Variation in the Ratio of $\sqrt{E}$ for Longitudinal Stress to the $\sqrt{E}$ for Wave Height with Respect to Heading – CHEW

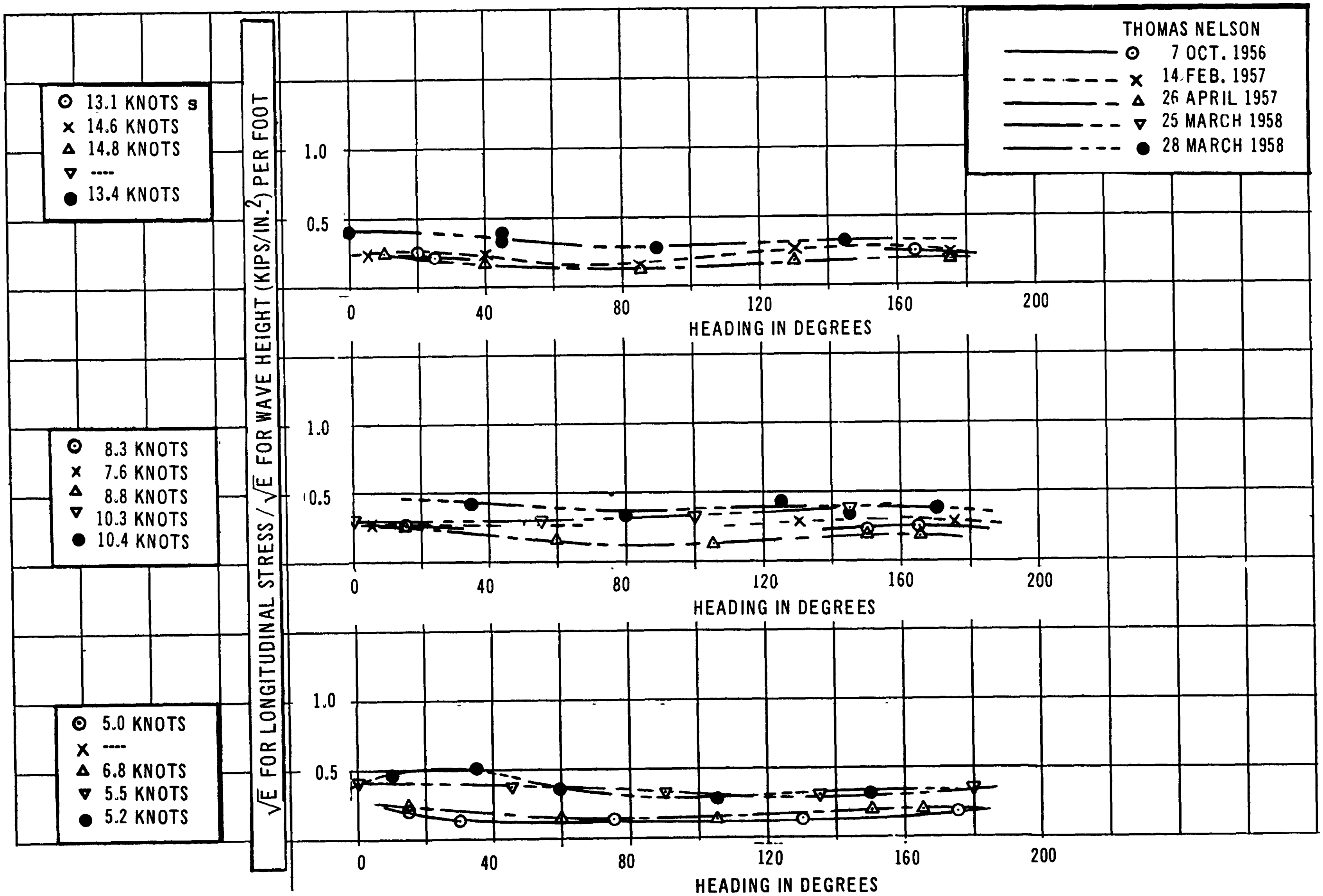


Figure 23 – Variation in the Ratio of $\sqrt{E}$ for Longitudinal Stress to the $\sqrt{E}$ for Wave Height with Respect to Heading – NELSON

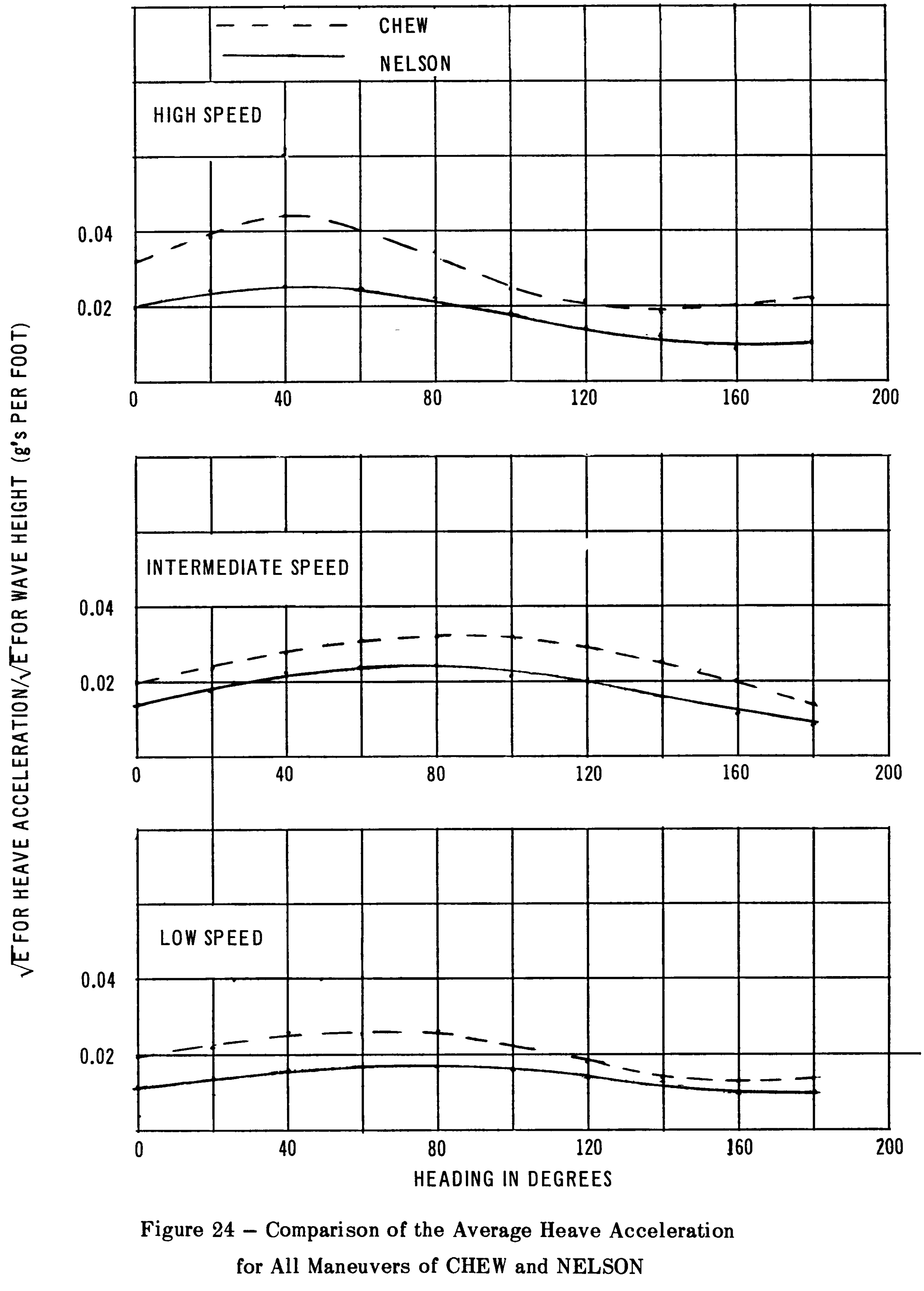


Figure 24 – Comparison of the Average Heave Acceleration for All Maneuvers of CHEW and NELSON

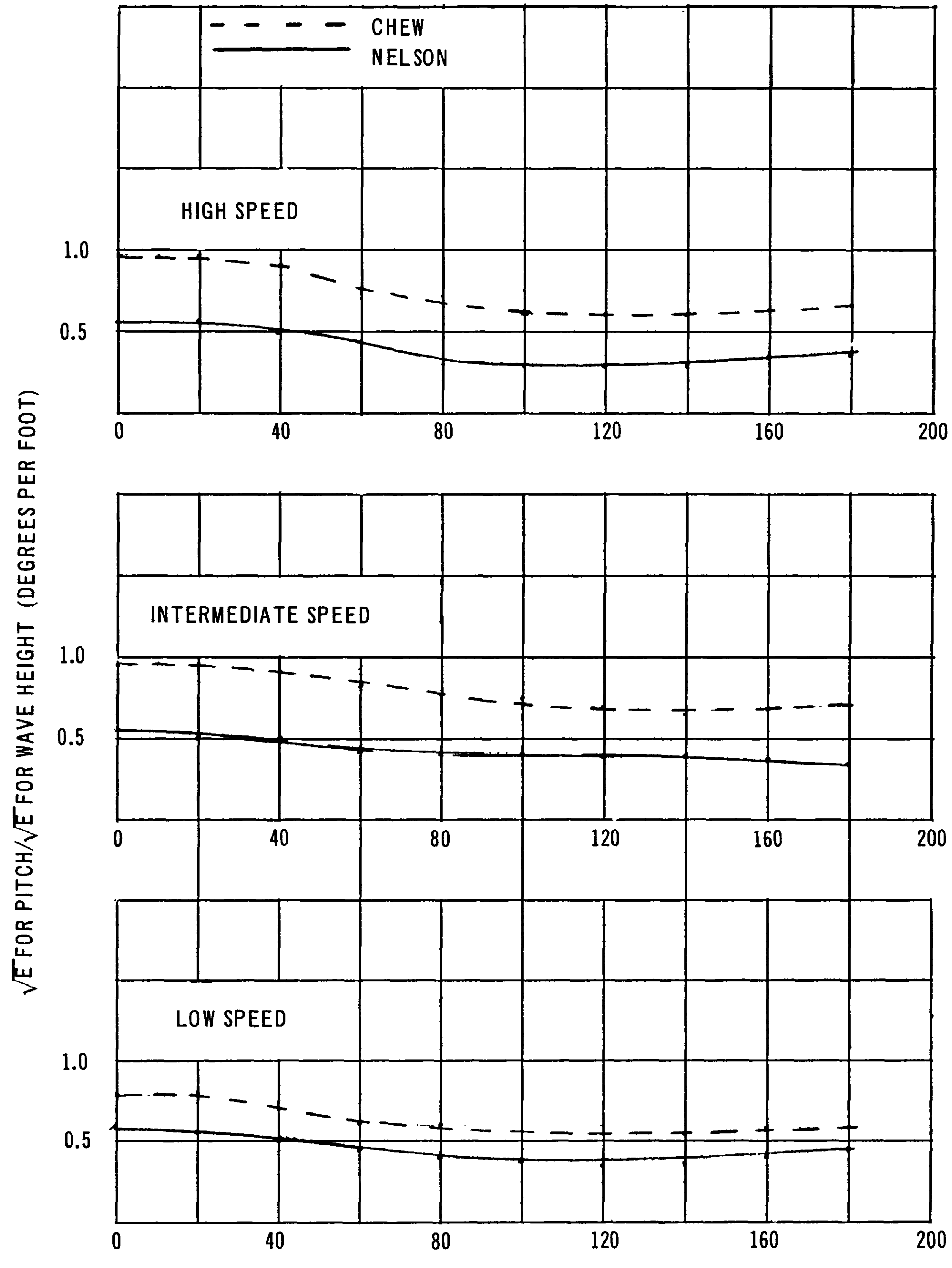


Figure 25 – Comparison of the Average Pitch Angle for All Maneuvers of CHEW and NELSON

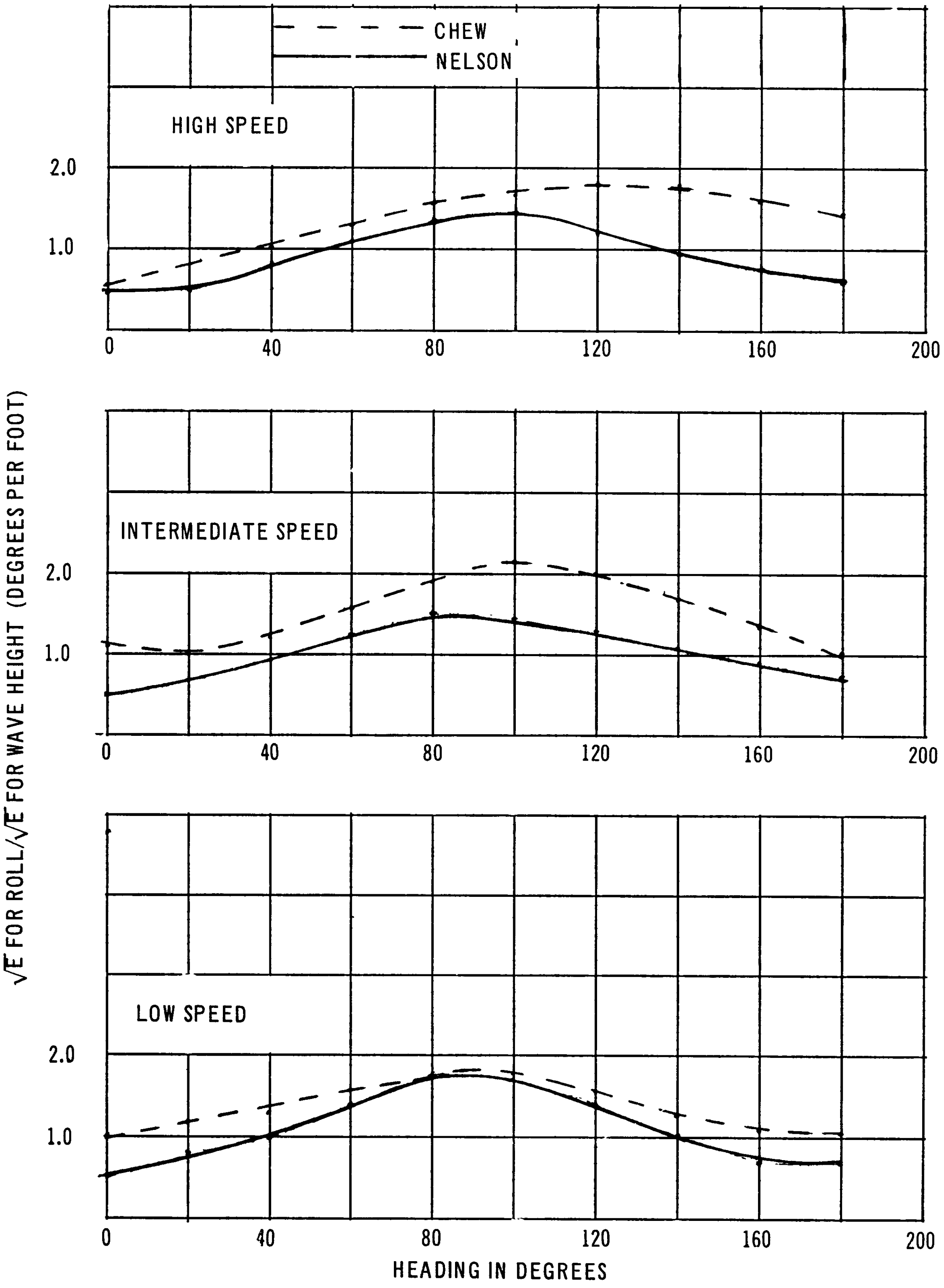


Figure 26 – Comparison of the Average Roll Angle for All Maneuvers of CHEW and NELSON

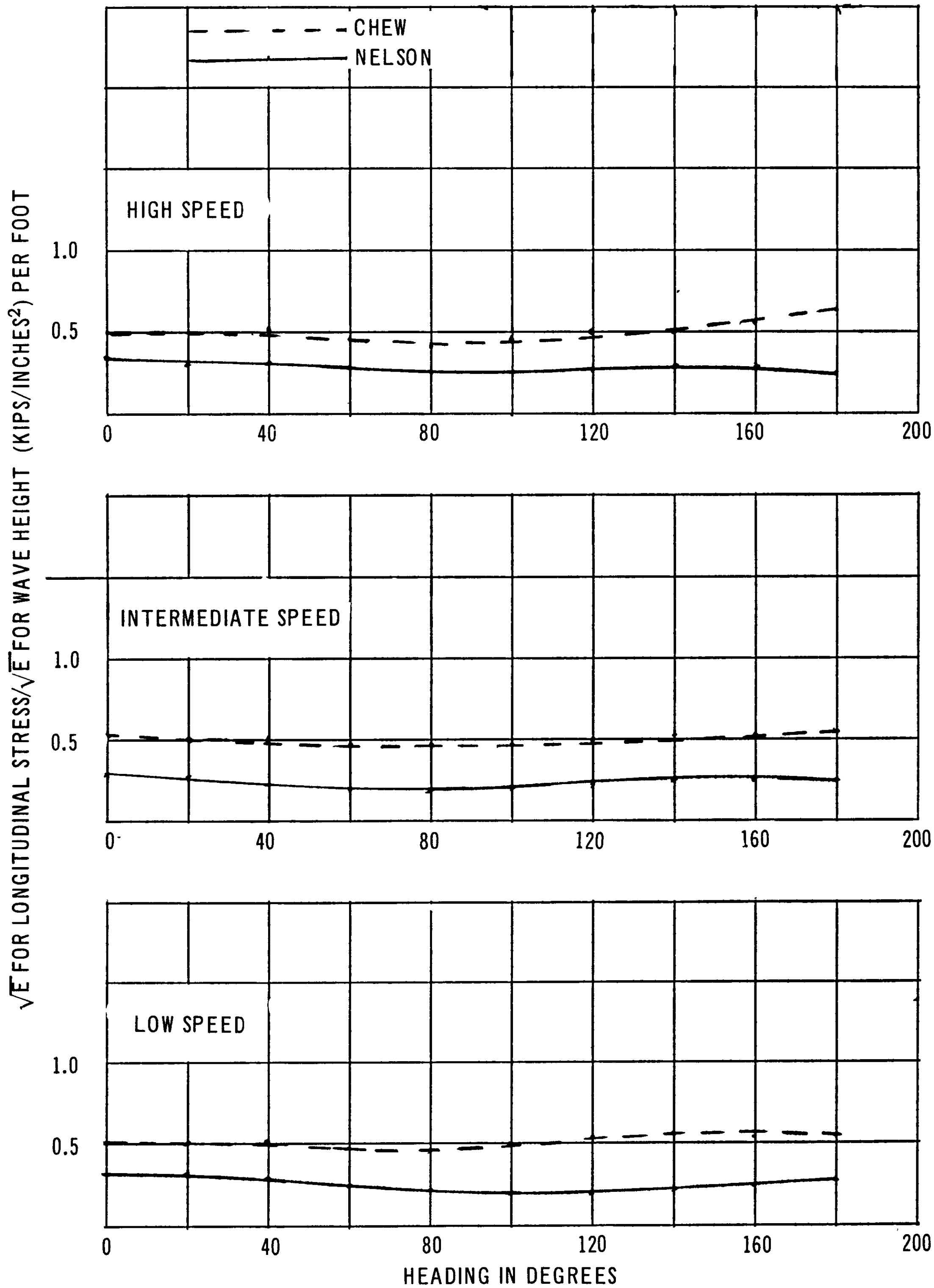


Figure 27 – Comparison of the Average Longitudinal Stress for All Maneuvers of CHEW and NELSON

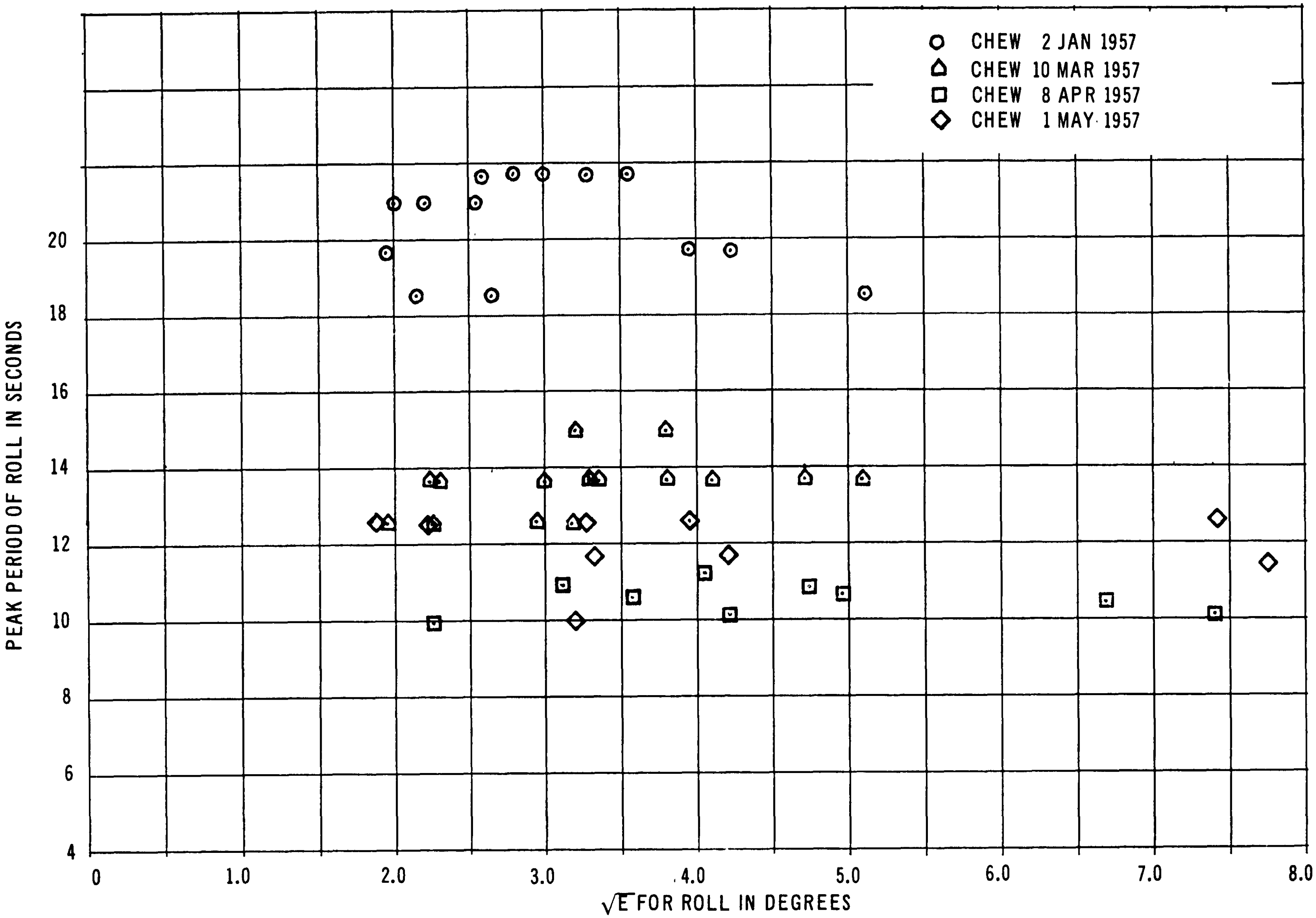


Figure 28 – Plot of Peak Period versus $\sqrt{E}$ for Roll for BENJAMIN CHEW

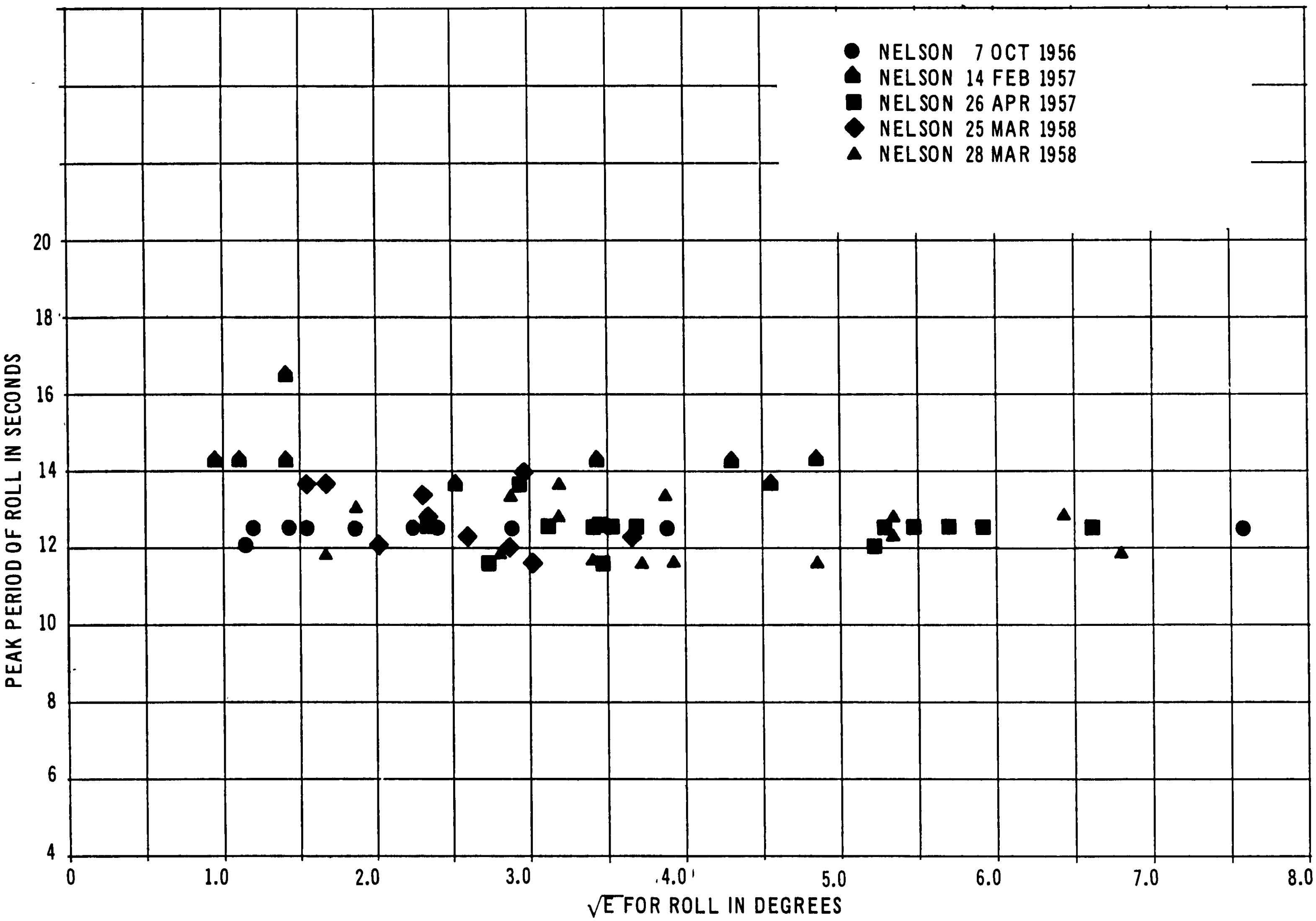


Figure 29 – Plot of Peak Period versus $\sqrt{E}$ for Roll for THOMAS NELSON

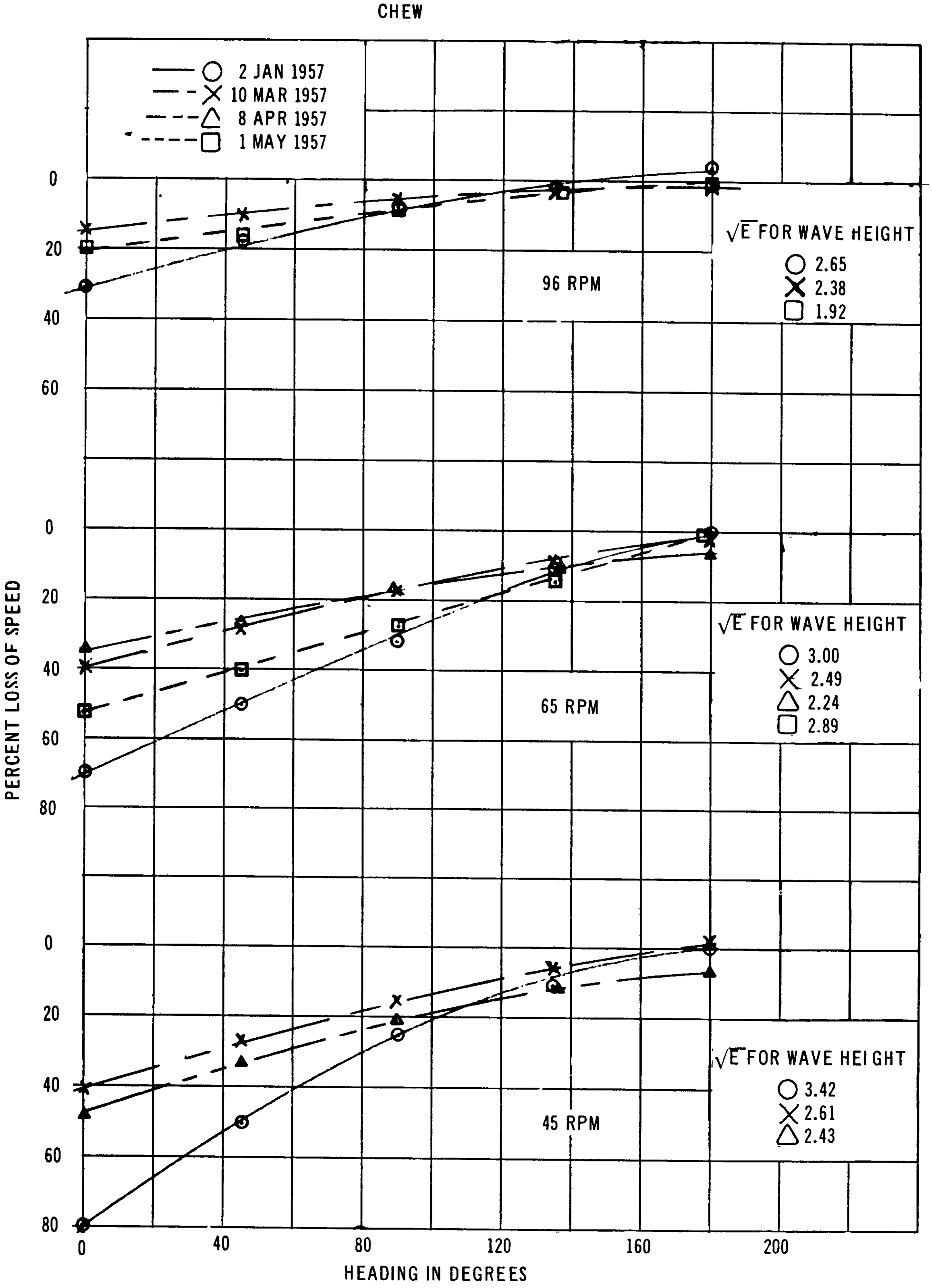


Figure 30 – Loss of Speed at Various Headings for CHEW

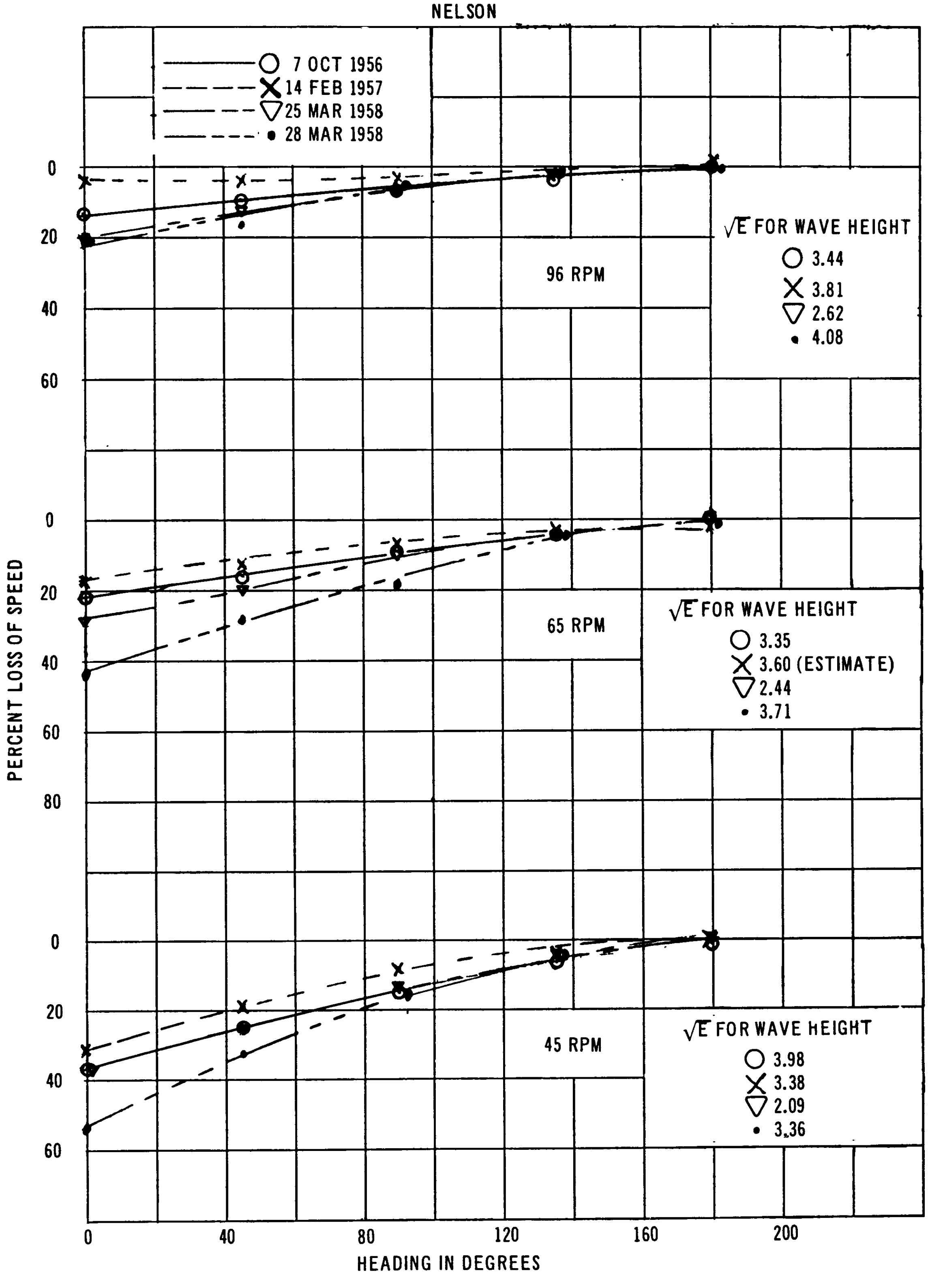


Figure 31 – Loss of Speed at Various Headings for NELSON

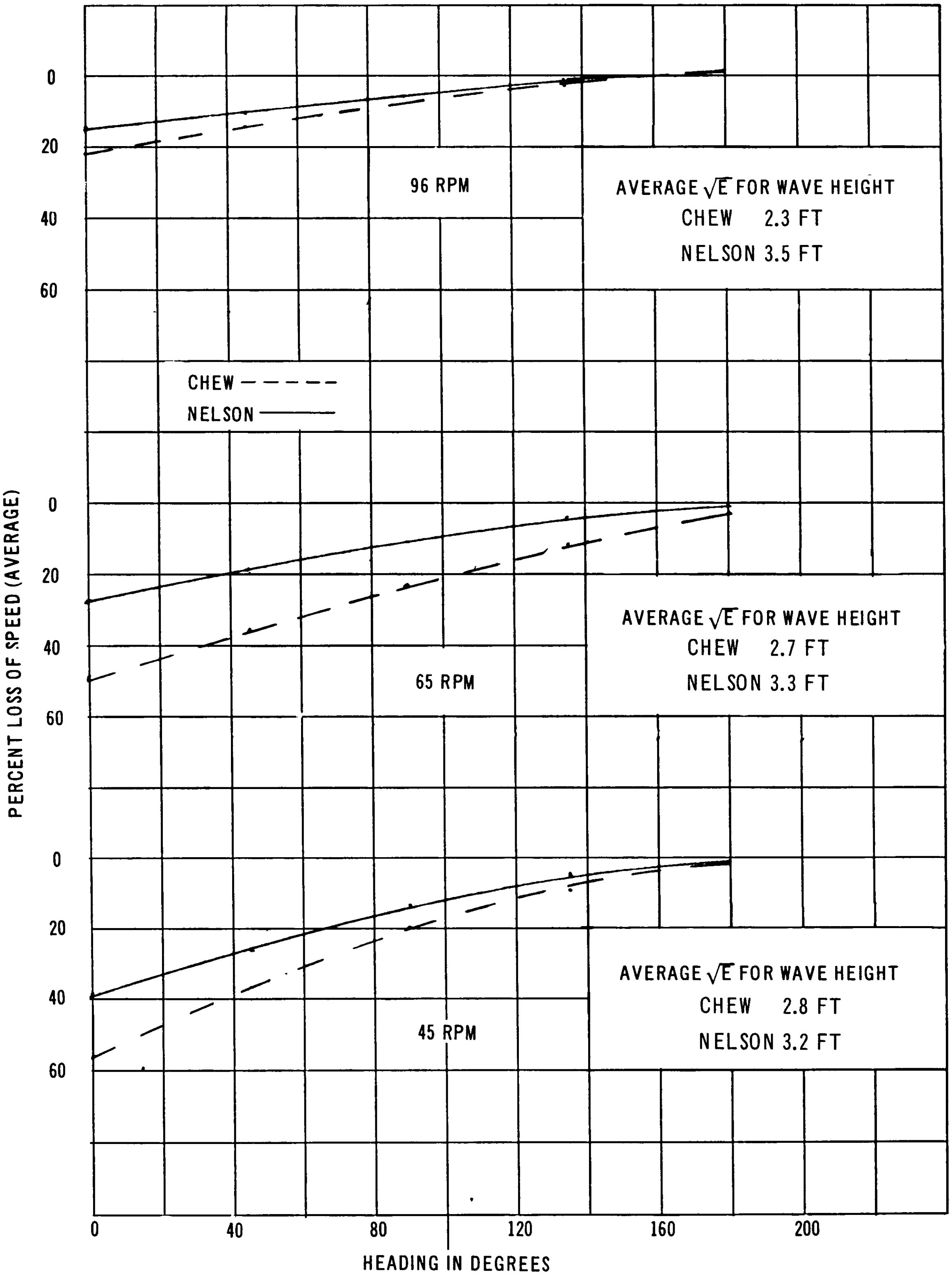


Figure 32 – Comparison of the Average Speed Loss of the Two Ships at Various Headings

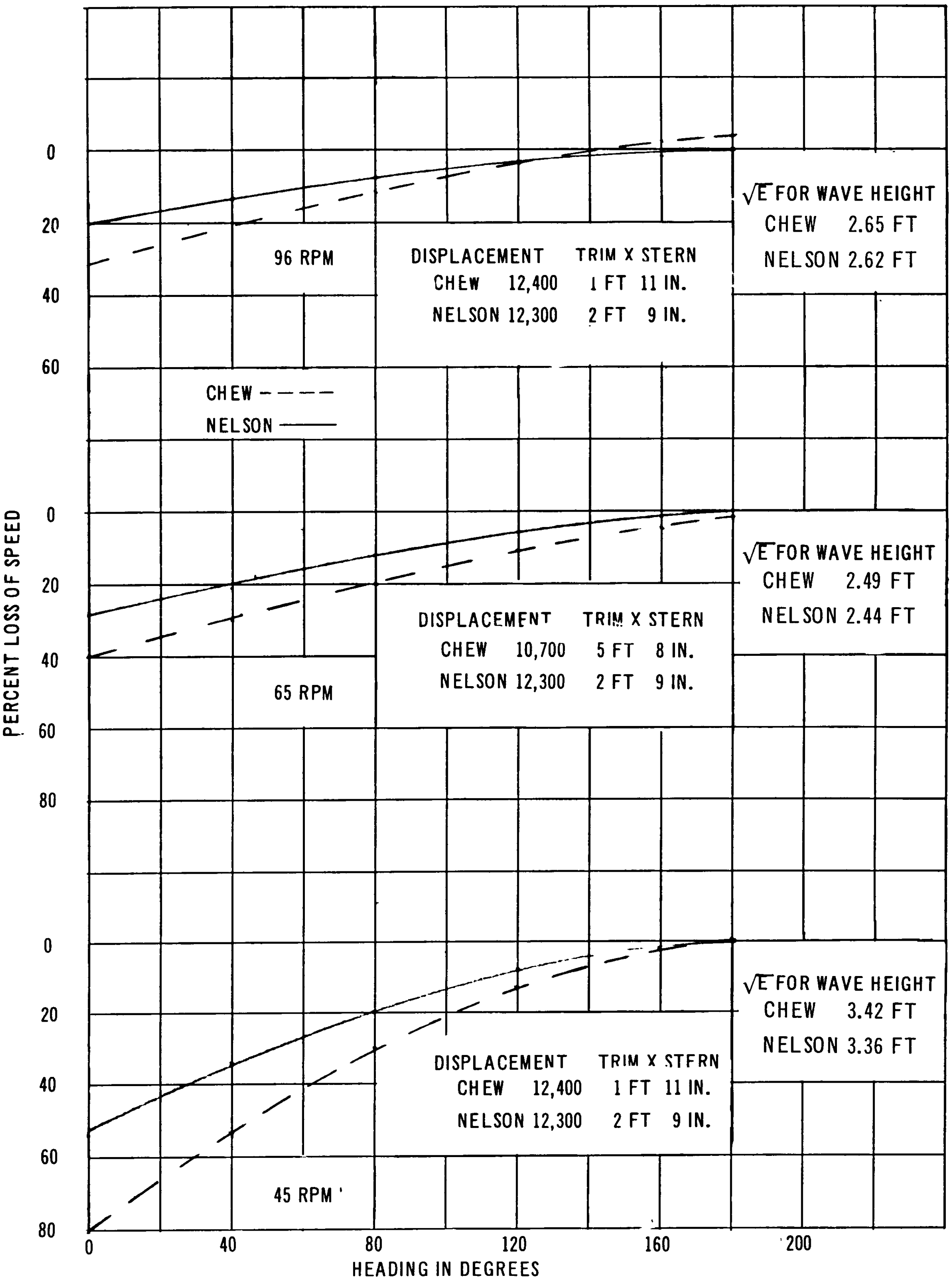


Figure 33 – Comparison of the Loss of Speed of the Two Ships in Equivalent Wave Heights

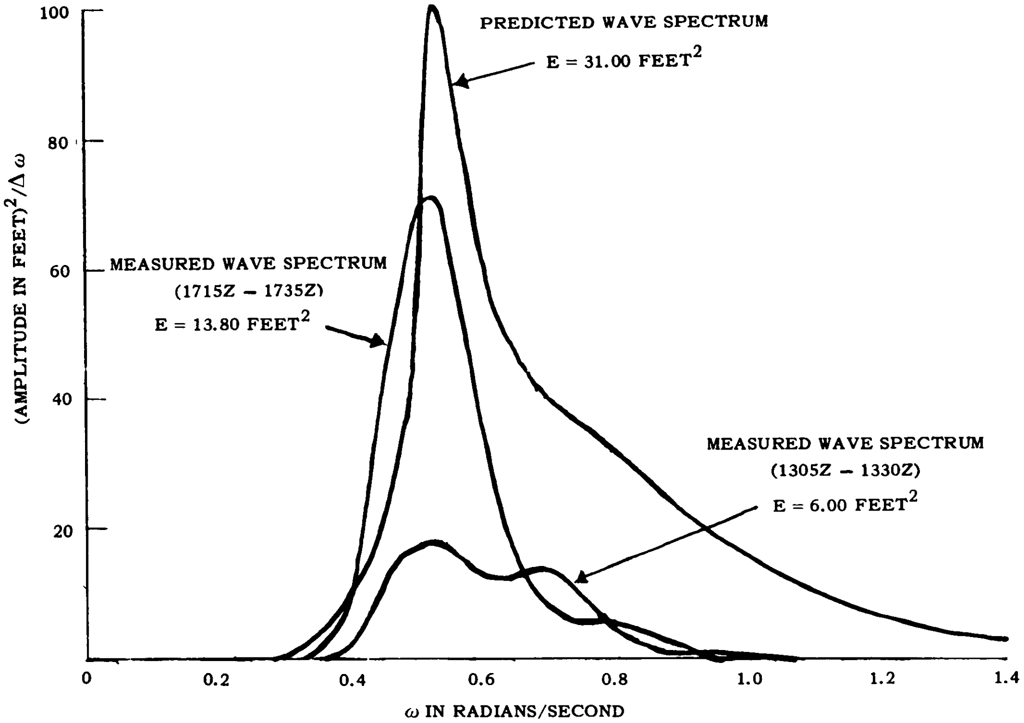


Figure 34 – Comparison of Neumann and Measured Wave Spectra in Operating Area of CHEW on 2 Jan 1957

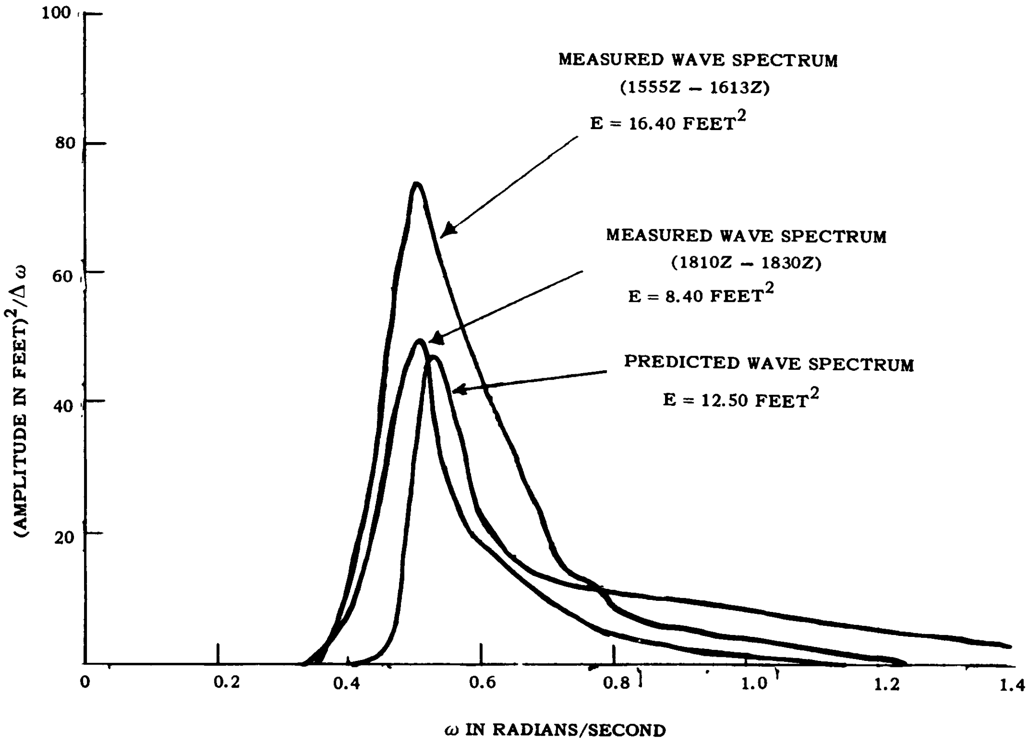


Figure 35 – Comparison of Neumann and Measured Wave Spectra in Operating Area of NELSON on 28 Mar 1958

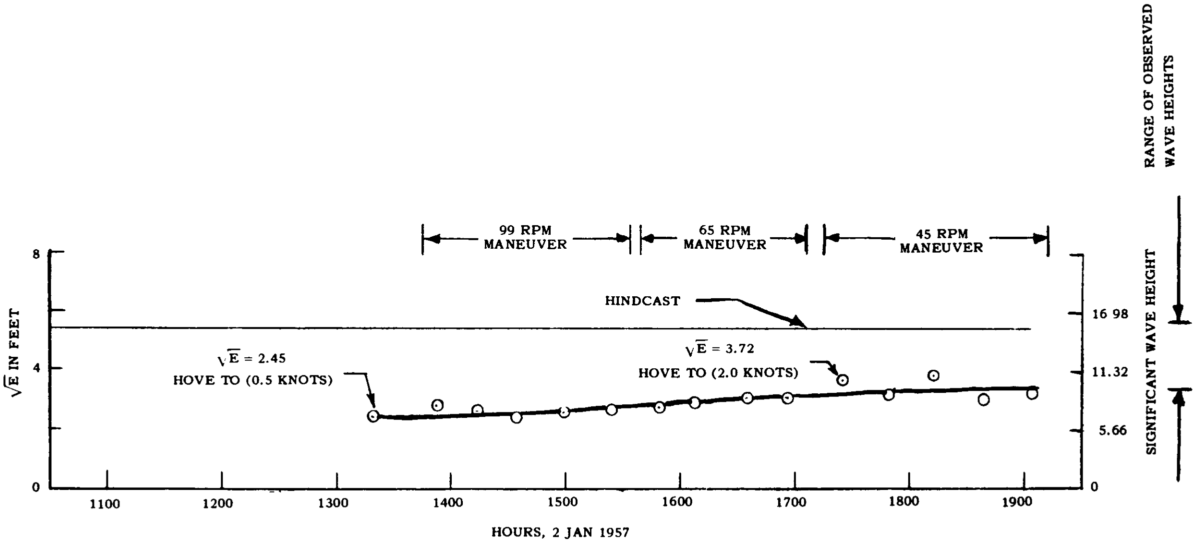


Figure 36 – Variation in the $\sqrt{E}$ for Wave Height during CHEW Maneuvers on 2 Jan 1957

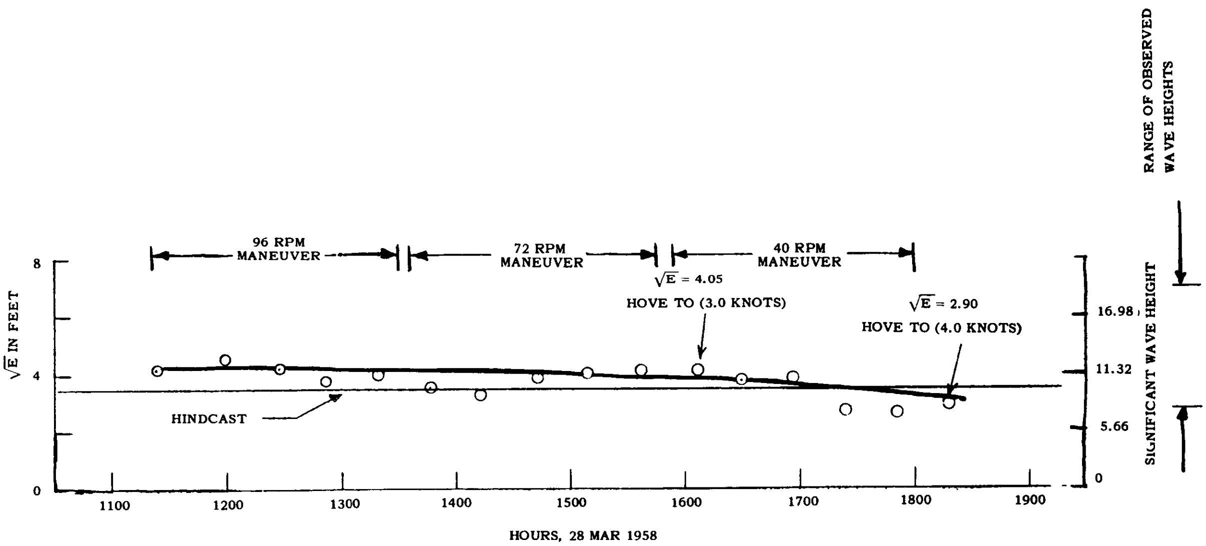


Figure 37 – Variation in the $\sqrt{E}$ for Wave Height during NELSON Maneuvers on 28 Mar 1958

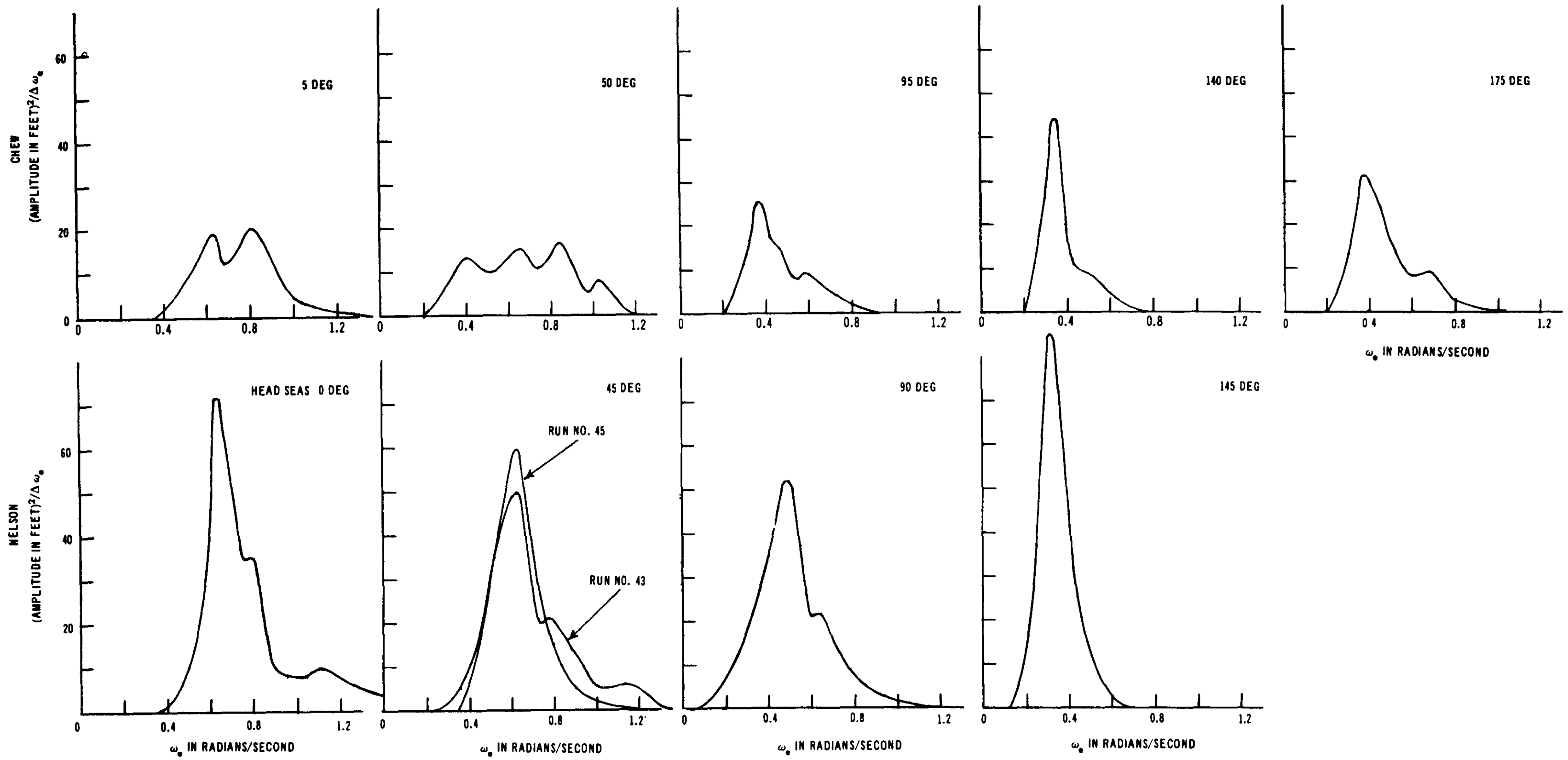


Figure 38 – Wave Spectra Encountered by the Two Ships at a Nominal Speed of 14 Knots

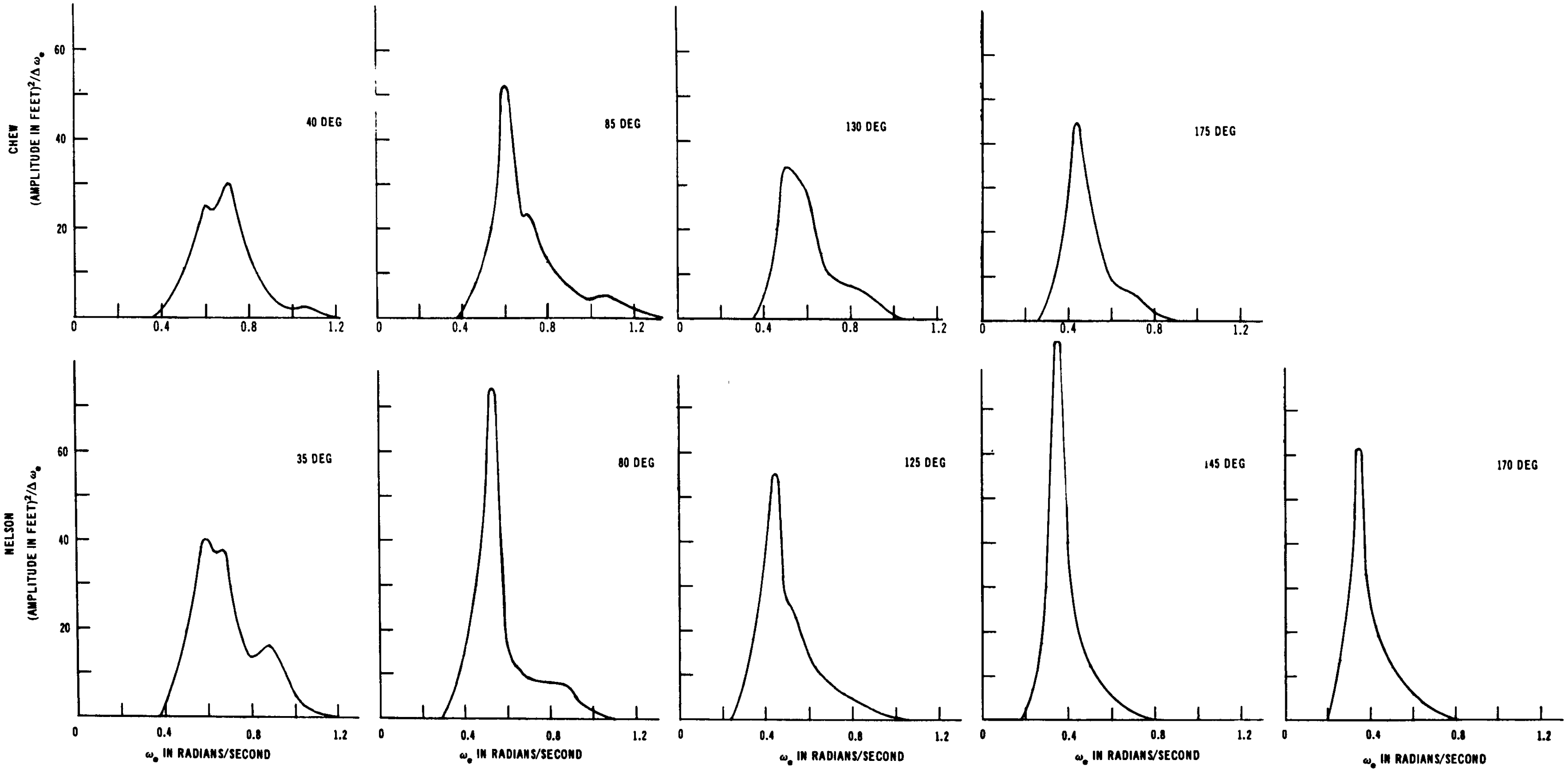


Figure 39 – Wave Spectra Encountered by the Two Ships at a Nominal Speed of 8 Knots for CHEW and 10 Knots for NELSON

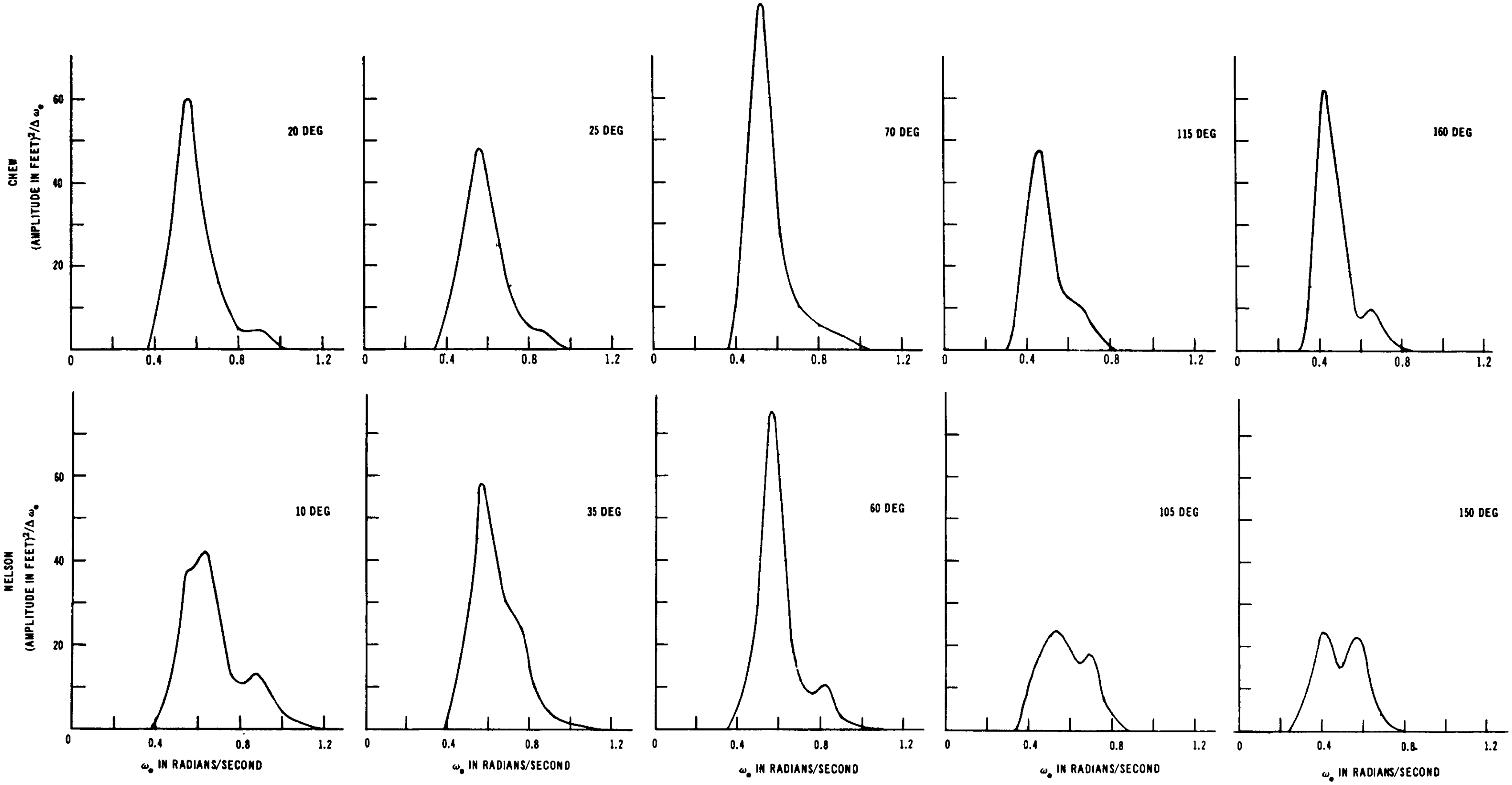


Figure 40 – Wave Spectra Encountered by the Two Ships at a Nominal Speed of 5 Knots

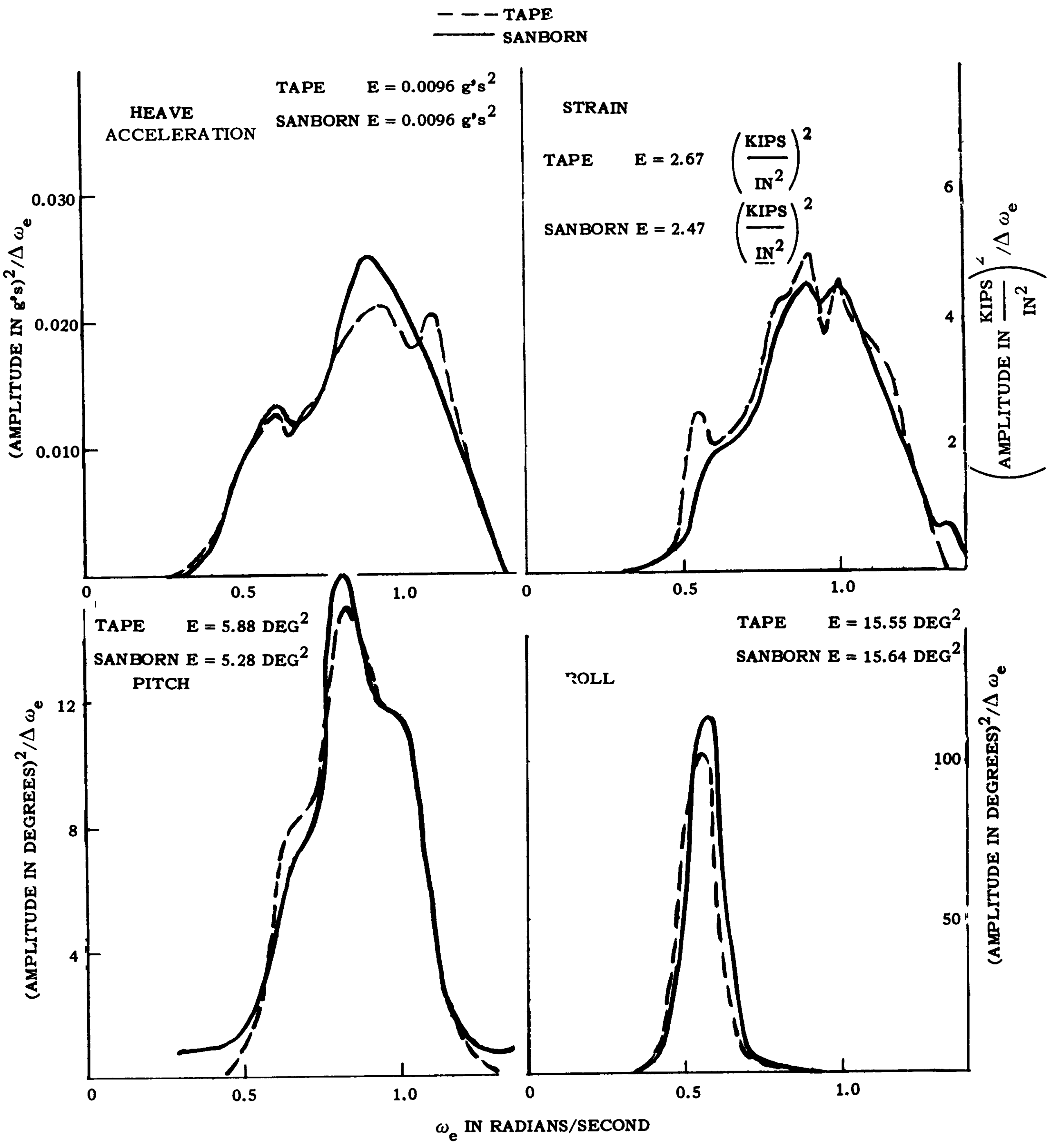


Figure 41 – Comparison of Spectra as obtained from Paper and Magnetic Tapes, Run Number 43, NELSON

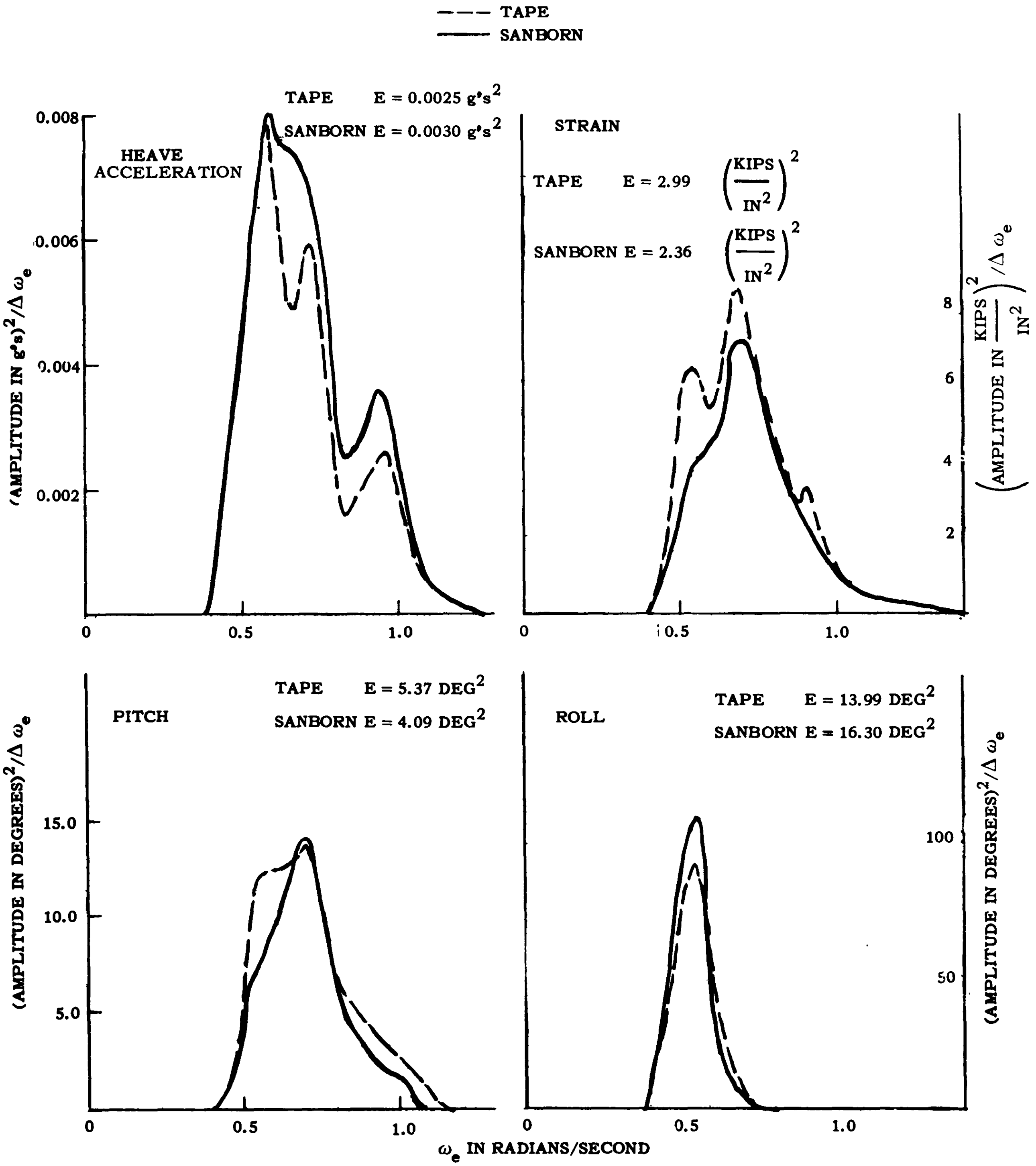


Figure 42 – Comparison of Spectra as obtained from Paper and Magnetic Tapes, Run Number 53, NELSON

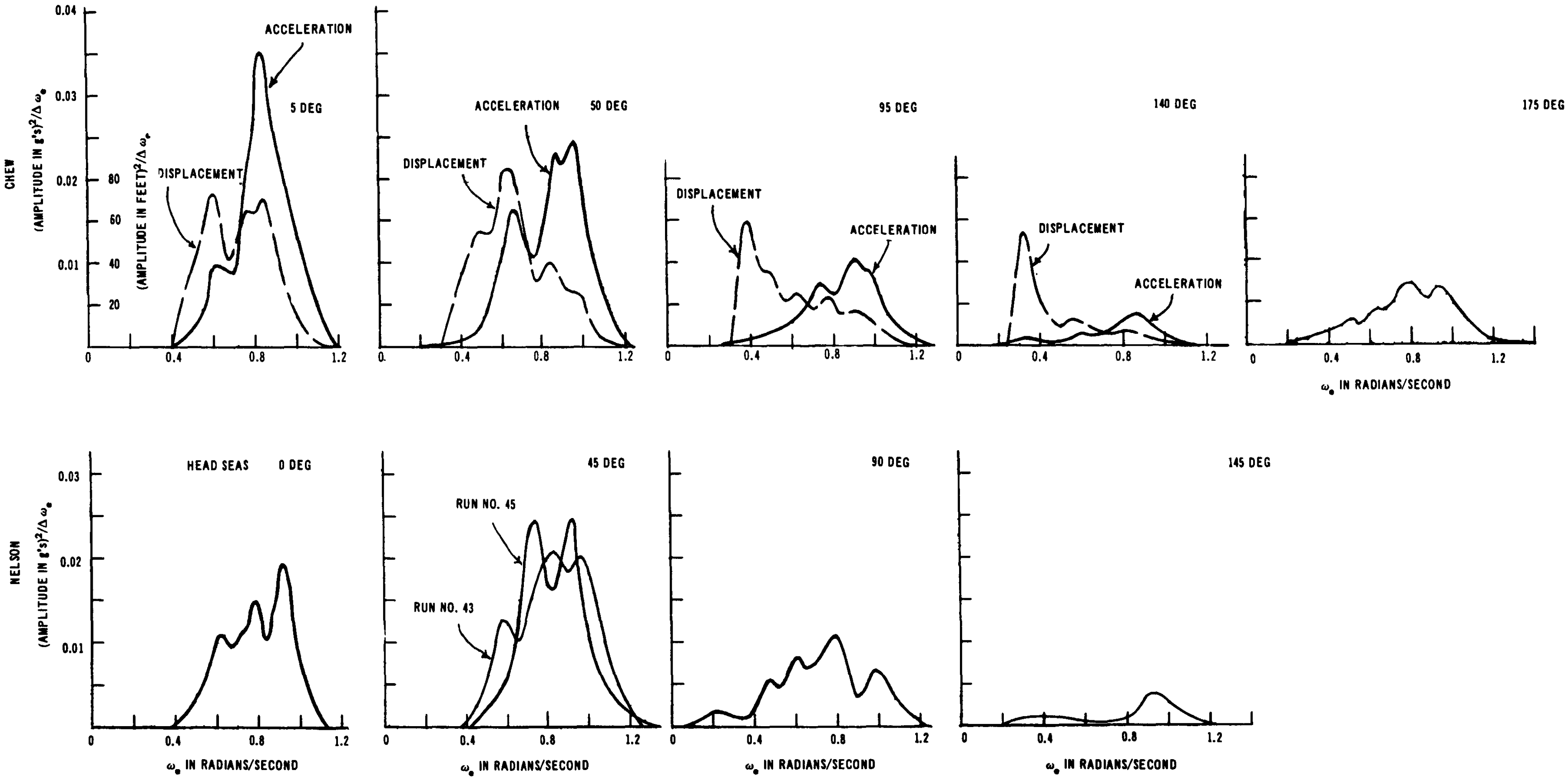


Figure 43 – Heave Acceleration Energy Spectra for the Two Ships at a Nominal Speed of 14 Knots

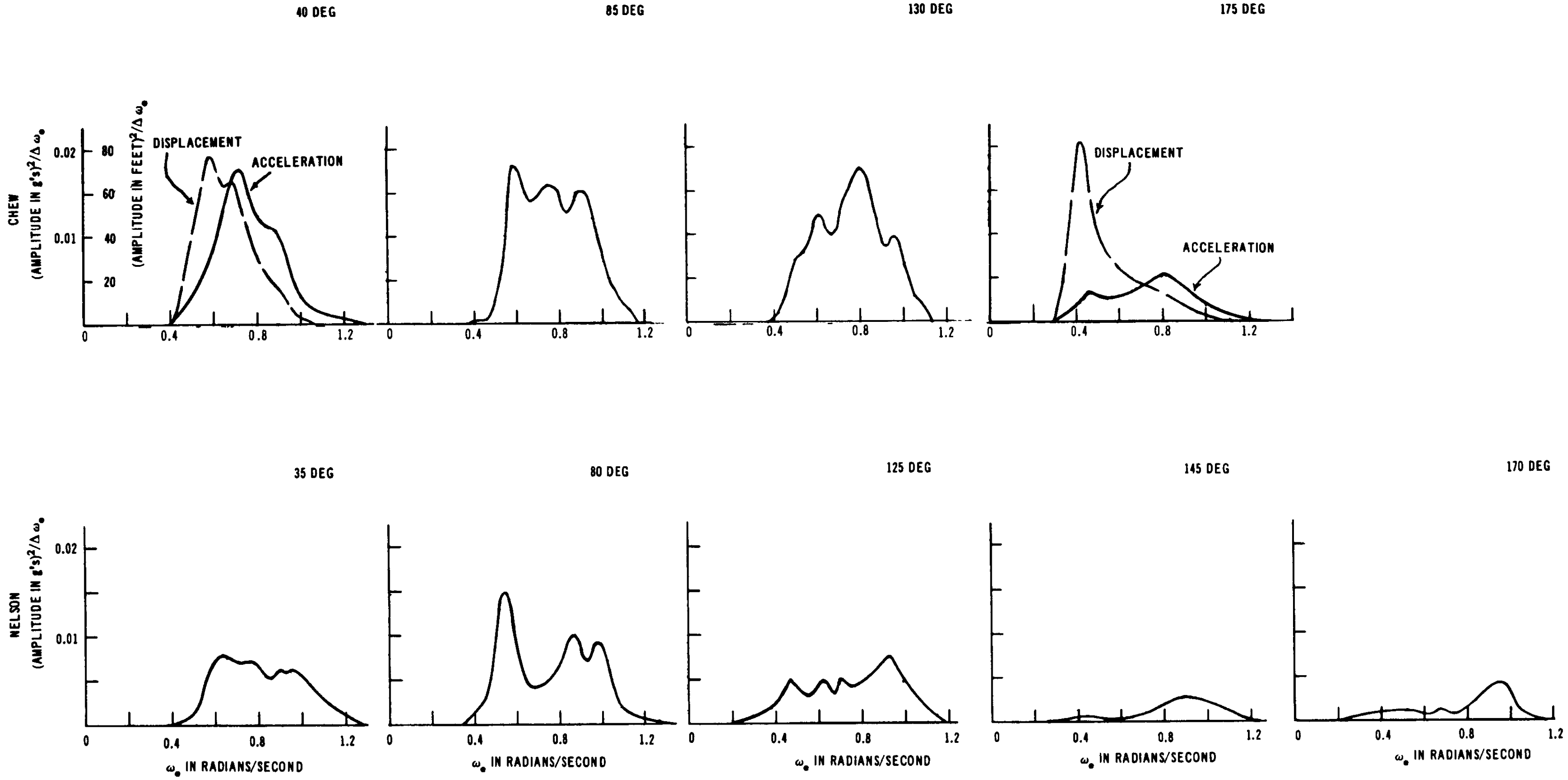


Figure 44 – Heave Acceleration Energy Spectra for the Two Ships at a Nominal Speed of 8 Knots for CHEW and 10 Knots for NELSON

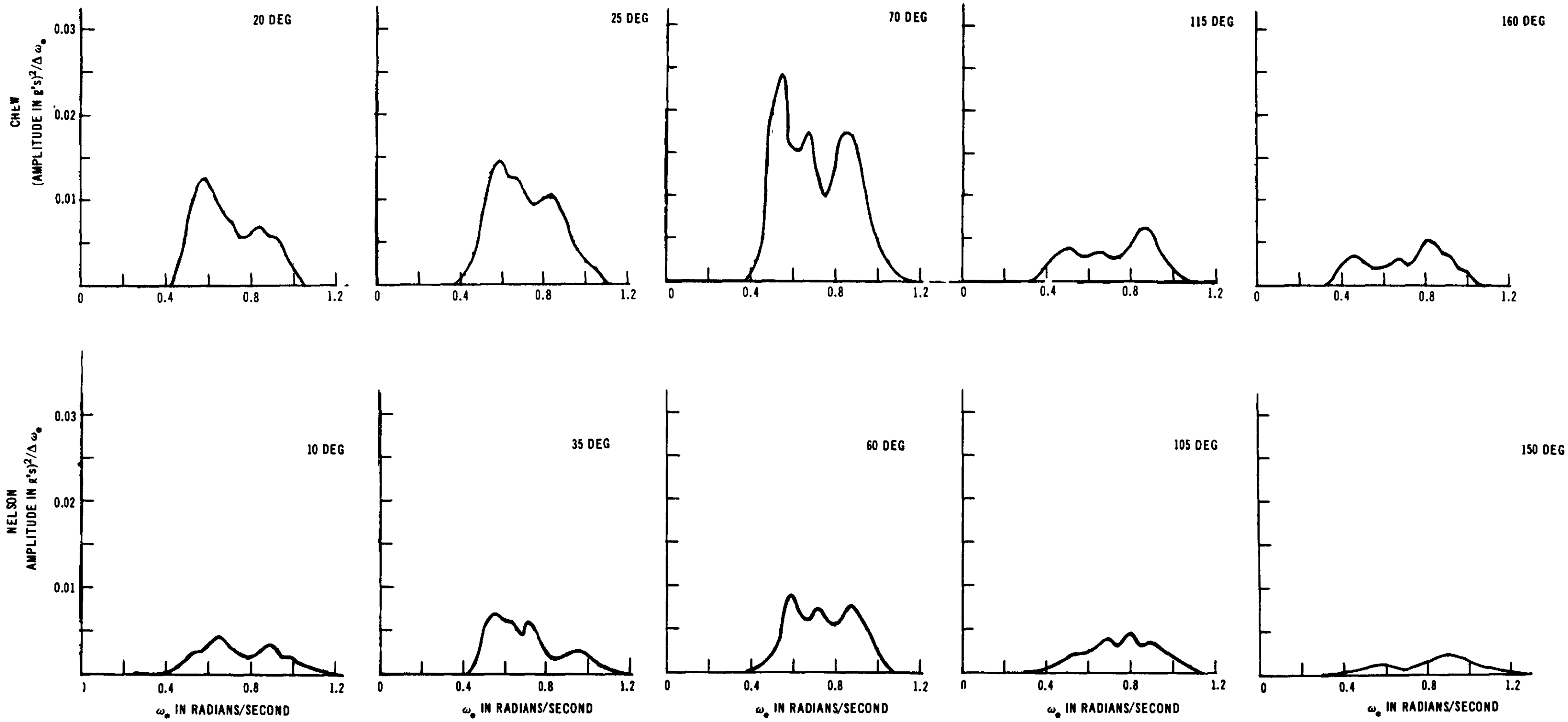


Figure 45 – Heave Acceleration Energy Spectra for the Two Ships at a Nominal Speed of 5 Knots

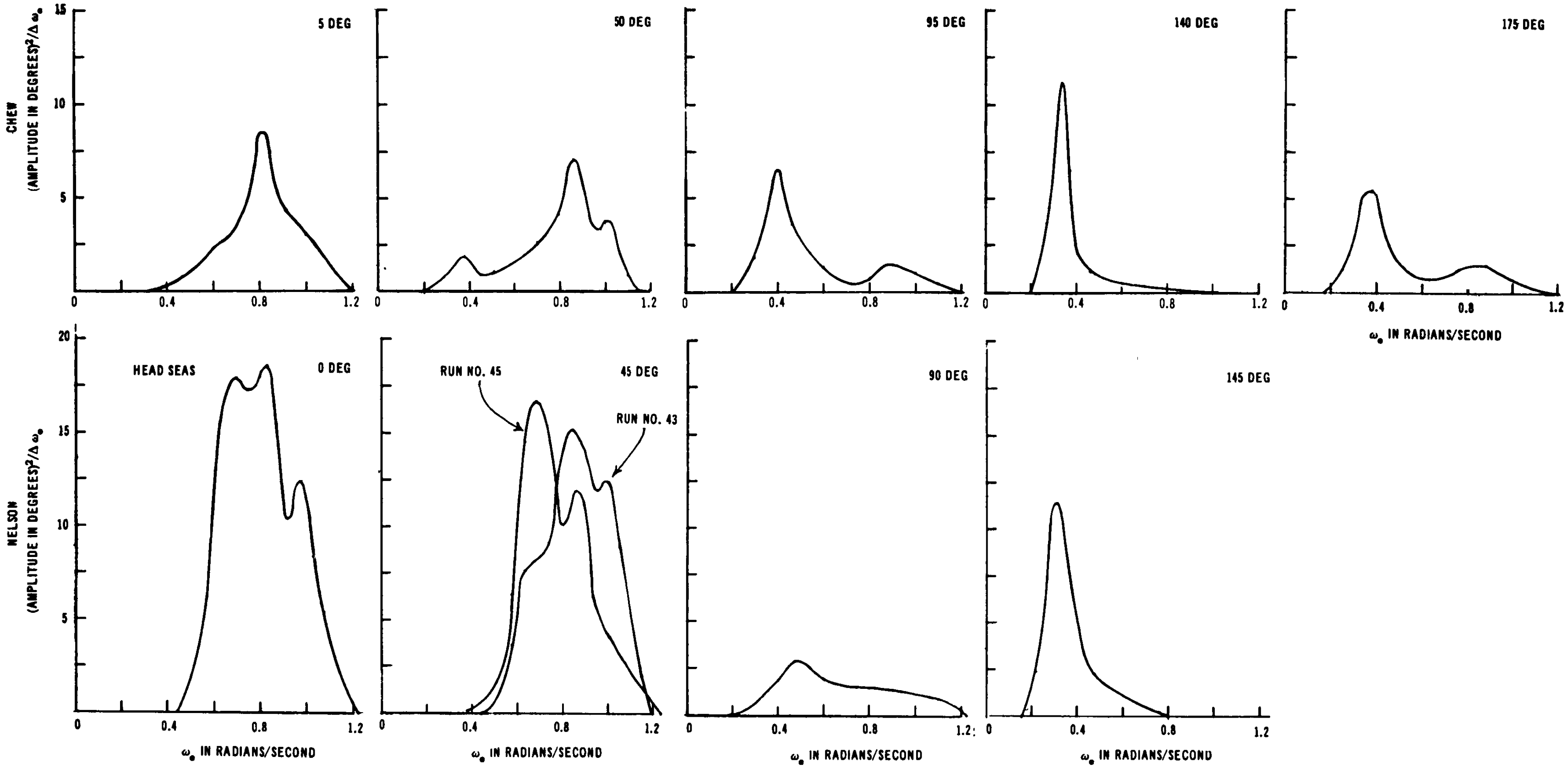


Figure 46 – Pitch Energy Spectra for the Two Ships at a Nominal Speed of 14 Knots

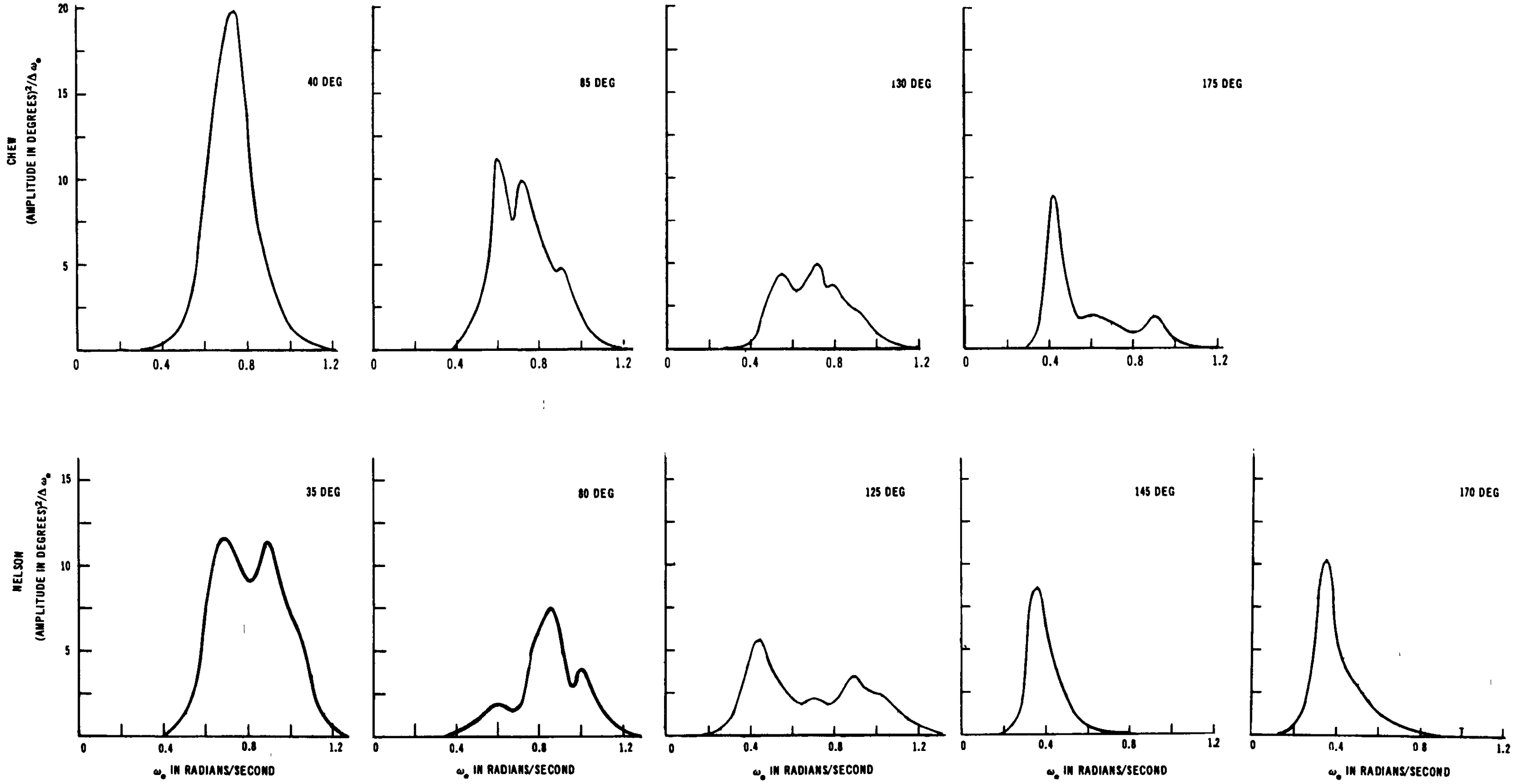


Figure 47 – Pitch Energy Spectra for the Two Ships at a Nominal Speed of 8 Knots for CHEW and 10 Knots for NELSON

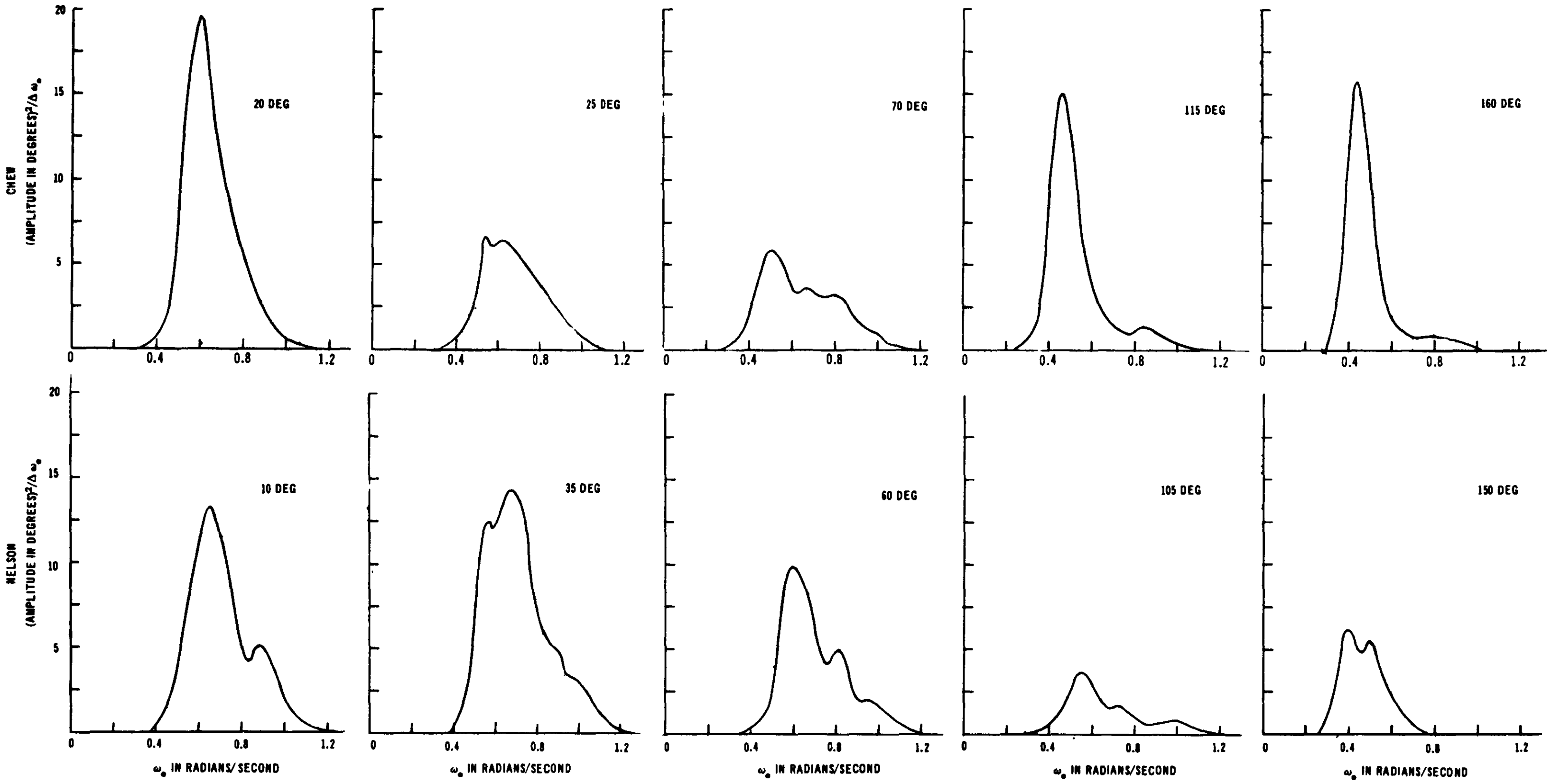


Figure 48 – Pitch Energy Spectra for the Two Ships at a Nominal Speed of 5 Knots

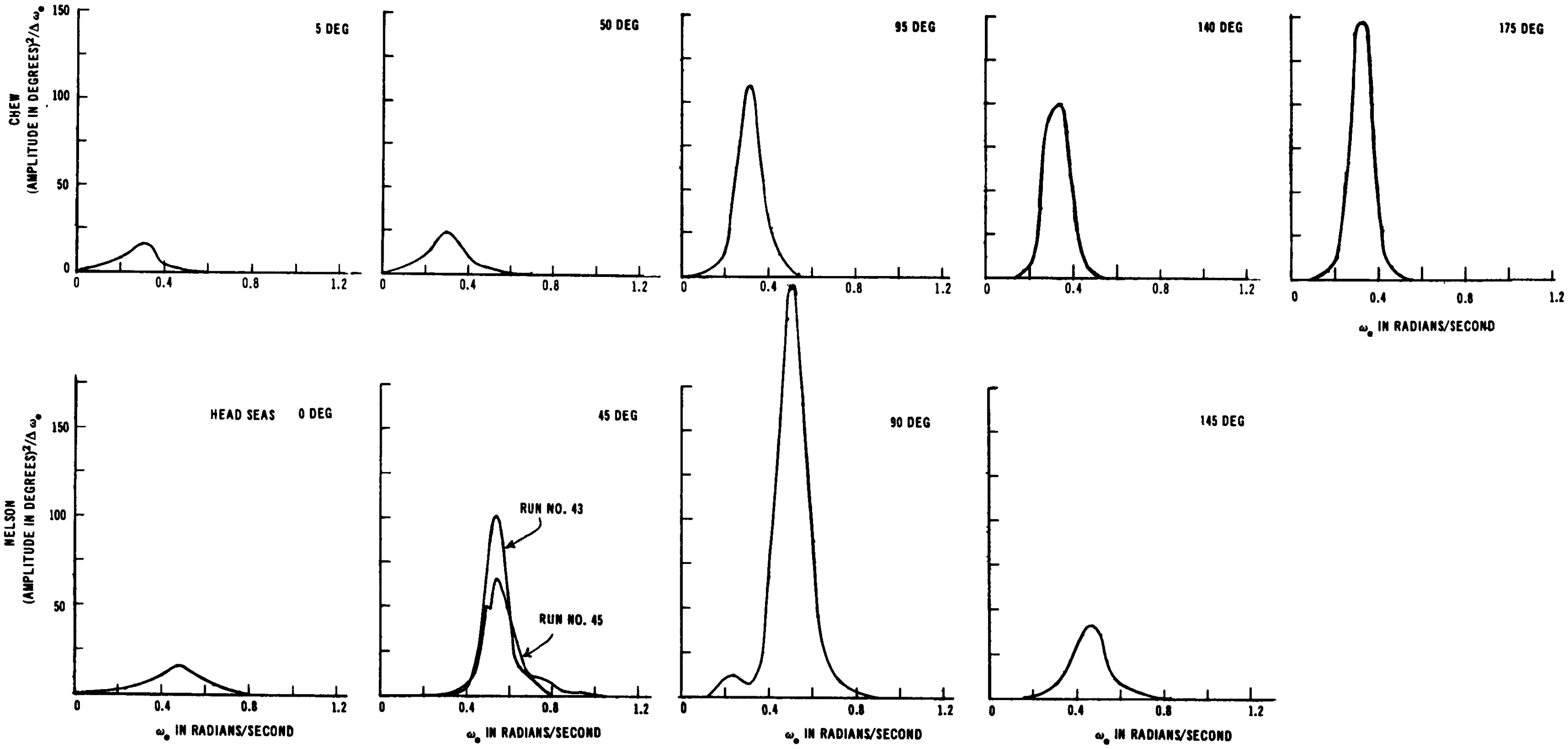


Figure 49 – Roll Energy Spectra for the Two Ships at a Nominal Speed of 14 Knots

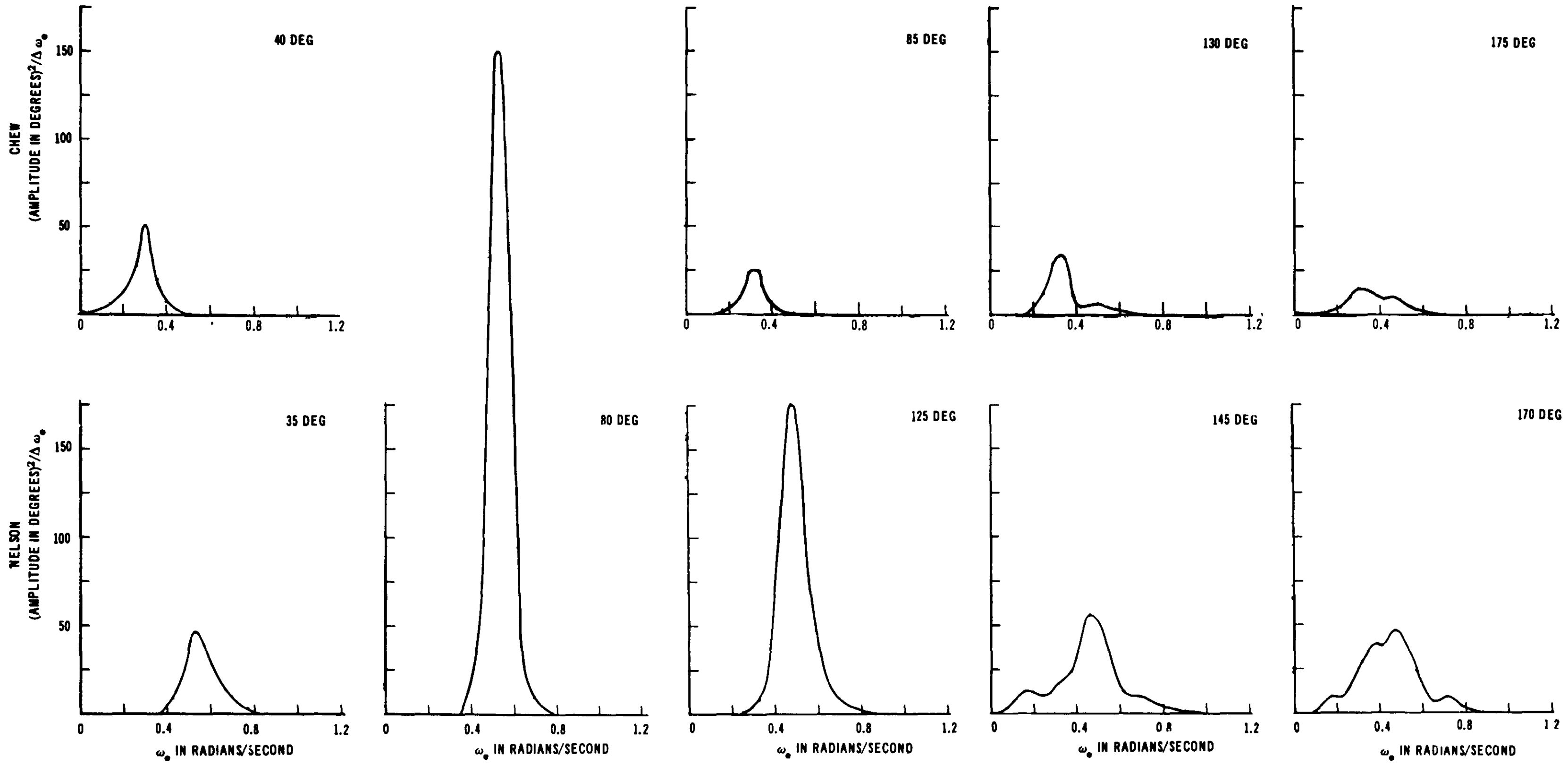


Figure 50 – Roll Energy Spectra for the Two Ships at a Nominal Speed of 8 Knots for CHEW and 10 Knots for NELSON

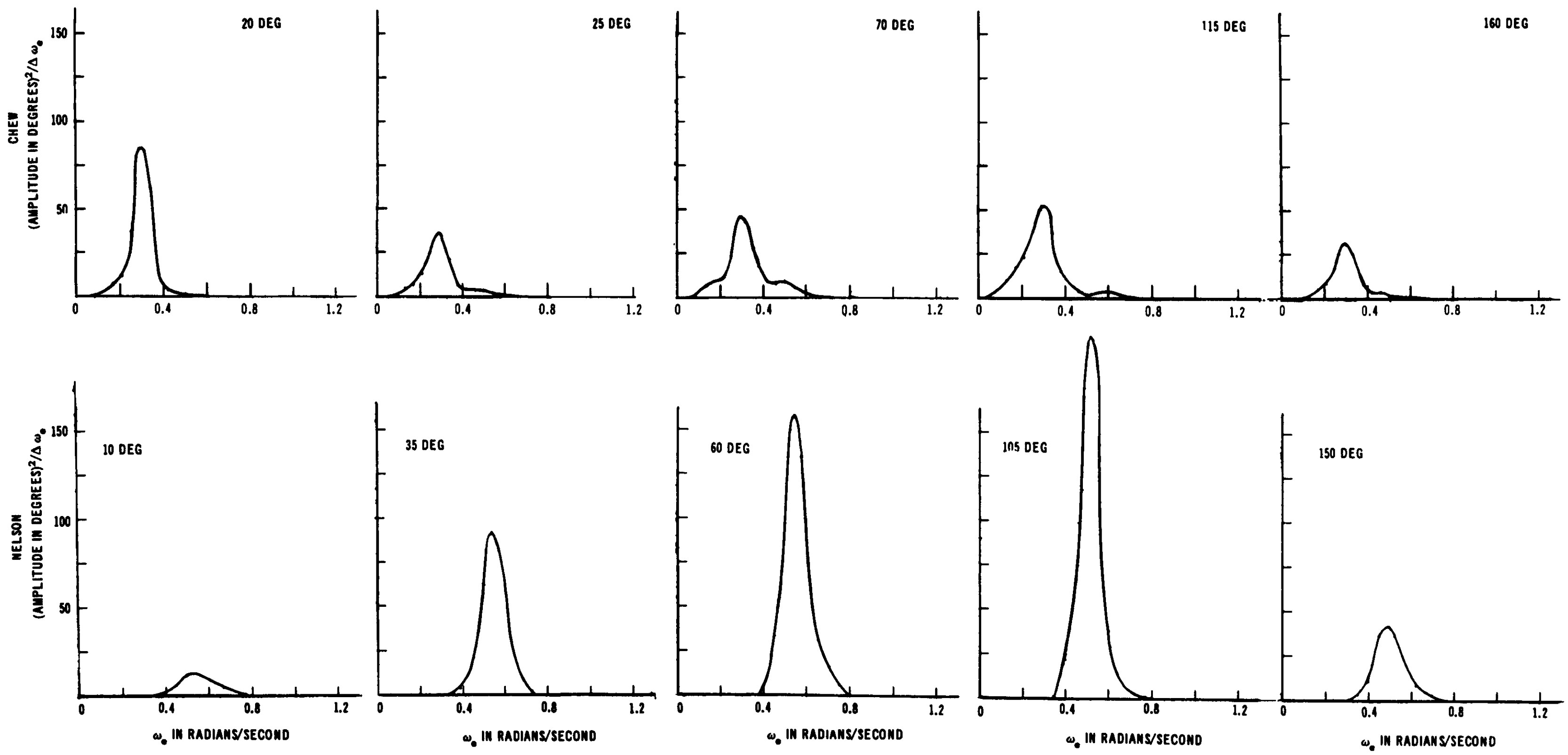


Figure 51 – Roll Energy Spectra for the Two Ships at a Nominal Speed of 5 Knots

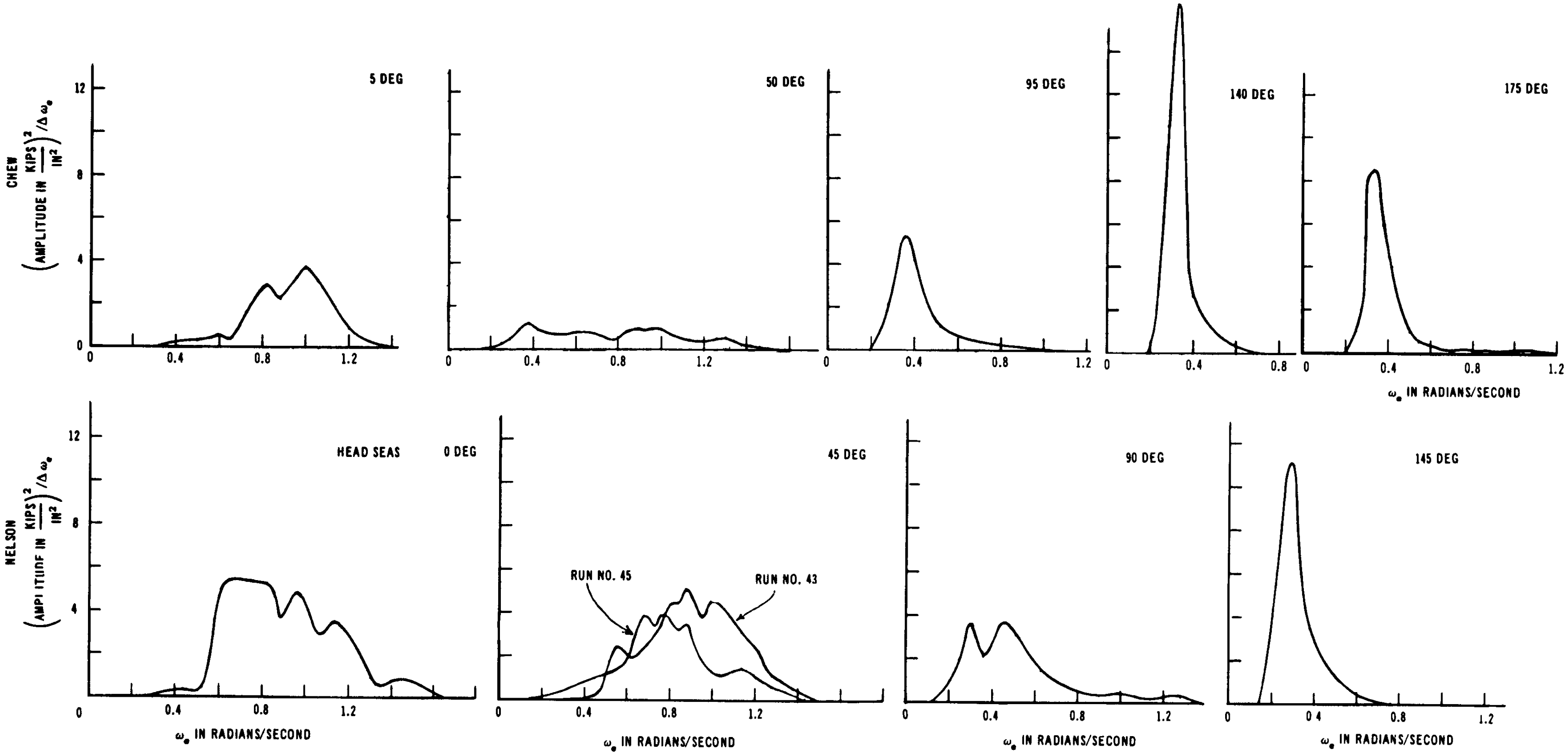


Figure 52 – Longitudinal Stress Energy Spectra for the Two Ships at a Nominal Speed of 14 Knots

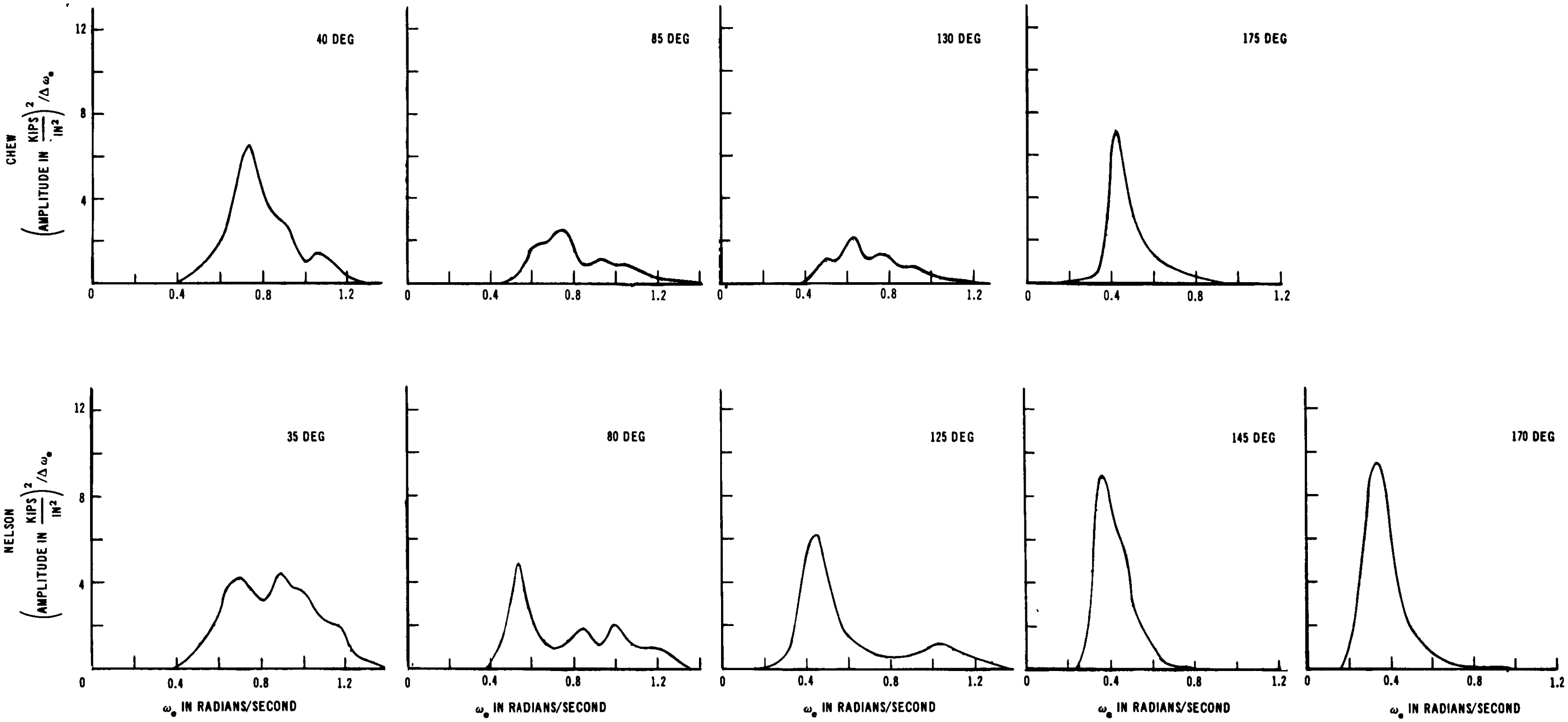


Figure 53 – Longitudinal Stress Energy Spectra for the Two Ships at a Nominal Speed of 8 Knots for CHEW and 10 Knots for NELSON

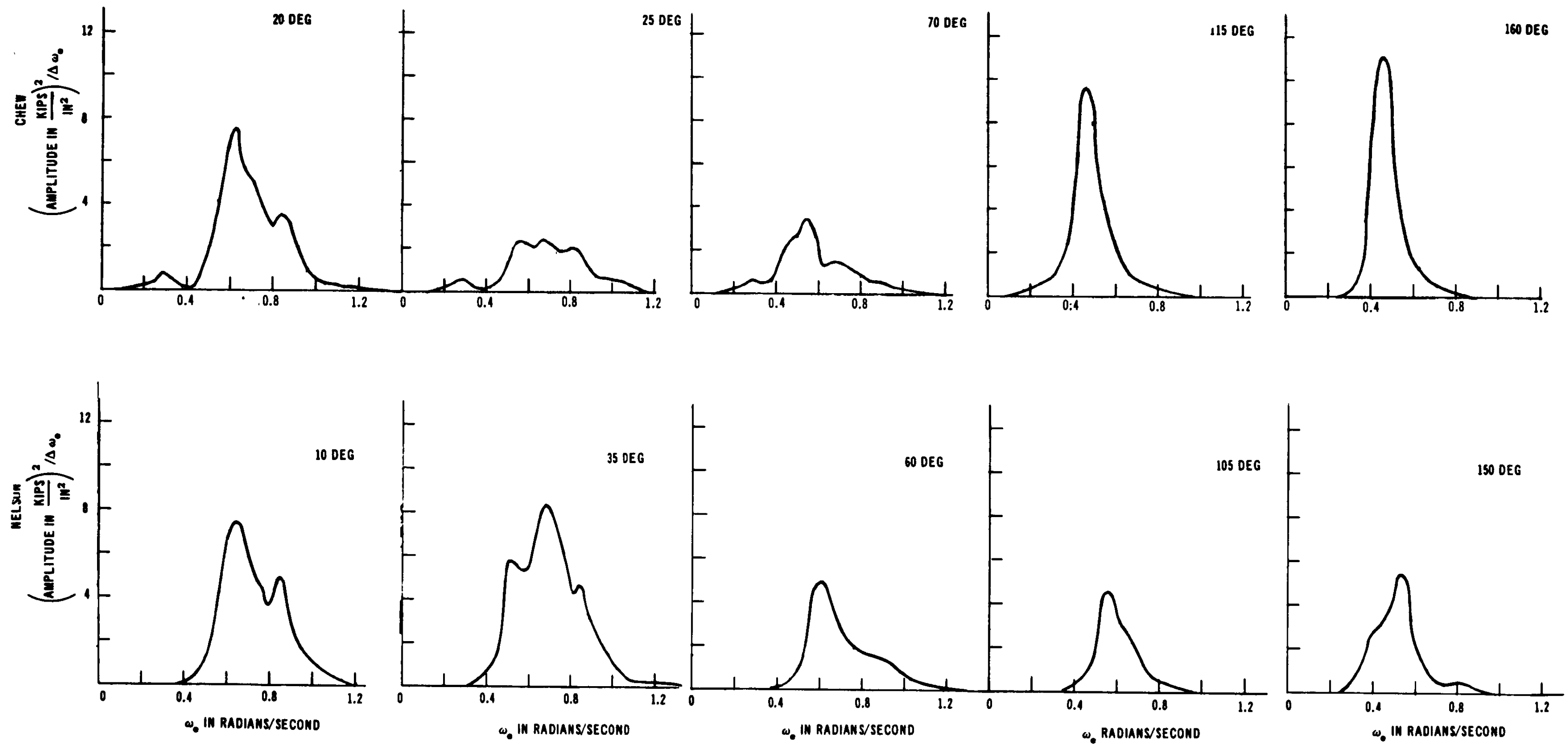


Figure 54 – Longitudinal Stress Energy Spectra for the Two Ships at a Nominal Speed of 5 Knots

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13. ABSTRACT

Seaworthiness trials were conducted to obtain sufficient data to evaluate the relative seakeeping ability of two types of modified Liberty Ships, MV THOMAS NELSON and SS BENJAMIN CHEW. Special maneuvers were conducted at several speeds for a series of ship headings relative to the oncoming sea. The plan of the tests, the instrumentation, and the variables measured during the trials are described. The two ships are compared by reducing the data for the nine special maneuvers to a ratio that is equivalent to motion or stress per unit wave height. Their ability to maintain speed in a seaway are also compared. The overall evaluation of the seaworthiness characteristics indicates that the THOMAS NELSON is superior to the BENJAMIN CHEW.

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(ENCLOSURE 1)

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Correlation Data for Ship and Model						
MV THOMAS NELSON						
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