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Bethesda, Maryland 20084

PERFORMANCE AND MANEUVERING TRIALS OF USNS HAYES (T-AGOR 16) WITH AND WITHOUT A TOWED ARRAY

by

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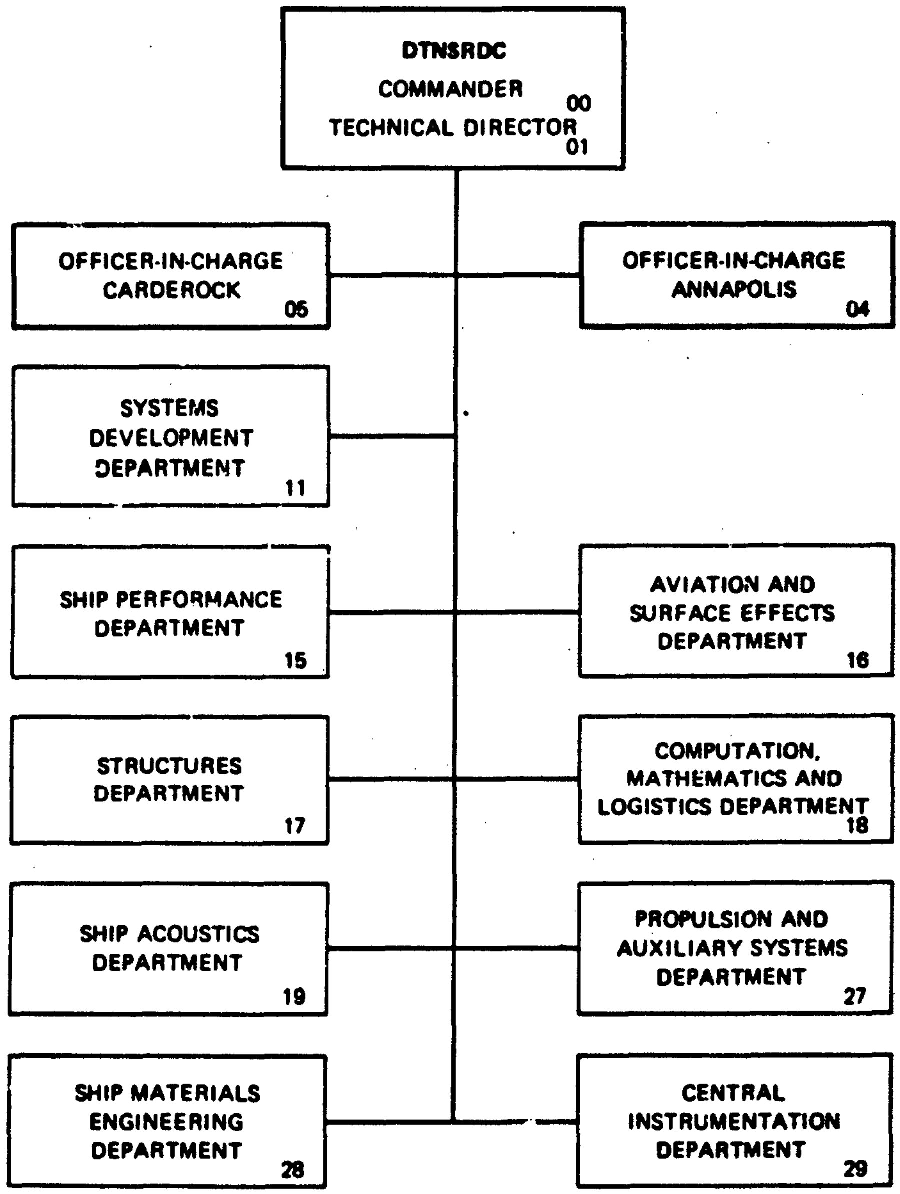

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This report contains the results of the performance and maneuvering trials conducted on USNS HAYES (T-AGOR 16). Trials were conducted with and without a towed array. Standardization trials were conducted at design, under-design, and over-design propeller pitch settings throughout a speed range of approximately 4 to 15 knots. For the design and off-design propeller pitches the shaft power remained essentially constant at any given speed. At 10 knots HAYES is laterally stable and requires 0.5 degree right rudder to maintain (over)

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a straight course. Right and left rudder are equally effective in initiating and checking changes in course. When towing the array, the following restraints were observed. It was necessary to tow the array at such a speed that the array maintained a constant depth. The highest towing speed tested which did not exceed the array towing cable limits was approximately 12.7 knots. When making course changes greater than 360 degrees with the array deployed, no rudder angle greater than 5 degrees was used. This was done to avoid fouling of the array with the hulls or propellers. Within the limits of the above restraints, the towed array had no significant effect on HAYES' powering and maneuvering characteristics.

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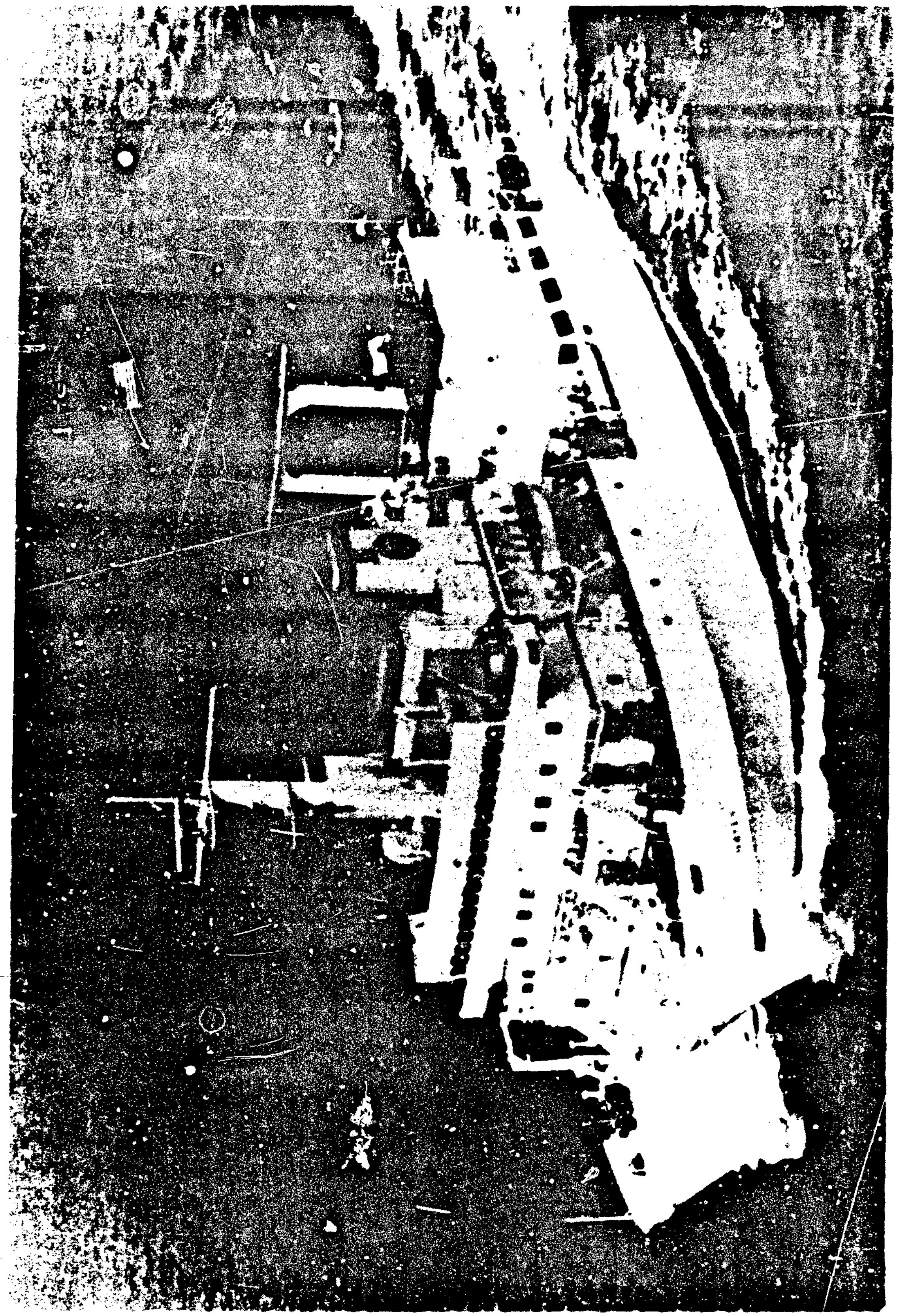

ABSTRACT

This report contains the results of the performance and maneuvering trials conducted on USNS HAYES (T-AGOR 16). Trials were conducted with and without a towed array. Standardization trials were conducted at design, under-design, and over-design propeller pitch settings throughout a speed range of approximately 4 to 15 knots. For the design and off-design propeller pitches the shaft power remained essentially constant at any given speed. At 10 knots HAYES is laterally stable and requires 0.5 degree right rudder to maintain a straight course. Right and left rudder are equally effective in initiating and checking changes in course. When towing the array, the following restraints were observed. It was necessary to tow the array at such a speed that the array maintained a constant depth. The highest towing speed tested which did not exceed the array towing cable limits was approximately 12.7 knots. When making course changes greater than 360 degrees with the array deployed, no rudder angle greater than 5 degrees was used. This was done to avoid fouling of the array with the hulls or propellers. Within the limits of the above restraints, the towed array had no significant effect on HAYES' powering and maneuvering characteristics.

ADMINISTRATIVE INFORMATION

This program was authorized and funded by the Naval Sea Systems Command (NAVSEA), PMS-383. The funding for this project was provided by NAVSEA Work Request N0002484WR12001 of 12 September 1983. The work reported herein was performed by the Full-Scale Trials Branch (Code 1523) of the David W. Taylor Naval Ship R&D Center (DTNSRDC). The trials were performed in accordance with the procedures listed in Enclosure (1) of DTNSRDC letter 1170:LFW, 3910 of 31 August 1983. This project was carried out under DTNSRDC Work Unit 1170-441.

INTRODUCTION

The HAYES was the first large ocean-going catamaran designed and built in the western hemisphere.[1*] The vessel was built at Todd Shipyard, Seattle, Washington with oceanographic research being its primary mission. HAYES is diesel powered and equipped with one controllable pitch propeller per hull.[2] Ship and propeller characteristics are given in Table 1. For the past year, HAYES has been pierside at the Military Sealift Command, Marine Ocean Terminal (MSC, MOT), Bayonne, New Jersey. During that time an investigation was begun to determine the feasibility of using HAYES as a replacement for the Mobile Noise Barge (MONOB) which is currently used by DTNSRDC for determining acoustic signatures of various marine vehicles. The catamaran design provides an ideal acoustic work platform because of the large open deck area and the capability of lowering research equipment into the sheltered water between the two hulls.

The Center was tasked by NAVSEA to perform combined trials that would provide the data required for a decision on the suitability of HAYES as the MONOB replacement vessel. One aspect of the combined trials was the performance and maneuvering trials conducted by the DTNSRDC Full-Scale Trials Branch. These trials were conducted in two phases. The baseline configuration without a towed array included standardization, lateral stability, and horizontal overshoot trials. The towed array phase included standardization, horizontal overshoot, acceleration, and tactical trials. The towed array configuration includes 4000 feet (1219 meters) of tow cable, 1968 feet (600 meters) of neutrally buoyant cable, and 984 feet (300 meters) of array. This configuration will hereafter be referred to as the towed array. This report presents the results of the performance and maneuvering trials both with and without the towed array.

The 10 knot lateral stability trial was conducted in transit from Bayonne, New Jersey to the Naval Supply Center (NSC), Cheatham Annex,

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*References are listed on page 18.

Virginia. With this exception, all non-array trials were conducted at the Hatteras East Coast Tracking Offshore Range (HECTOR) from 5 through 7 October 1983. HECTOR is located 50 nautical miles (92.6 kilometers) northeast of Cape Hatteras, North Carolina. A brief description of range capabilities and operation is given in Appendix A. All towed array trials were conducted at the Atlantic Undersea Test and Evaluation Center (AUTEC) Weapons Range on 29 and 30 October 1983. The AUTEC range is located just east of Andros Island, Bahamas. A brief description of the AUTEC range and test facilities is given in Appendix B.

Standardization trials were conducted in order to determine the speed and powering characteristics of the ship for a series of speeds up to and including full power. An instrumented tracking range (HECTOR or AUTEC) was used to obtain the data required to determine accurate speed. Since the HAYES is equipped with controllable pitch propellers, standardization trials were conducted with the propeller at design pitch and at under- and over-design propeller pitch settings.

The handling qualities of primary interest for HAYES were the ability to maintain course, to initiate rapid changes in course, to effectively check changes in course, and to safely make course changes greater than 360 degrees while towing an array. These characteristics were measured and defined by lateral stability trials (spirals), horizontal overshoot trials (zig-zags), and tactical turns. The term lateral stability applies to the inherent dynamic stability of the ship in the horizontal plane of motion. The spiral trial is the definitive maneuver to indicate lateral stability or instability. A ship is considered to be laterally stable if after a disturbance from steady state motion on a straight course, it resumes its motion on another straight course with rudder held fixed at zero or a neutral angle. Zig-zag maneuvers define the inherent ability of the ship to effectively initiate and check changes in course.

Tactical trials were conducted to determine the turning characteristics of the ship (advance, transfer, and tactical diameter). Acceleration trials were used to determine the speed, reach, and time to attain the steady ship speed associated with various engine orders. These acceleration trials were conducted in conjunction with tactical trials so that the drift vectors obtained from the circles could be applied to the acceleration data.

TRIAL CONDITIONS

Sea State 2 to low Sea State 3 conditions were prevalent during both the baseline and towed array trials. These conditions are considered marginal for standardization and maneuvering trials. Additional details of the trial conditions are presented in table 2.

HULL CLEANING AND INSPECTION

An underwater hull cleaning was performed on HAYES at MSC, MOT. The cleaning was performed by the Trell Company of Virginia Beach, Virginia on 27 and 28 August 1983. An inspection of the hulls and propellers was performed by divers from DTNSRDC Code 1925 and Sun Marine Company who determined that the cleaning did not meet Navy standardization trial requirements. Approximately 50 percent of the underwater portion of the hull, including the propellers, sonar dome, and all curved surfaces with less than a 10-foot (3.0-meter) radius, was improperly cleaned.*

A second hull cleaning and subsequent inspection was conducted from 17 through 21 September 1983 at MSC, MOT. DTNSRDC Code 1925 supervised the operation. Diving support was provided by Seward Marine Services, Norfolk, Virginia; Annapolis Naval Station, Annapolis, Maryland; and Shore Intermediate Maintenance Activity (SIMA), Mayport, Florida. This cleaning was found to meet the requirements for the standardization trials.**

PROPELLER PITCH CALIBRATIONS

Propeller pitch calibrations were conducted on HAYES while at MSC, MOT and in transit to NSC. Scribe marks on one of the starboard propeller palms and hub were located by divers. No scribe marks were found on the port propeller palms or hub. The scribe marks found corresponded to the zero pitch setting. Using these marks as a reference point, the divers used a template made according to the propeller drawings to locate the full

*Partlow reported in DTNSRDC Technical Memorandum TM-1925.1-83-109 (Sept. 1983) that the underwater portion of the hull was improperly cleaned.

**Partlow reported in DTNSRDC Technical Memorandum TM-1925-83-117 (Oct. 1983) that this second cleaning met Navy standardization trial requirements.

ahead, design, and full astern pitch positions. When the propeller was positioned, the angle shown on the mechanical quadrant indicator on the O.D. Box was recorded. An electrical pitch/voltage calibration was also conducted to determine the relationship between the scribed propeller pitch settings and the pitch indicators on the bridge, the Engine Order Station (EOS), and the mechanical quadrant.

Due to the absence of scribe marks on the port propeller hub and palms, it was necessary to conduct a dynamic pitch calibration on the port propeller while at sea. The procedure was as follows. With the propulsion plant operating in the manual mode, the starboard shaft was brought to a given rpm and the propeller was brought to the desired pitch as determined from the pre-trial calibration. The port shaft was then brought to the same rpm. The port propeller pitch was then adjusted until port shaft torque matched the starboard shaft torque. This procedure was repeated at various shaft rpms and propeller pitch settings until a calibration was obtained for the port propeller pitch. The validity of the procedure was shown by the consistent matching of port and starboard torque when both shafts were set at the same shaft rpm and calibrated pitch throughout the baseline trials.

DISPLACEMENT

Baseline Trial Displacement

Displacement calculations based on ship fuel and water consumption was not possible due to the unavailability of this information. Hence, the baseline trial displacement was derived from visually sighted draftmarks and the Hydrostatic Properties Table obtained from the ship. It is assumed that these properties are characteristic of the ship in its present configuration.

Readings of draft and specific gravity were taken pierside at Cheatham Annex, Virginia before sailing. Readings were also taken at HECTOR before and after the trials. Draft readings taken on the range were considered inaccurate due to the motions of the ship in conjunction with excessive wave action. Hence, these readings were not used in calculating displacement.

The displacement of the ship was calculated using the draft readings and specific gravity taken pierside. Mean draft, as determined from pierside readings, was 21.4 feet (6.51 meters). Displacement from the ship's Hydrostatic Properties Chart was modified by the pierside specific gravity and temperature readings and a corrected ship displacement was calculated to be 3634 tons (3692 metric tons). Details of these calculations are shown in Appendix C.

Towed Array Trial Displacement

Draft readings were taken immediately before and after the trials were conducted at AUTEC. The average mean draft for these trials was found to be 21.0 feet (6.40 meters). After corrections for specific gravity, the trial displacement was determined to be 3600 tons (3658 metric tons). The method of displacement calculation is further discussed in Appendix C.

TRIAL PROCEDURES AND INSTRUMENTATION

The standardization trials were conducted in accordance with Chapter 094 of the Naval Ship's Technical Manual.[3] Data were obtained throughout a speed range of approximately 4 to 15 knots. Two or three runs, alternating 180 degrees in direction and of three minutes duration, were made at HECTOR. At AUTEC, the runs were six minutes in duration. An average was applied to take into account the effects of current. For a two-pass spot, a simple average of the data from the two passes was used. For a three-pass spot, the data for the odd direction was weighted twice and the four passes were then averaged.

Port and starboard measurements taken include shaft rpm, shaft torque, propeller pitch, and rudder angle. Motorola Mini-Ranger III (MRS III) position data, EM Log speed, ship heading, angle of heel, relative wind direction and speed were also obtained. Shaft horsepower was calculated from the measured shaft rpm and torque. Ship speed was calculated from MRS III positional data. A Hewlett-Packard (HP-9825) computer system digitized these signals at a pre-determined rate and was utilized to determine the run averages and the maximum and minimum points.

After digitizing the data, it was then stored on flexible discs. The data were also converted into suitable engineering units and then displayed in a hard copy format as output from a line printer.

The torque signals were telemetered from each propeller shaft via an Acurex torque-strain monitoring system. The rpm was obtained by using an infrared light sensor pick-up which was mounted adjacent to the shaft. As the shaft rotated, a pulse was generated each time a tape strip passed the sensor pick-up. The frequency at which these pulses were generated was directly proportional to the shaft rpm. These frequency signals were converted to analog voltage with a frequency-to-voltage (F/V) converter.

Propeller pitch data were obtained during the trials by electrically connecting into the ship's propeller pitch synchro circuit. The signal was then converted to a voltage through a synchro-to-voltage (S/V) converter. This propeller pitch signal was then sent to the computer for digitizing and to the bridge for port and starboard pitch voltage readouts.

Additional measurements such as EM log (see Appendix D) and rudder position were obtained using the ship's synchro signal voltages. The synchro voltages going to the ship's indicators were connected through cables to a DTNSRDC multi-channel synchro DC converter unit. Converter unit outputs were sent through calibrated amplifiers to the HP-9825 computer where they were digitized and stored on flexible discs.

Ship speed at HECTOR was obtained by the MRS III. The MRS III operates on the principal of radar (pulse tracking). A transmitter located on the ship was used to interrogate two reference station transponders. These transponders were mounted on towers which are separated by a known distance. The elapsed time between the transmitted interrogation produced by the MRS III transmitter and the reply received from each transponder was used as the basis for determining the distance to each transponder. This range information, together with the known location of each transponder, was triangulated to provide a position fix of the ship. Successive positional fixes enable the calculation of ship speed.

Ship speed at AUTEC is discussed in the Towed Array Standardization Trials section of this report.

Ship's heading was obtained from the ship's gyro. The gyro produced a single-speed, three-phase, 60-cycle signal. This signal was converted to an analog voltage using a solid state S/A converter. Roll and pitch angles were obtained from a stable table provided by DTNSRDC Code 1561. Relative wind direction and speed were recorded from the ship's anemometer. Ship's heading, ship's speed, and relative wind direction and speed were used to calculate the true wind direction and speed.

PRESENTATION AND DISCUSSION OF TRIAL RESULTS

STANDARDIZATION TRIALS

Baseline Standardization Trials

The results of the baseline standardization trials conducted at HECTOR are summarized in Tables 3 through 5 and are shown graphically in Figure 1. The results have not been corrected for wind effect or reduced to standard conditions of sea water temperature and density. These trials were conducted at propeller pitches of 36 percent, 52 percent, 87 percent, 100 percent, 104 percent, 111 percent, and 118 percent of design. The shaft rpm was varied at each condition to obtain the speed conditions desired. The ship displacement was 3634 tons (3692 metric tons). The main propulsion plant was in the manual mode at the EOS due to a failure in the direct control mode system. While conducting the 100 percent propeller pitch trials, the shaft rpm and the propeller pitch were manually adjusted to the values found in the direct control mode schedule. For the off-design propeller pitch trials, the shaft rpm and propeller pitch were manually adjusted to values determined from the pre-trial propeller pitch calibration.

The plant's maximum steady state values were not exceeded during the trial. These limiting values are as follows:

1. Shaft rpm - 139 rpm.
2. Shaft torque - 97,727 pound force-foot (131,144 Newton-meters) per shaft.
3. Shaft power - 2,560 horsepower (1,909 kilowatts) per shaft.

The maximum powering condition reached when operating at 100 percent propeller pitch was:

1. Ship speed - 14.80 knots.
2. Shaft rpm - 137.8 rpm.

3. Shaft torque - 176,500 pound force-foot (239,300 Newton-meters).

4. Shaft power - 4,630 horsepower (3,450 kilowatts).

The limiting performance parameter in this condition would have been shaft rpm.

The nominal 4 and 5 knot speeds were conducted at the minimum operating rpm obtainable for this plant. At 73 rpm, both propeller pitches were set according to the direct control mode schedule. An accurate port propeller pitch value was not available. This port pitch value was adjusted until starboard and port torque matched. Since the rpms and torques matched, the port propeller pitch was assumed to be equal to the starboard propeller pitch. Hence, the starboard propeller pitch value was used in lieu of a port pitch reading.

When operating at an under-design propeller pitch of 87 percent, the limiting performance factor would have been shaft rpm. The maximum performance attained in this condition was:

1. Ship speed - 13.63 knots.
2. Shaft rpm - 135.3 rpm.
3. Shaft torque - 136,000 pound force-foot (184,400 Newton-meters).
4. Shaft power - 3,500 horsepower (2,610 kilowatts).

Three over-design propeller pitch conditions, 104, 111, and 118 percent, were investigated. The 104 percent propeller pitch condition would have been shaft rpm limited if greater plant performance was required. The following performance was observed for this condition:

1. Ship speed - 15.17 knots.
2. Shaft rpm - 137.5 rpm.
3. Shaft torque - 187,100 pound force-foot (253,700 Newton-meters).
4. Shaft power - 4,900 horsepower (3,650 kilowatts).

The highest powering performance attained at 111 percent propeller pitch was:

1. Ship speed - 15.08 knots.
2. Shaft rpm - 131.2 rpm.
3. Shaft torque - 192,500 pound force-foot (261,000 Newton-meters).
4. Shaft power - 4,800 horsepower (3,580 kilowatts).

At the maximum over-design propeller pitch tested, 118%, the following maximum performance was observed:

1. Ship speed - 13.46 knots.
2. Shaft rpm - 111.0 rpm
3. Shaft torque - 154,100 pound force-foot (209,000 Newton-meters).
4. Shaft power - 3,260 horsepower (2,430 kilowatts).

The maximum values of shaft rpm or torque were not reached in this condition. The main propulsion plant was slowly overheating and becoming a concern to ship's force. Further testing was not done since sufficient data were available to extrapolate the 118 percent pitch powering curves to their maximum operating conditions.

When comparing the effect of propeller pitch on shaft rpm and torque, certain trends are evident. As expected, to maintain a constant speed as the propeller pitch increases, the shaft rpm decreases and the shaft torque increases. It should be noted that shaft power remained essentially constant at any given speed.

Towed Array Standardization Trials

Abbreviated standardization trials were conducted on HAYES on 29 and 30 October 1983. These trials were performed on the AUTEC range. HAYES deployed an array with four instrumented modules. Each module contained a pinger operating at its own discrete frequency. Another pinger was mounted on HAYES. AUTEC received and tracked each of these ship and array pinger signals by means of sea bottom mounted hydrodphone arrays. This monitoring enabled the range to determine ship and array module positional data. The motion characteristics of the array will be addressed in a separate report.[4] The ship positional data were used to calculate ship speed.

Nominal speeds of 5, 10, and 12 knots were investigated and ship powering performance monitored. It was found that 5 knots was the minimal speed at which the ship could operate and stay within the maximum towed array depth limit set by the Naval Underwater Systems Center (NUSC), New London, Connecticut, trial personnel. The greatest speed at which the ship operated without exceeding the maximum array cable tension as determined at the tow point was 12.73 knots. Ten knots was previously determined by the

DTNSRDC Acoustic Department (Code 19) as the likeliest operating tow speed. These trials were conducted in the same manner as the baseline trials and are presented in Table 6 and shown graphically in Figure 1.

The ship's plant was in the manual control mode. The ship displacement was 3,600 ton (3,658 metric tons). The powering characteristics of HAYES at the operational tow speed were:

1. Ship speed - 10.58 knots.
2. Shaft rpm - 89.7 rpm.
3. Shaft torque - 82,200 pound force-foot (111,400 Newton-meters).
4. Shaft power - 1,400 horsepower (1,050 kilowatts).

The maximum speed attained without exceeding the array towing cable limits was 12.73 knots. Other powering characteristics at this speed were:

1. Shaft rpm - 109.3 rpm.
2. Shaft torque - 125,300 pound force-foot (169,900 Newton-meters).
3. Shaft power - 2,610 horsepower (1,950 kilowatts).

Due to a port pitch voltage shift, an accurate port pitch reading was not available. Therefore, for each run, the starboard pitch was set to the value in the direct control mode schedule. Both port and starboard rpm were set at the desired values and the port pitch was then adjusted until starboard and port torques were equal. With this rpm/torque match, it was felt that both pitches were the same. Starboard pitch readings were considered to be good and are used in lieu of the port pitch readings.

Comparison of Baseline and Towed Array Standardization Trial Results

Comparison of the baseline and the towed array standardization trial results indicates that the array has little or no effect on HAYES powering characteristics. This is shown as a plot of power versus speed cubed in Figure 2.

The displacement during the towed array trials was approximately one percent less than the displacement during the baseline trials. At any given speed, a comparison of the two 100% propeller pitch trials (baseline and towed array), shows that the towed array trial had lower rpm and higher torque values than its baseline counterpart. The difference in displacement was so small that changes in power due to displacement were not evident.

There does not appear to be any significant difference between the indicated starboard propeller pitch for the baseline and towed array trials. Throughout both trials the port shaft RPM and torque were matched to the starboard shaft RPM and torque. The port propeller pitch was assumed to be the same as the starboard propeller pitch. Figure 1 shows small differences in the RPM and torque curves at comparable points of the two trials. The differences seen in the figure may be due to a variation between indicated pitch and actual pitch at the propeller hub.

LATERAL STABILITY TRIALS

Lateral stability, or spiral maneuvers, were conducted to obtain a measure of the steering characteristics of the ship. This was determined by the relationship between rudder angle and the ship's rate of change of heading. Five and 10 knot nominal approach speeds and rudder angles ranging from 15 degrees right to 15 degrees left were investigated. These maneuvers commenced after steady conditions of course and speed were attained. The rudders were deflected to each of the scheduled angles and held until the rate of change of heading was constant for at least 30 seconds. Results of the spiral maneuvers are shown in Figures 3 and 4.

The 5-knot spiral is shown in Figure 3. The ship is not laterally stable at this speed as indicated by the hysteresis loop between 5 degrees right rudder and 5 degrees left rudder. The sea state and wind velocity and direction were such that at 5 knots it was difficult to maintain lateral control of the ship at the lower rudder angles. Due to its large superstructure, HAYES is extremely susceptible to the effects of wind and waves.

The 10-knot spiral, as shown in Figure 4, indicates that HAYES is laterally stable. This stability is shown by the symmetry between right and left rudder response. It can also be noted that a 0.5 degree right rudder is required to maintain a constant heading.

HORIZONTAL OVERSHOOT TRIALS

Baseline Horizontal Overshoot Trials

Horizontal overshoot trials (zig-zag maneuvers) were conducted to determine the ship's response to changes in rudder angle at selected approach speeds. This is determined by the overshoot angle and overshoot time.

The overshoot angle is defined as the number of degrees in change of heading between the point at which the rudder is deflected and the point at which the ship's change of heading reverses. The overshoot time corresponds to this heading change. Zig-zag maneuvers were conducted at nominal approach speeds of 5 and 10 knots. Effects of initial rudder angles of 10 and 20 degrees right and left were investigated at each speed. Each run was ended after six rudder movements (3 right rudder and 3 left rudder deflections) were completed. Results of the baseline zig-zag maneuvers are presented graphically in Figures 5 through 12. A summary of these maneuvers is given in Table 7. Appendix E graphically describes the terms used in presenting these data.

The second rudder execution in Figure 5 (Run H1002) occurred before the ship had altered 20 degrees from the baseline course. The early rudder movement at the second execute did not effect any of the later overshoot angles and times for that run.

The data show that the reach (time from initial execute to when the ship passes through the original base course) was greater for the 5-knot runs than for the 10-knot runs. The average period (period being defined as the time between every other execute) was larger for the 5-knot runs than for the 10-knot runs. Left and right rudder deflections result in approximately the same reach and period. The overshoot angles for 20-degree rudder deflections are greater at 10 knots than at 5 knots. Overshoot times at 10 knots are less than at 5 knots. Within any given run, neither right nor left rudder is more effective than the other (overshoot angles are within ± 2 degrees and overshoot times are within 2 or 3 seconds). Hence, the test results show that HAYES responds approximately the same to right and left rudder deflections.

Towed Array Horizontal Overshoot Trials

Horizontal overshoot trials were conducted on the AUTEC range while towing an array. Nominal approach speeds of 5 and 10 knots were investigated. Initial rudder angles of 10, 15, and 20 degrees were used for various runs. These trials were conducted in the same manner as those conducted at HECTOR. The towed array zig-zag trial results are presented in Figures 13 through 19. A numerical presentation is given in Table 8.

The data show the following trends. The reach and the period for the 10-knot zig-zags are less than those for the 5-knot zig-zags. The data for the 10-knot runs show that increasing the execute rudder angles increased the overshoot times and angles. As expected, the time between consecutive executes also increased as execute rudder angles increased.

It should be noted that a 10-knot run using 15 degrees right rudder deflection was conducted to observe how close the array came to the stern of the ship. This was done as a precautionary measure before running the 20-degree rudder deflections to avoid the possibility of array/propeller fouling.

The effect of nominal approach speed on the zig-zag maneuvers for the runs with the 20-degree execute rudder angles show the following trends. As the speed increases, the overshoot time decreases and the overshoot angle will increase. The reach, period, and time between consecutive executes will also decrease with increasing speed.

When comparing the results of right and left execute rudder angles, no trends are apparent. The overshoot angles are generally within ±2 degrees when the wind direction is nominally ahead or astern. The overshoot times tend to be within ±2 seconds.

When running at wind directions and velocities other than ahead or astern, HAYES' response to its rudders is affected such that overshoot times and angles are increased or decreased. The amount of increase or decrease is highly dependent on wind direction and speed.

Comparison of Baseline and Towed Array Horizontal Overshoot Trial Results

The following trends were observed when comparing the two horizontal overshoot trials. The overshoot angles obtained with the array deployed are smaller than those observed during the comparable baseline trials. However, there is no apparent trend for overshoot times when comparing trials with and without the array. With the array deployed, the reach, period, and time between consecutive executes are shorter than without the array. Although these trends do occur, the differences between baseline and towed array trial results are small and fall within measurement accuracy. Thus, it can be said that the towed array has no significant effect on HAYES' ability to check or change course at the speeds and rudder angles tested.

TOWED ARRAY TACTICAL TURN TRIALS

Tactical trials were conducted at AUTEC on 30 October 1983. Data from these trials have been corrected for drift due to wind and current.

Initially, for a 5-knot nominal approach speed, a tactical turn using a 10-degree right rudder was attempted. The run was aborted after only 360 degrees because it was not possible to maintain the array at a constant depth. This was a direct result of a lessening tension on the array tow cable as the ship proceeded through the turn. The use of a 10-degree right rudder caused a towed-array-to-ship-hull angle that came to within 5 degrees of fouling the ship's propeller. Hence, it was deemed prudent not to exceed 5 degrees of rudder at higher speeds.

Two tactical turns at a 10-knot nominal approach speed were then conducted using 5 degrees left and right rudder. The change of heading versus time curves for these two runs are shown in Figure 20. It can be seen in this figure that the ship is very susceptible to wind.

Corrected data from these trials is summarized in Table 9. Comparing these data, it appears that the right rudder is more effective than the left rudder, i.e., smaller advance, transfer, tactical diameter, and steady turning diameter. However, no definitive trends can be determined from only two runs.

TOWED ARRAY ACCELERATION TRIALS

Two acceleration runs were conducted; one run was from slow ahead to full ahead, and the other from 1/2 ahead to full ahead. Care was exercised to ensure that the towed array was straight and maintained a constant depth before each run commenced. Time histories of these towed array acceleration trials are presented in Figures 21 and 22. These data have not been corrected for drift due to wind and current. The drift vectors derived from the tactical circles were considered non-representative of the time and location where the acceleration runs were conducted. The data presented were derived from range positional data.

Figure 21 is the time history of an acceleration run from an initial engine order of 1/2 ahead to a final engine order of full ahead. The data show that the ship accelerated from an average approach speed of 7.2 knots and 69.9 rpm to a steady speed of 11.2 knots and 106.8 rpm in 220 seconds while traveling a distance of 1240 yards (1134 meters).

Figure 22 shows the time history of an acceleration run from an initial engine order of slow ahead to a final engine order of full ahead. These data indicate that HAYES accelerated from 3.8 knots and 70.0 rpm to 11.2 knots and 106.0 rpm in 240 seconds and traveled a distance of 1182 yards (1081 meters).

CONCLUSIONS

The results of the performance and maneuvering trials conducted on HAYES are considered to be good. The data are applicable and representative of HAYES in the conditions tested.

When towing the array, the following restraints were observed. It was necessary to tow the array at such a speed that the array maintained a constant depth. The highest attainable ship speed could not exceed the array towing cable limits. When making course changes greater than 360 degrees, no rudder angle greater than 5 degrees was used. This was done to avoid fouling of the array with the hulls or propellers.

The following conclusions can be drawn from the data presented herein:

1. For the design and off-design propeller pitches, the shaft power remained essentially constant at any given speed.

2. The design and under-design propeller pitch conditions would have been shaft rpm limited and the over-design propeller pitch condition would have been shaft torque limited if higher speed/powering conditions were tested.

3. The towed array had no significant effects on HAYES' speed and powering characteristics at the conditions tested. The force exerted on the tow cable by the array will be the factor limiting ship speed.

4. The greatest speed attained while towing an array was 12.73 knots. At this speed, HAYES operated at 109.3 shaft rpm, 125,300 pound force-foot shaft torque (169,900 Newton-meters), and 2,610 horsepower (1,950 kilowatts).

5. At 10 knots, HAYES is a laterally stable ship which requires 0.5 degree right rudder to maintain a constant heading.

6. Right and left rudders are equally effective in initiating and checking changes in course. The towed array had no significant effect on these handling qualities.

7. HAYES' handling and maneuvering characteristics are greatly affected by wind direction and speed due to the large superstructure and hull areas.

8. A comparison of the two tactical turns indicates that HAYES responded to a right rudder more effectively than to a left rudder. However, no definitive trend can be determined from this limited data base.

9. While towing an array, the ship was accelerated from 3.8 knots to the speed associated with a full ahead engine order. The time and distance intervals required to reach 11.2 knots (106.0 rpm) were 240 seconds and 1182 yards (1081 meters), respectively.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation for the cooperation and hospitability given to the DTNSRDC trial personnel by Captain Robert A. Williams and the crew of the HAYES. Appreciation is also expressed to all of the Code 1523 personnel who assisted in the acquisition and analysis of trial data.

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4. Steward, W., Webster, B., Diggs, J., "An Evaluation of USNS HAYES as a Towing Platform for a Towed Array," DTNSRDC Ship Performance Department Report, SPD-2001-01, March 1984.

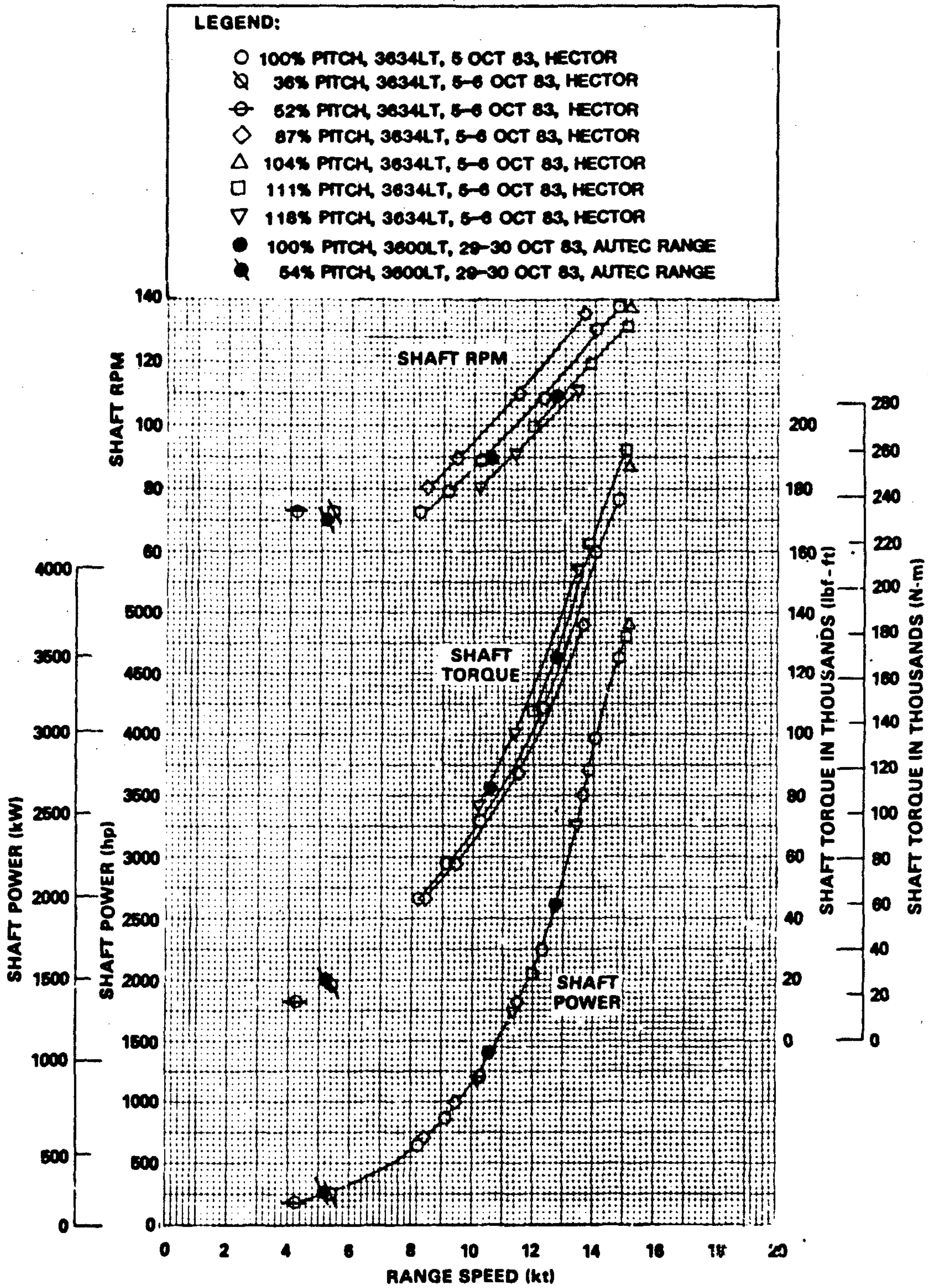


Figure 1 - Results of Baseline and Towed Array Standardization Trials

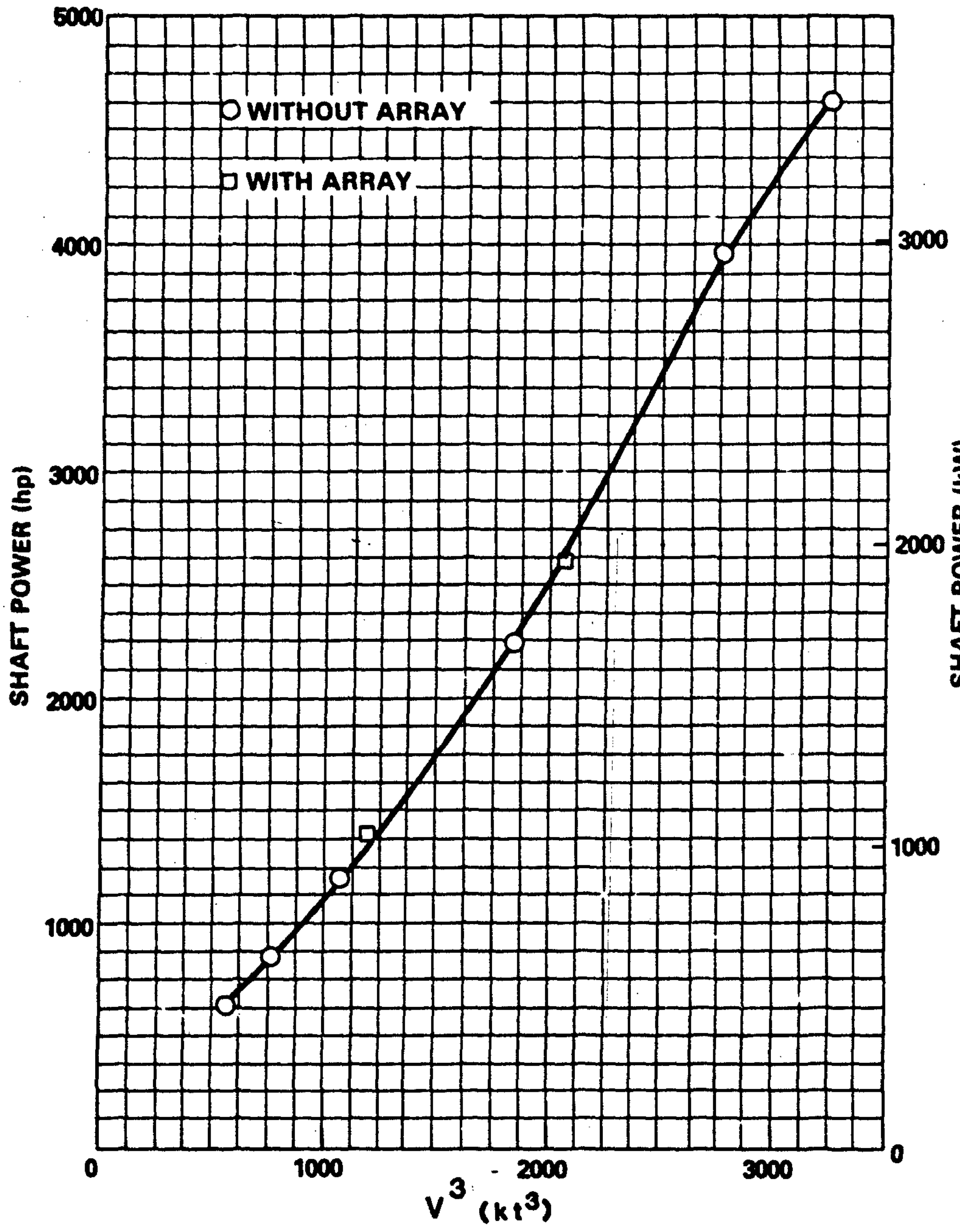


Figure 2 - Comparison of the Baseline and Towed Array Speed versus Power Relationship at Design Propeller Pitch

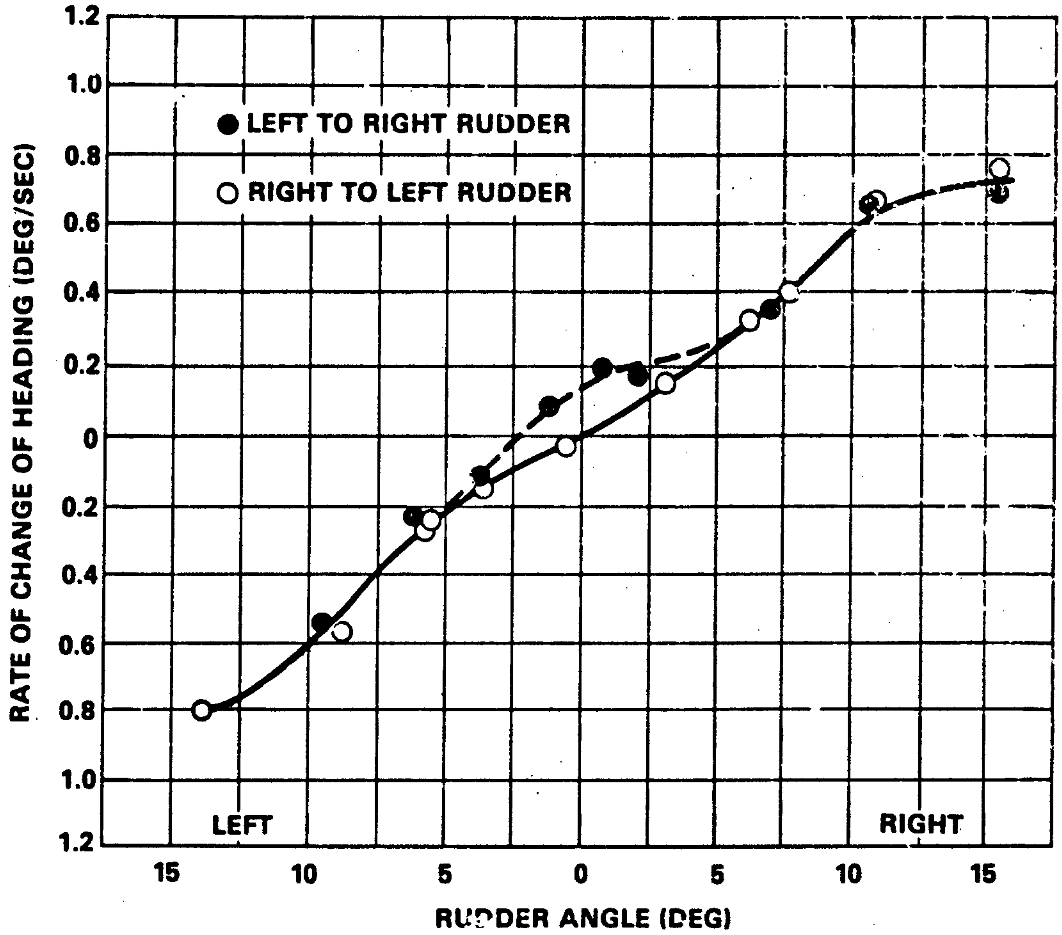


Figure 3 - Results of a Lateral Stability Test at a Nominal Approach Speed of 5 knots

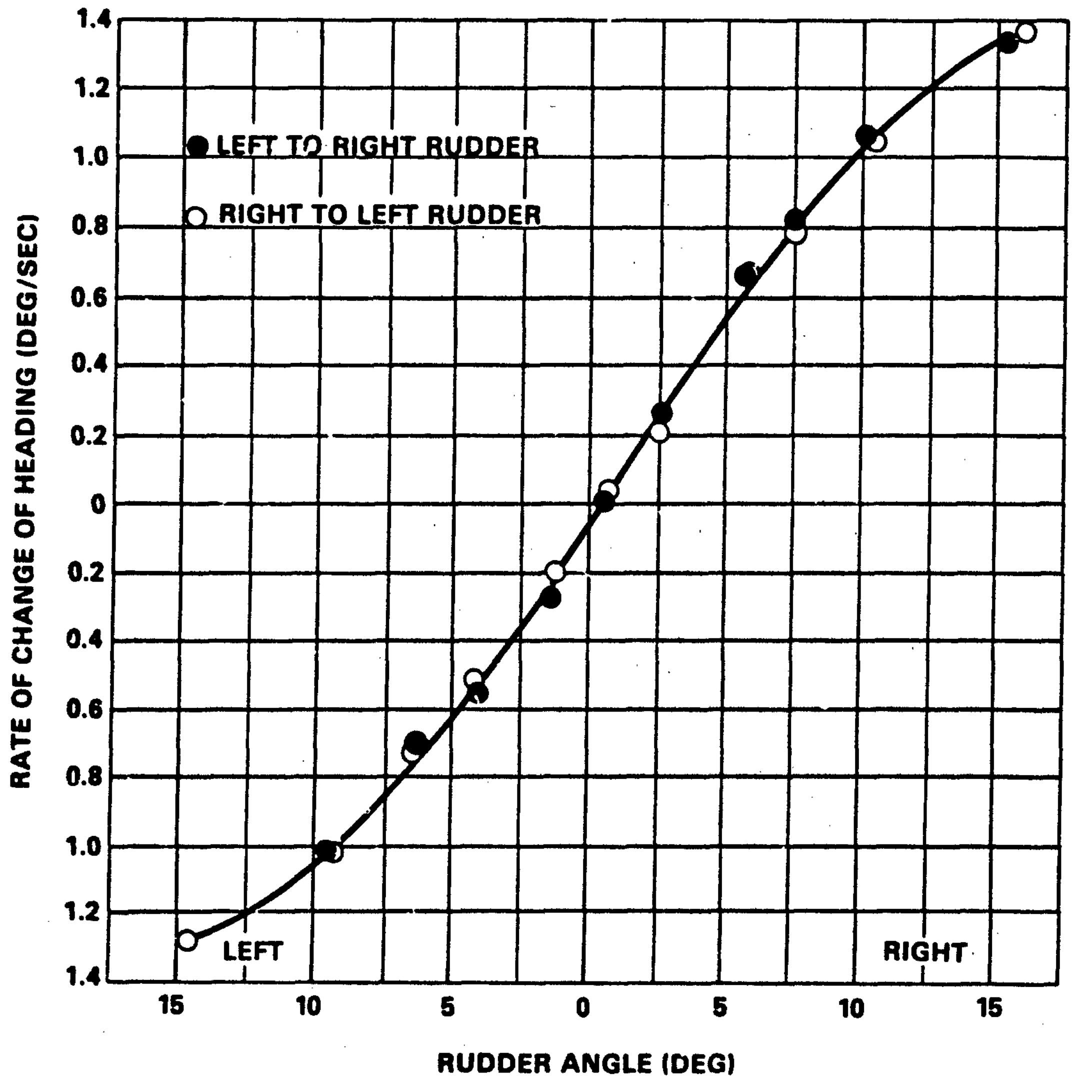


Figure 4 - Results of a Lateral Stability Test at a Nominal Approach Speed of 10 knots

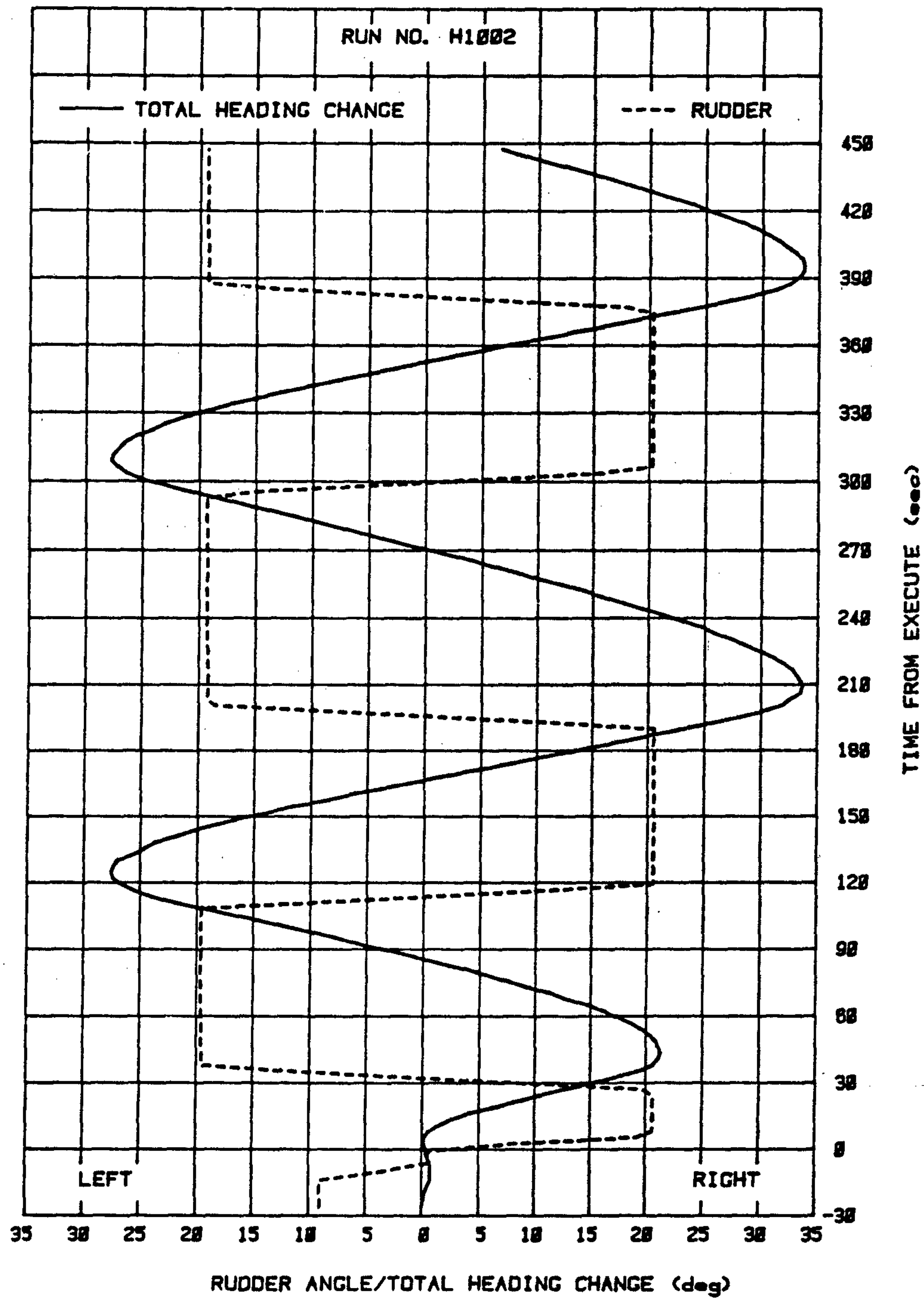


Figure 5 - Baseline Zig-Zag Maneuver from a Nominal 5-Knot Approach Speed Using an Initial 20-Degree Right Rudder

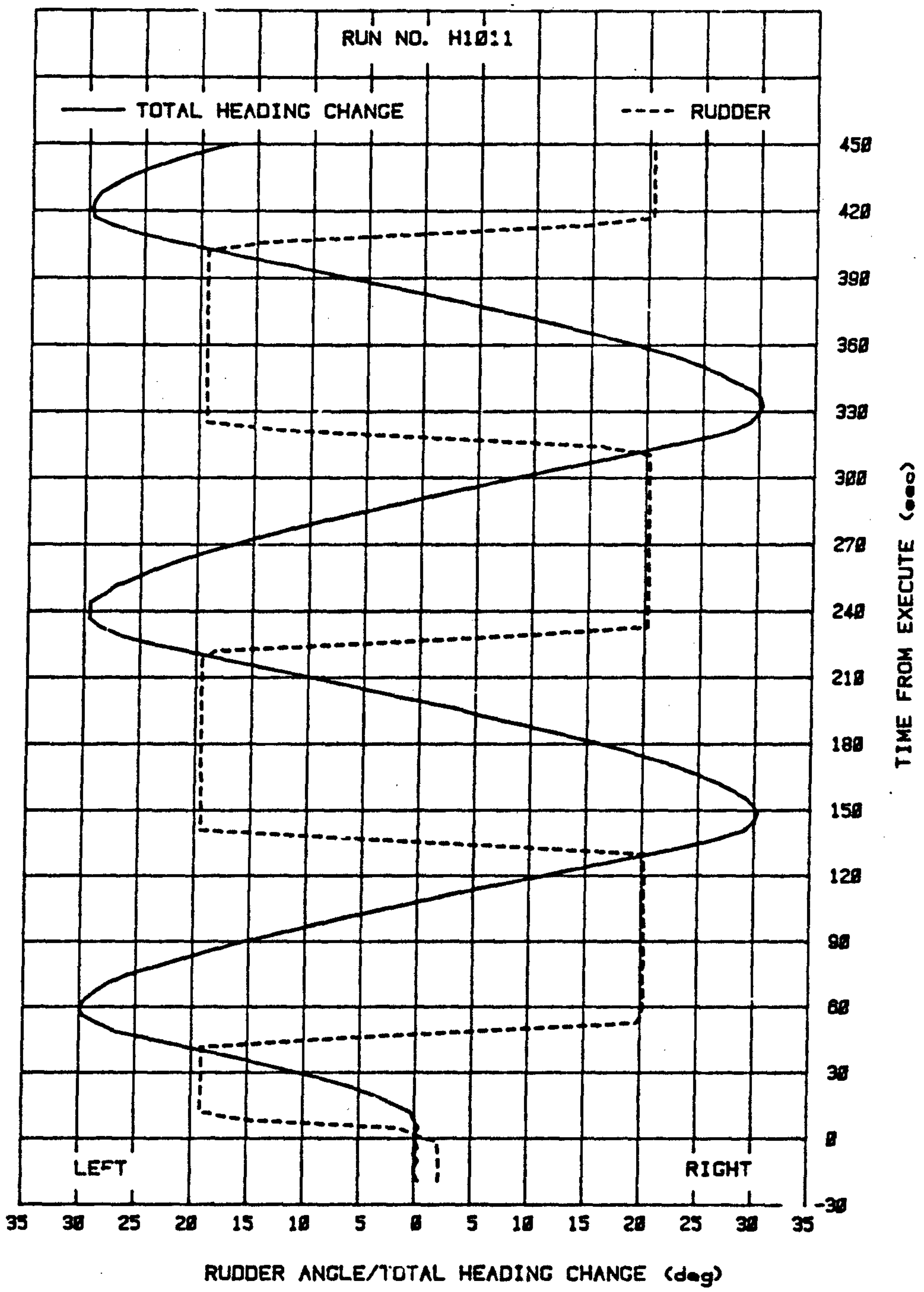


Figure 6 - Baseline Zig-Zag Maneuver from a Nominal 5-Knot Approach Speed Using an Initial 20-Degree Left Rudder

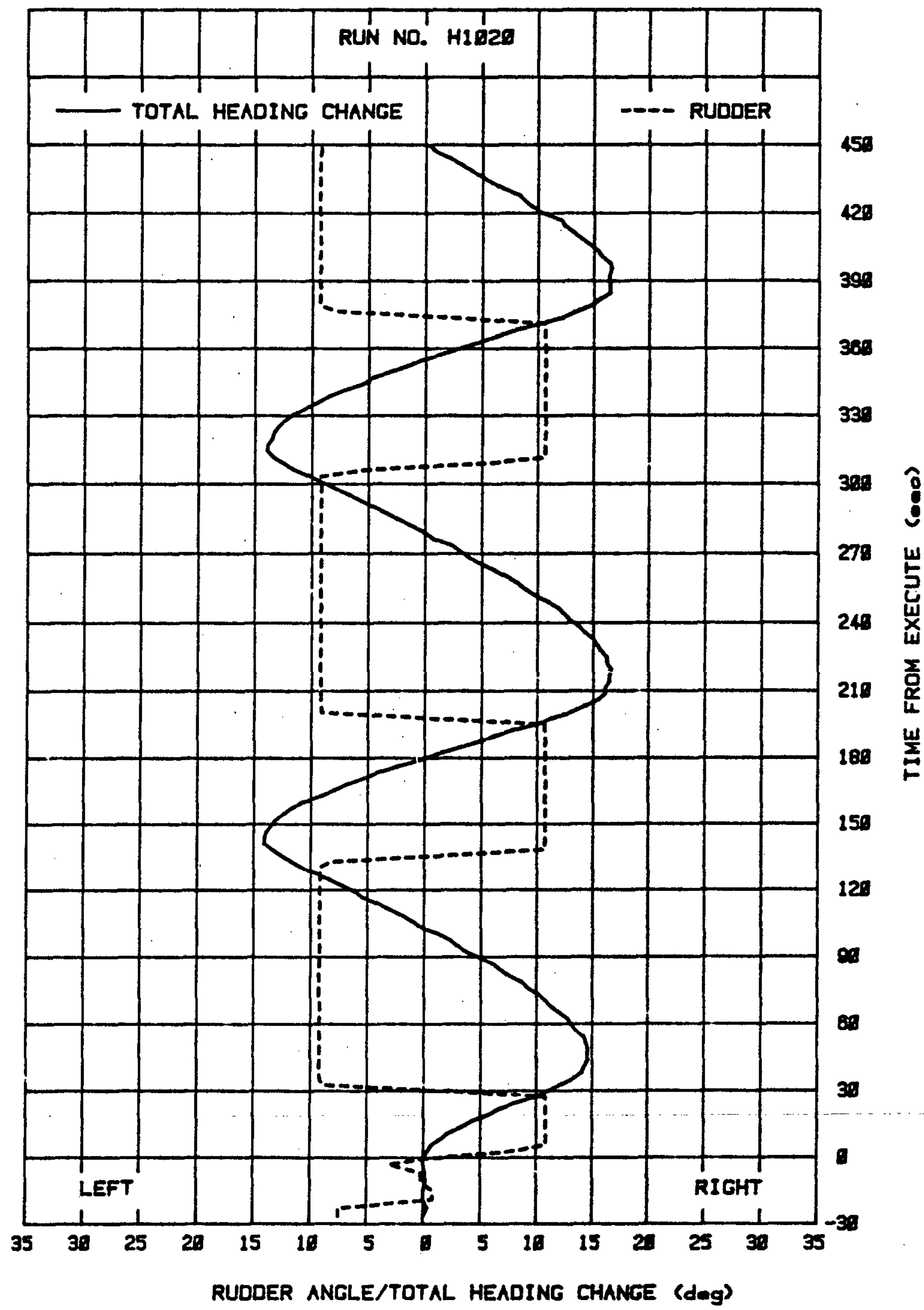


Figure 7 - Baseline Zig-Zag Maneuver from a Nominal 5-Knot Approach Speed Using an Initial 10-Degree Right Rudder

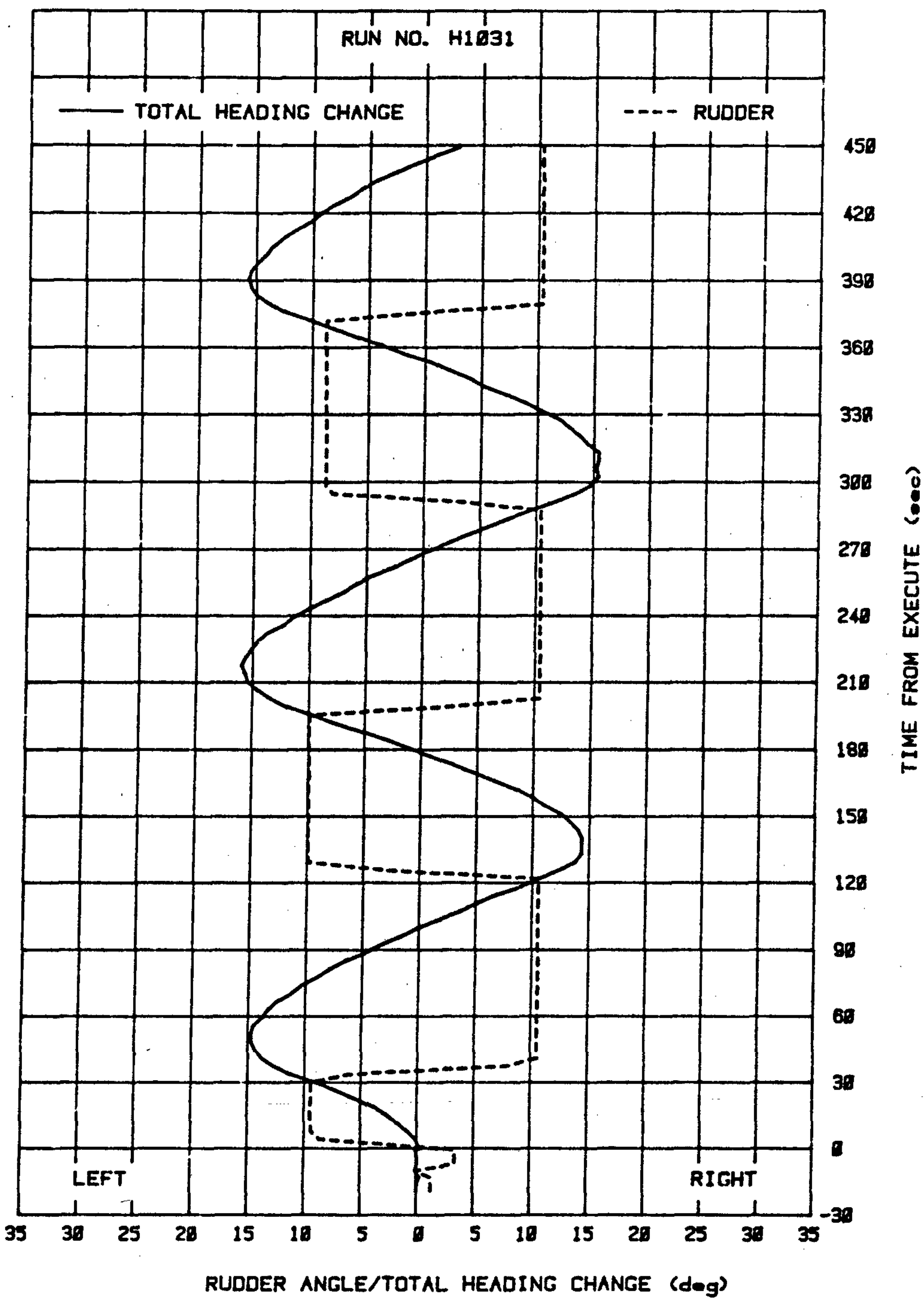


Figure 8 - Baseline Zig-Zag Maneuver from a Nominal 5-Knot Approach Speed Using an Initial 10-Degree Left Rudder

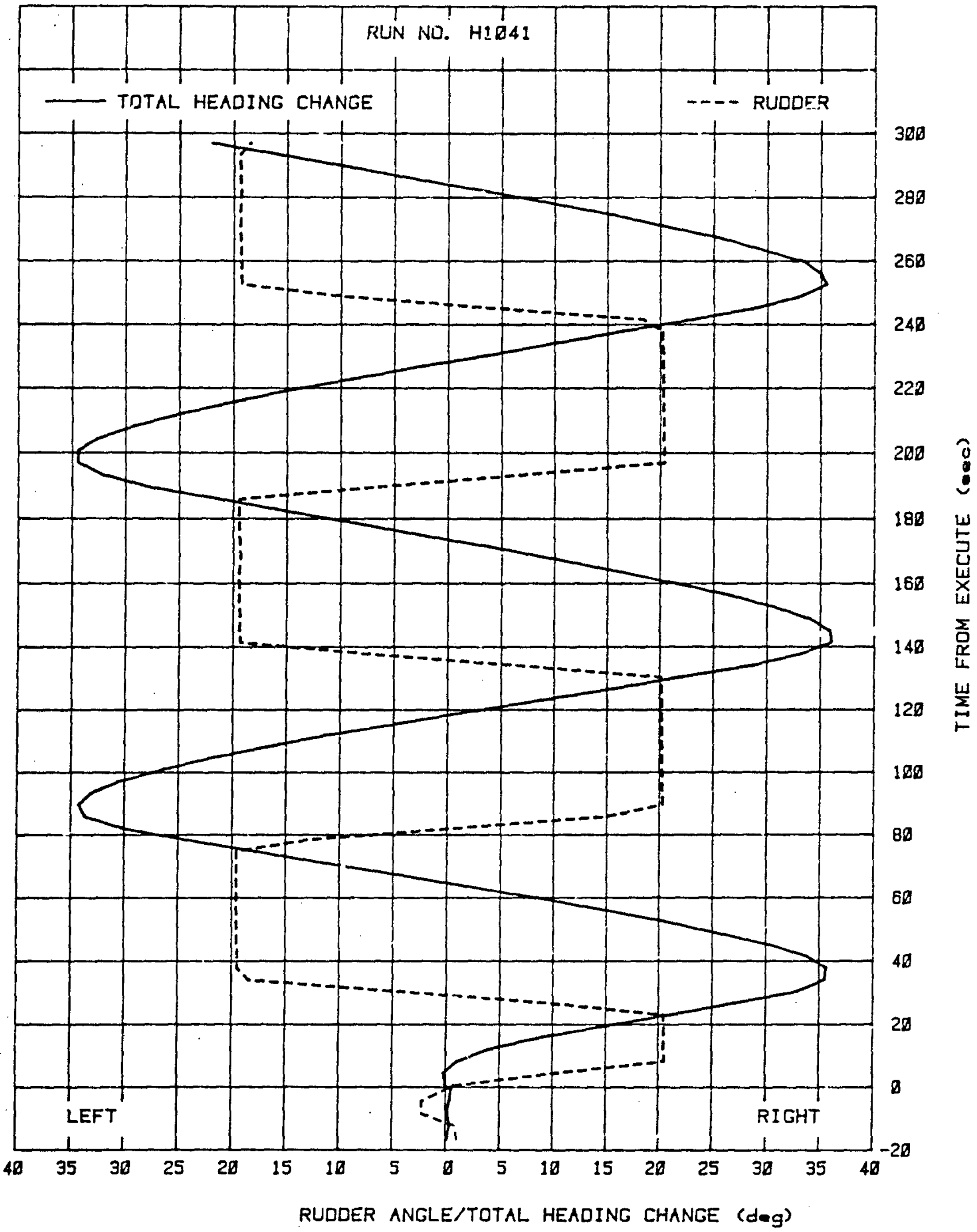


Figure 9 - Baseline Zig-Zag Maneuver from a Nominal 10-Knot Approach Speed Using an Initial 20-Degree Right Rudder

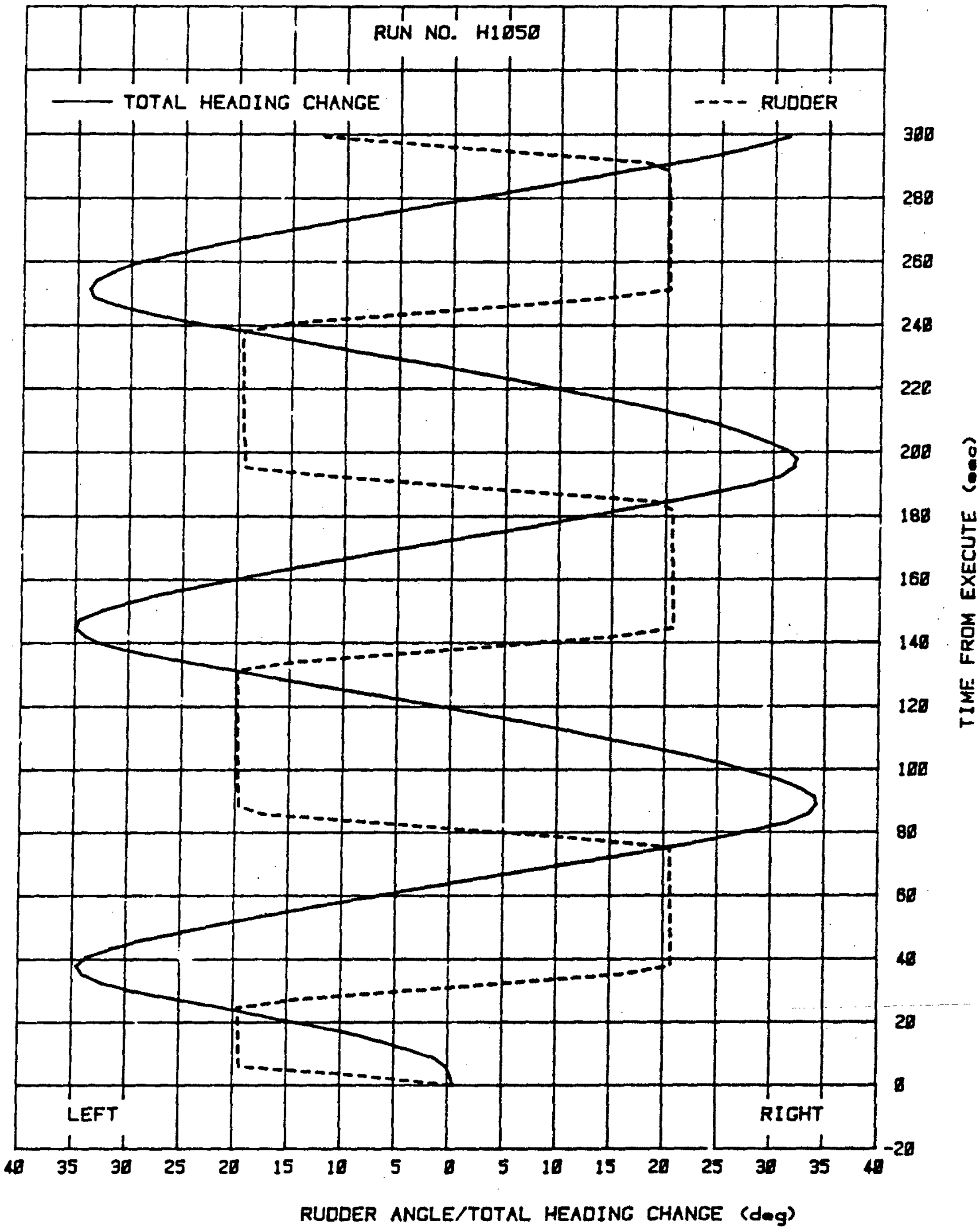


Figure 10 - Baseline Zig-Zag Maneuver from a Nominal 10-Knot Approach Speed Using an Initial 20-Degree Left Rudder

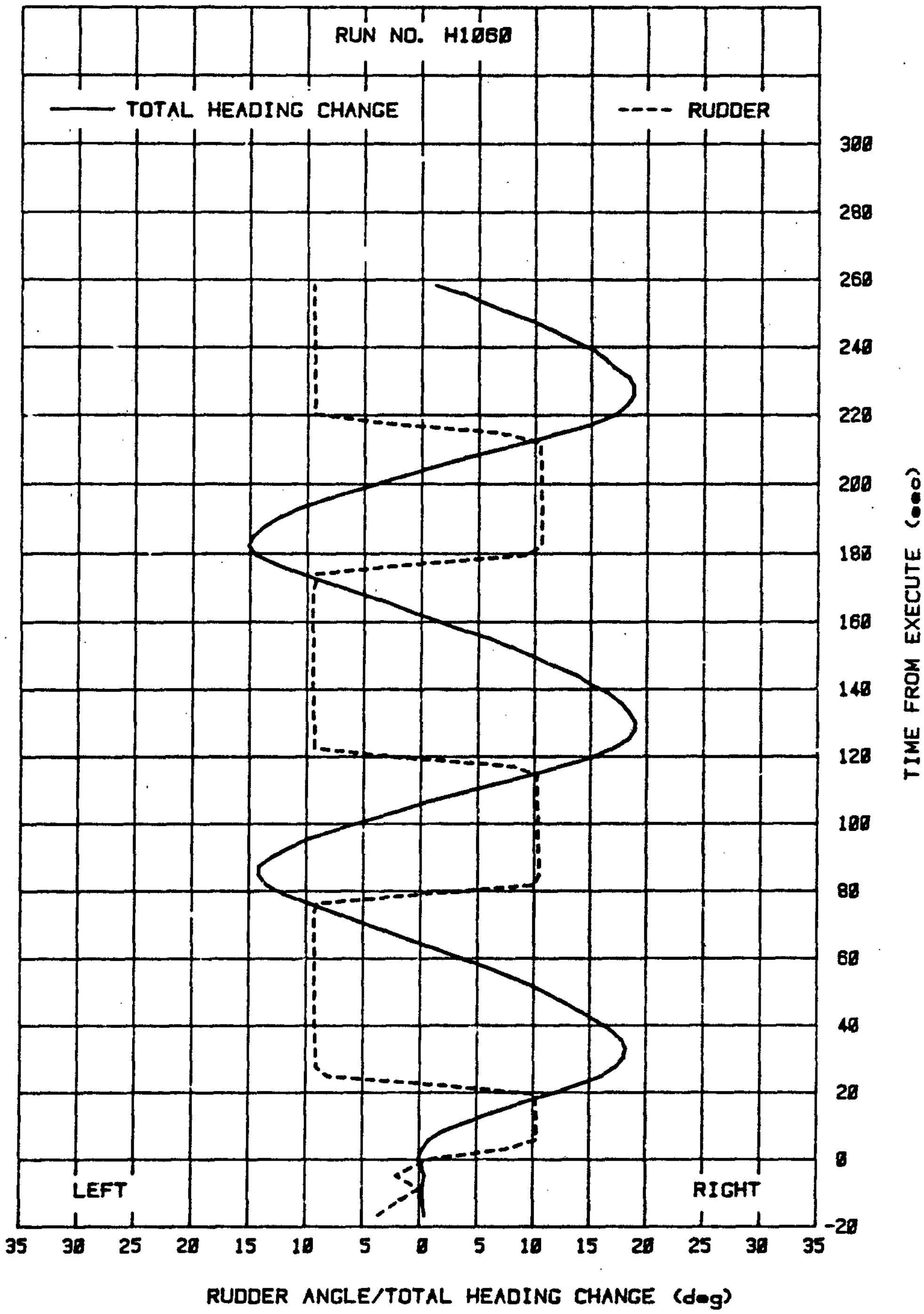


Figure 11 - Baseline Zig-Zag Maneuver from a Nominal 10-Knot Approach Speed Using an Initial 10-Degree Right Rudder

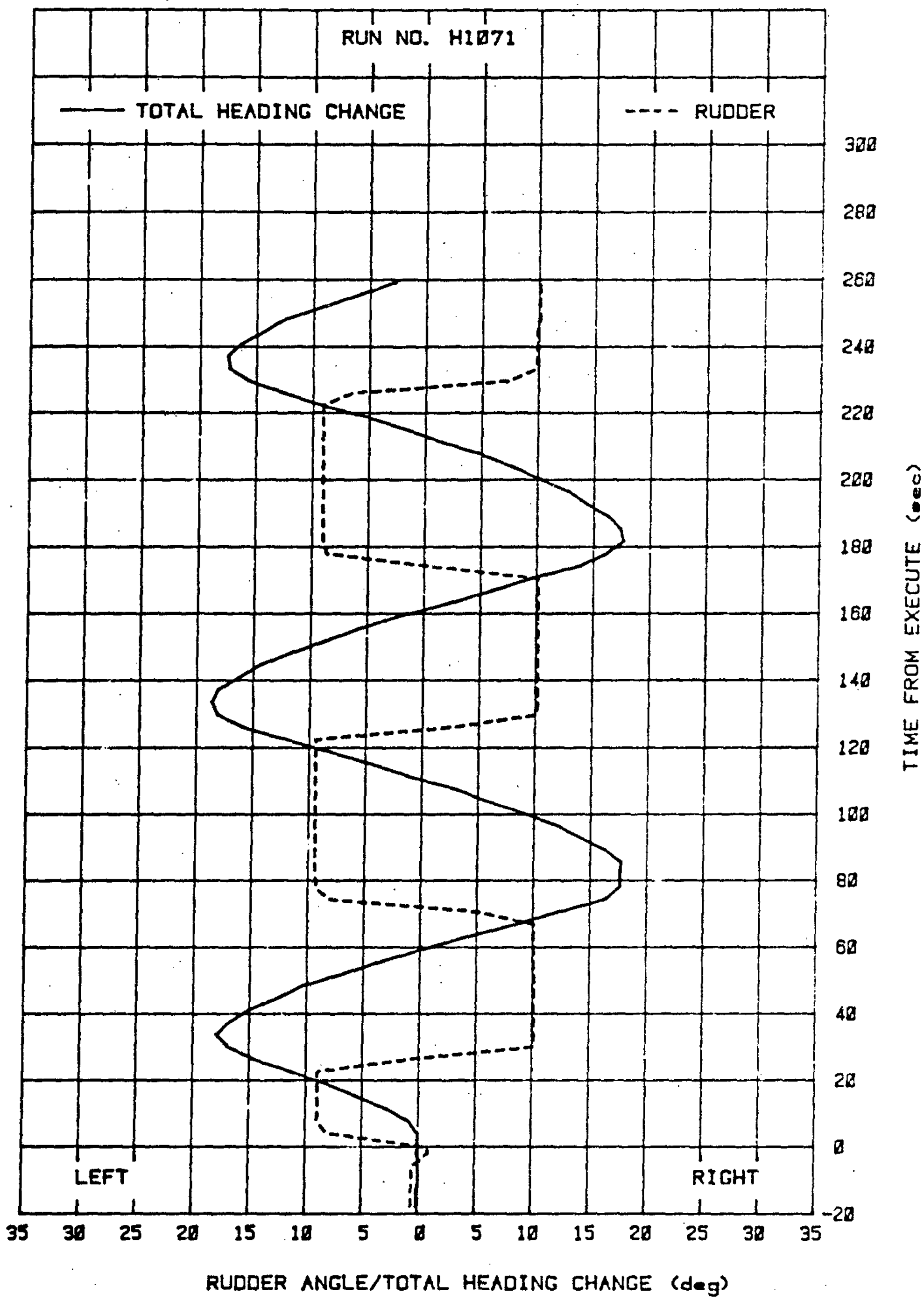


Figure 12 - Baseline Zig-Zag Maneuver from a Nominal 10-Knot Approach Speed Using an Initial 10-Degree Left Rudder

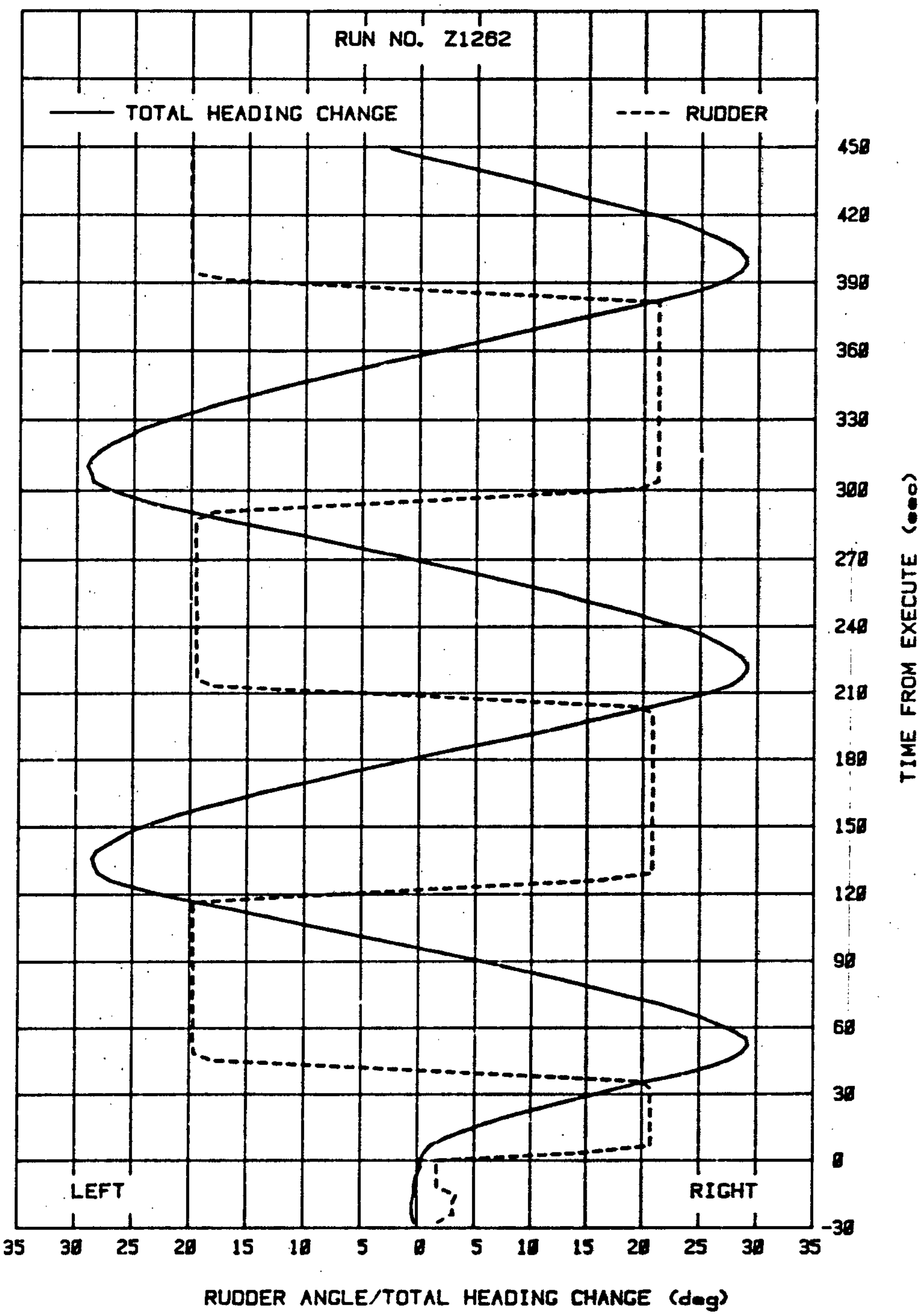


Figure 13 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 5 Knots Using an Initial 20-Degree Right Rudder

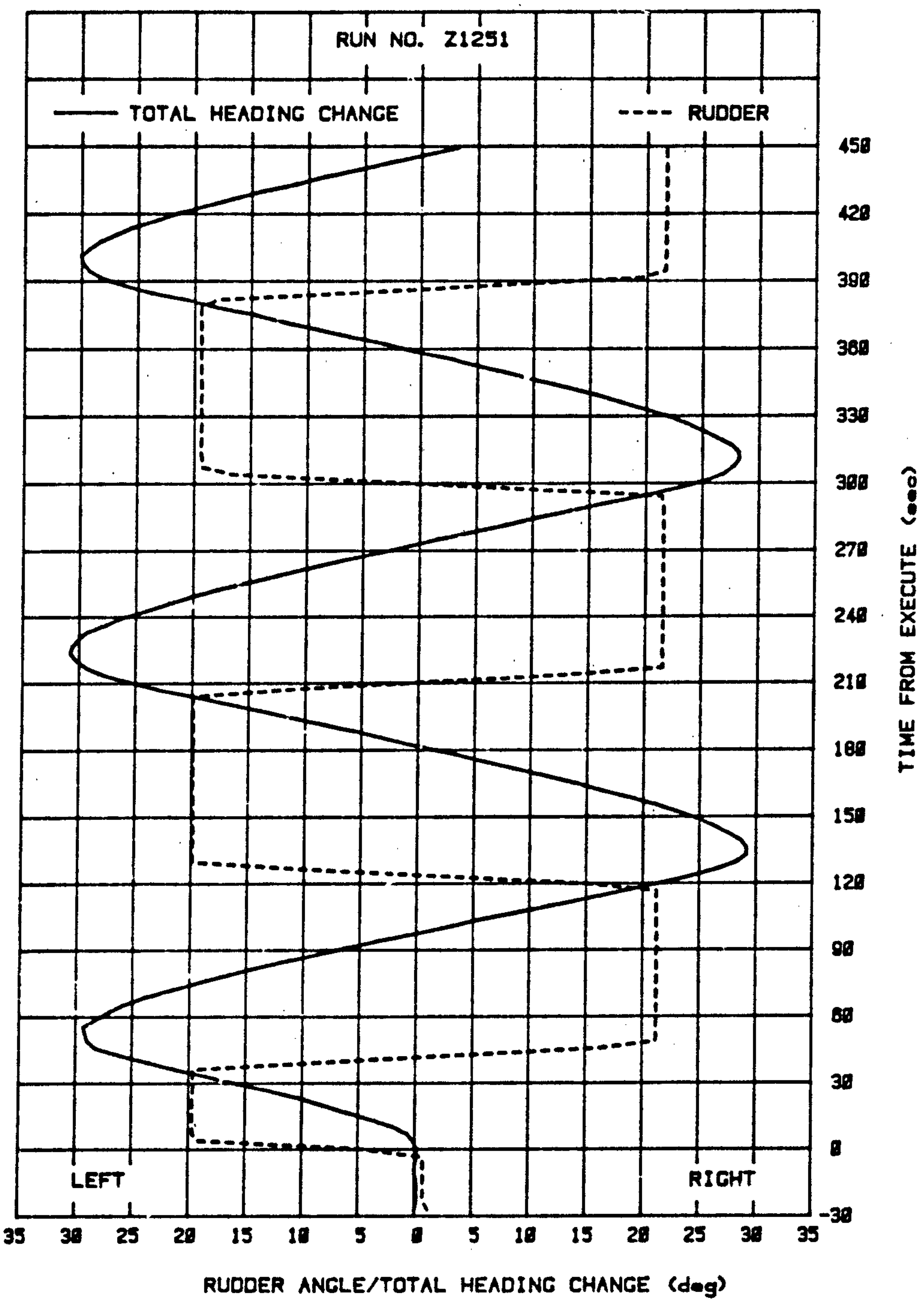


Figure 14 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 5 Knots Using an Initial 20-Degree Left Rudder

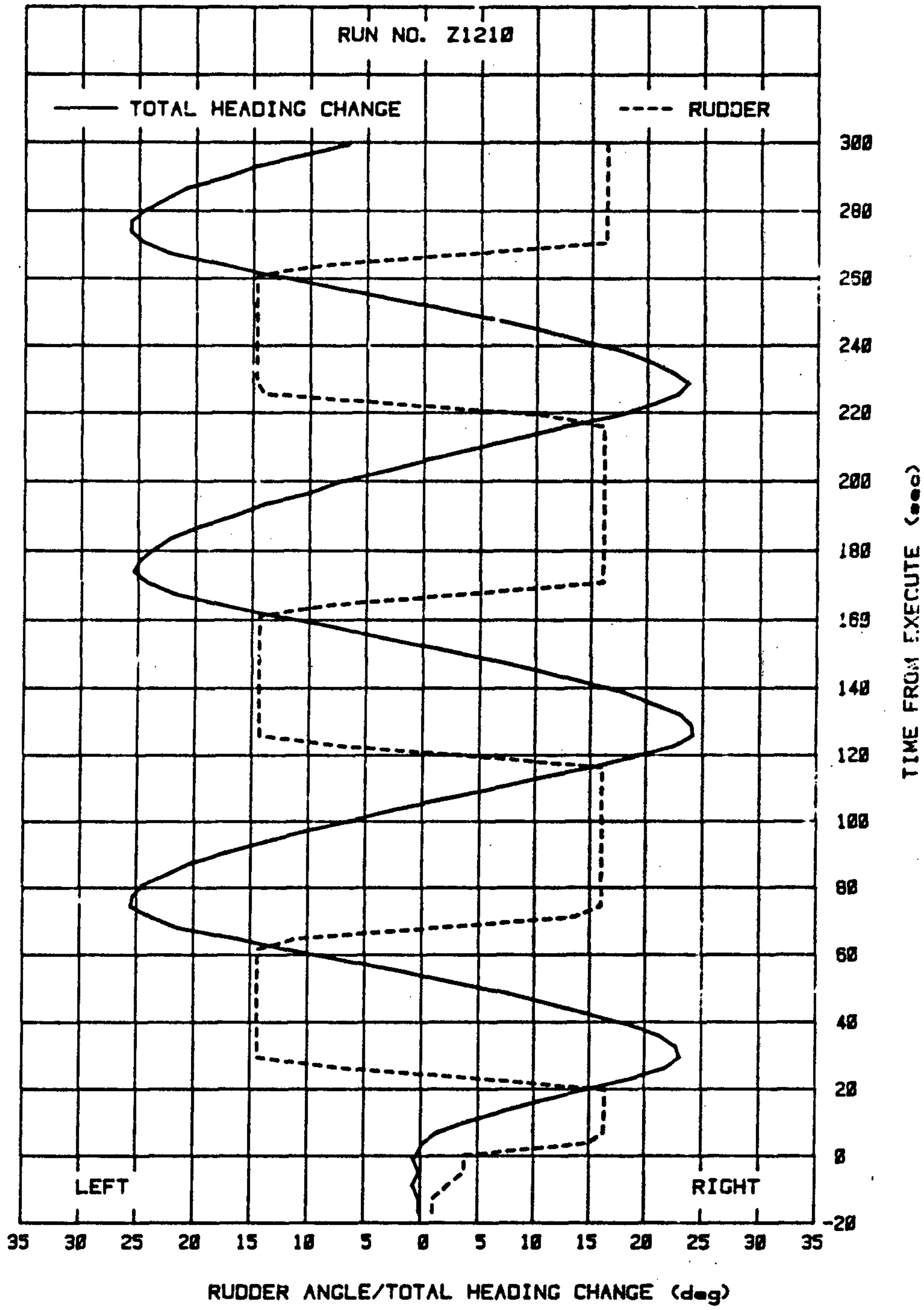


Figure 15 - Towed Array Zig-Zag Maneuver from a Nominal Apprcach Speed of 10 Knots Using an Initial 15-Degree Right Rudder

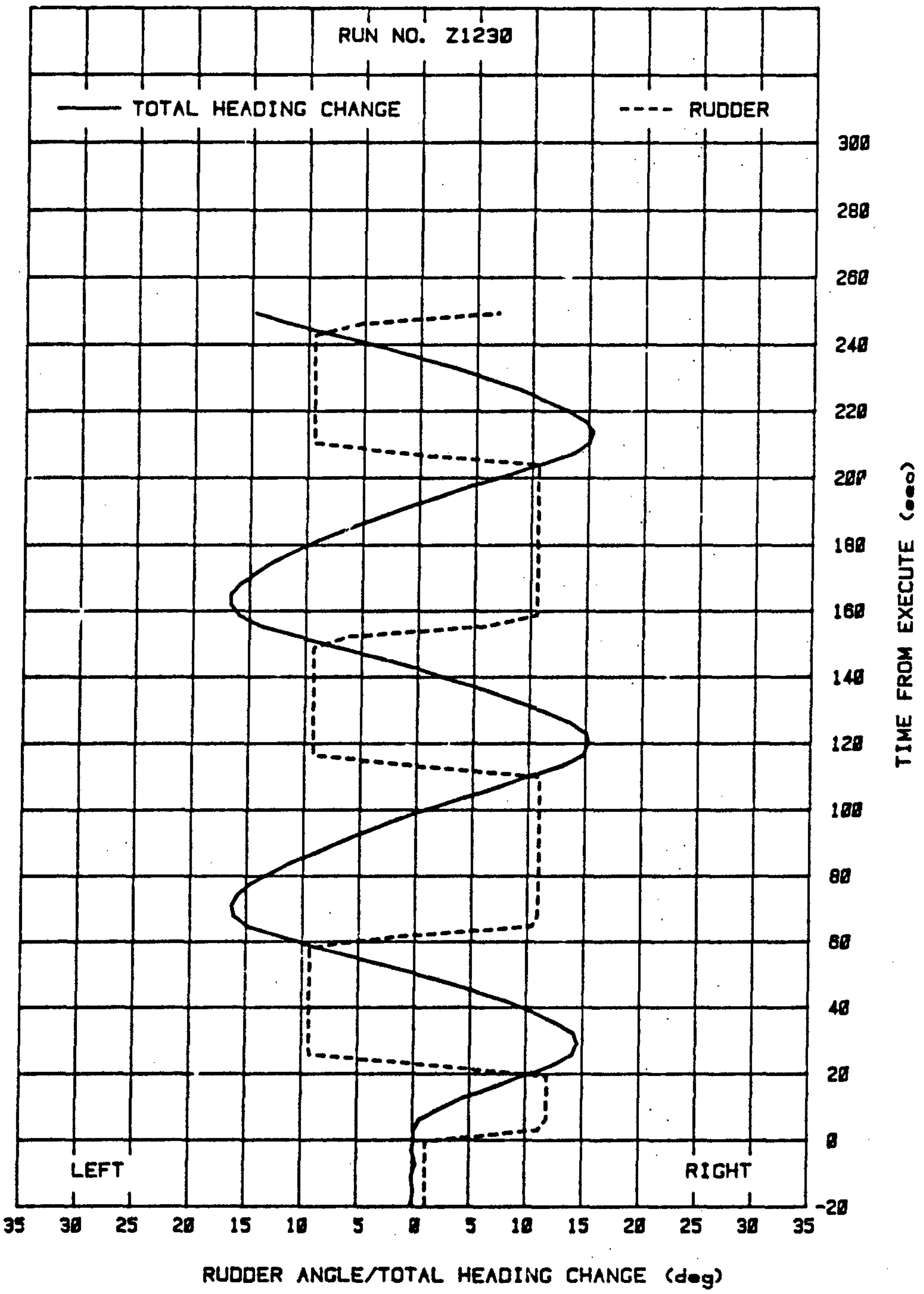


Figure 16 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 10 Knots Using an Initial 10-Degree Right Rudder

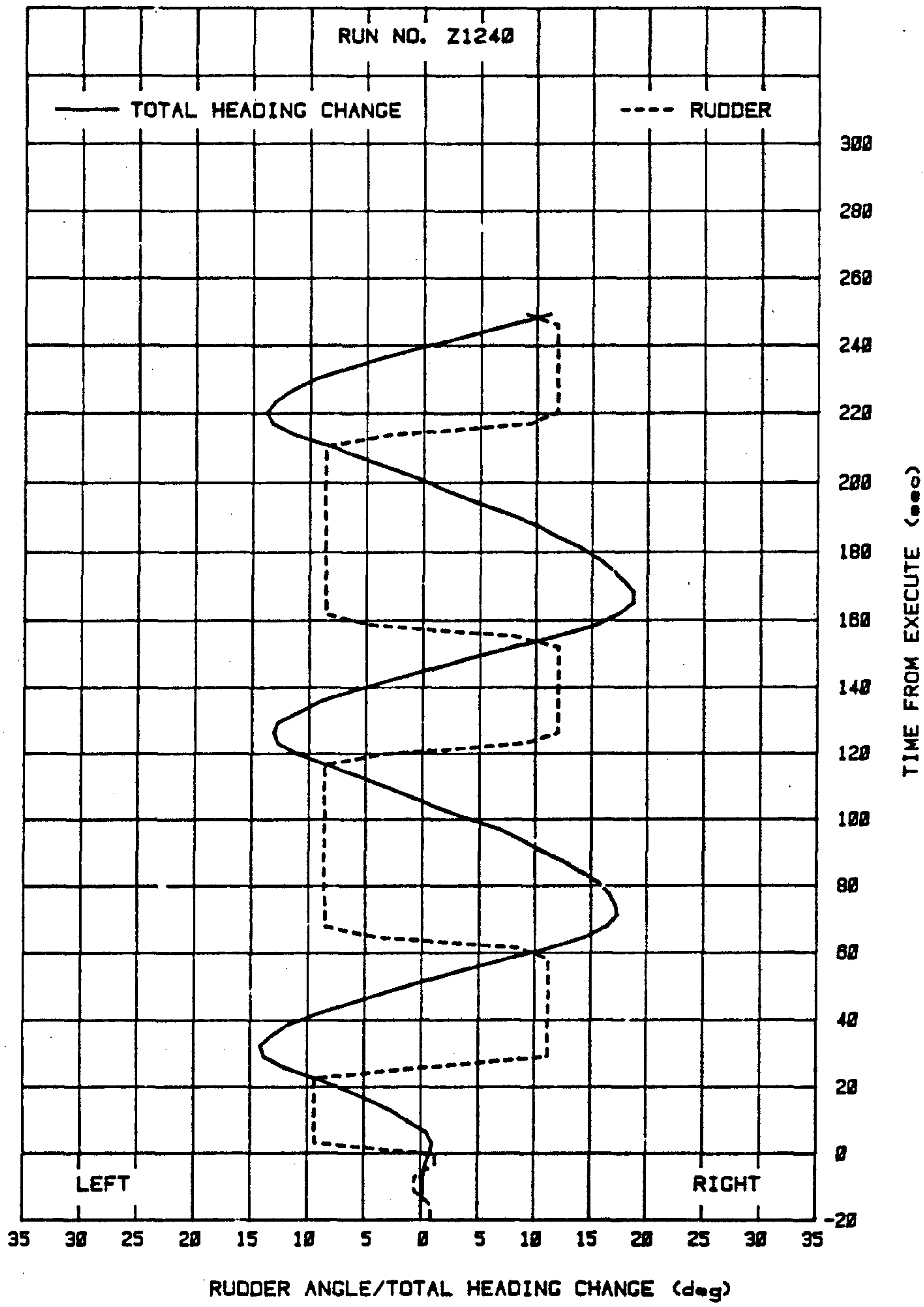


Figure 17 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 10 Knots Using an Initial 10-Degree Left Rudder

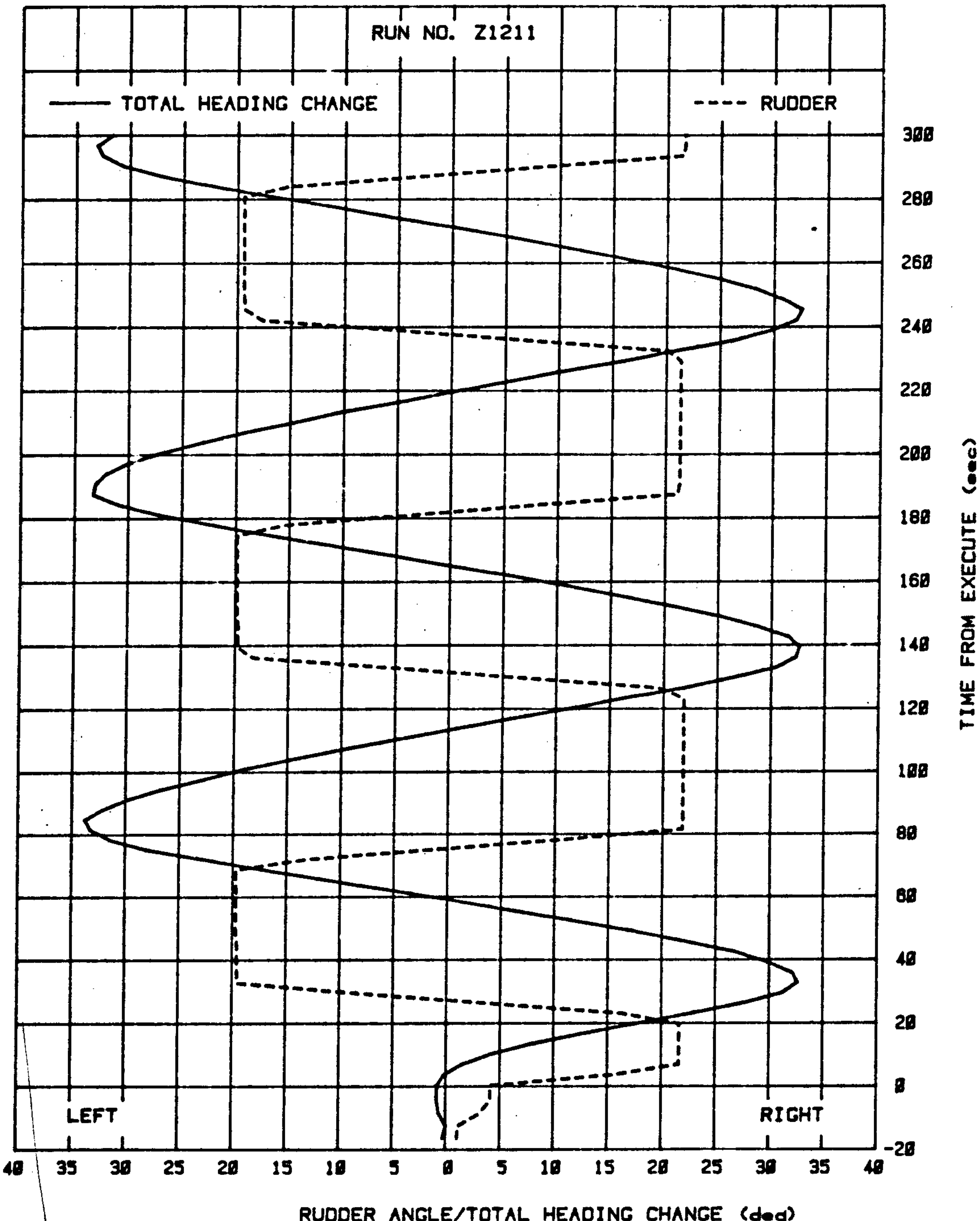


Figure 18 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 10 Knots Using an Initial 20-Degree Right Rudder

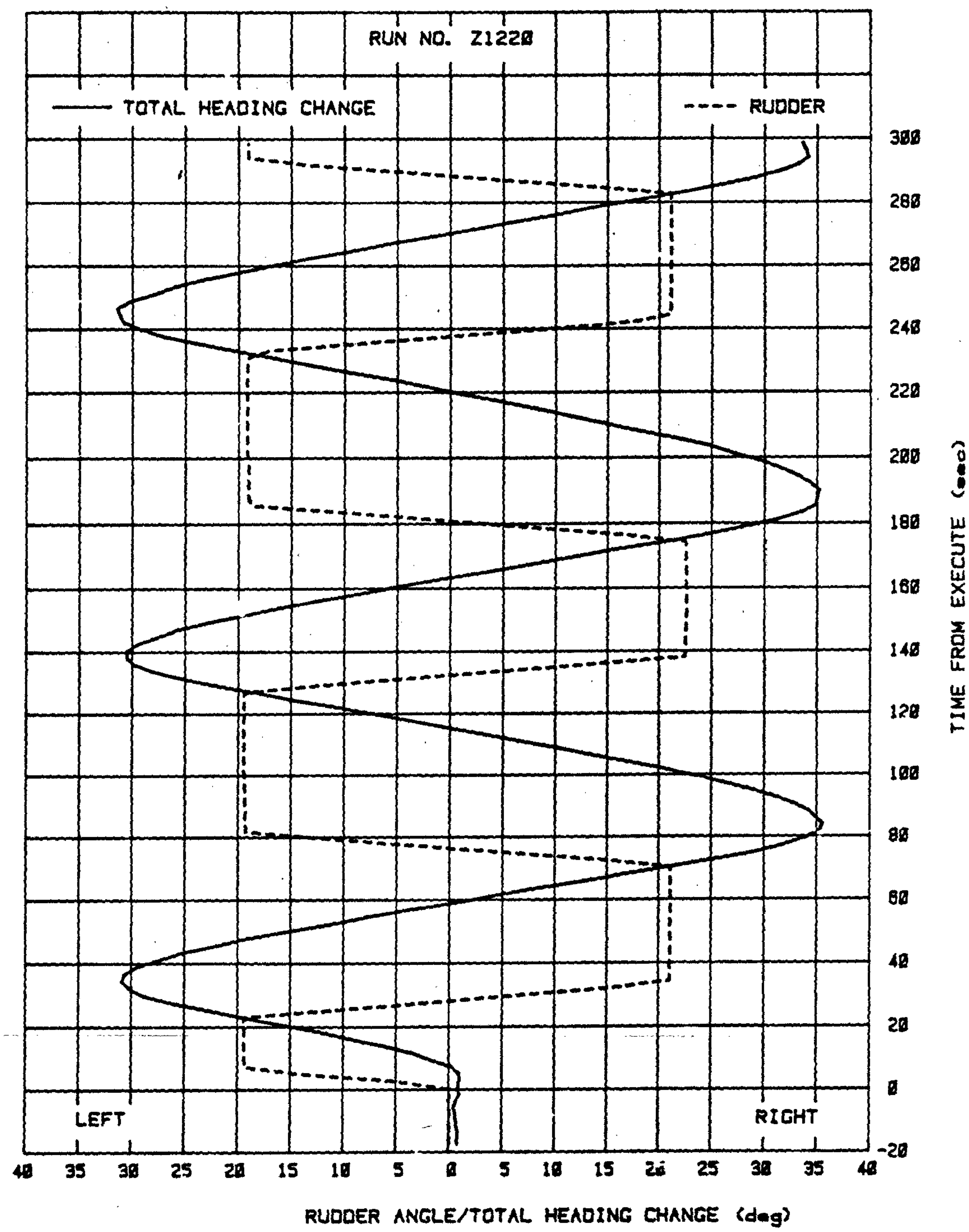


Figure 19 - Towed Array Zig-Zag Maneuver from a Nominal Approach Speed of 10 Knots Using an Initial 20-Degree Left Rudder

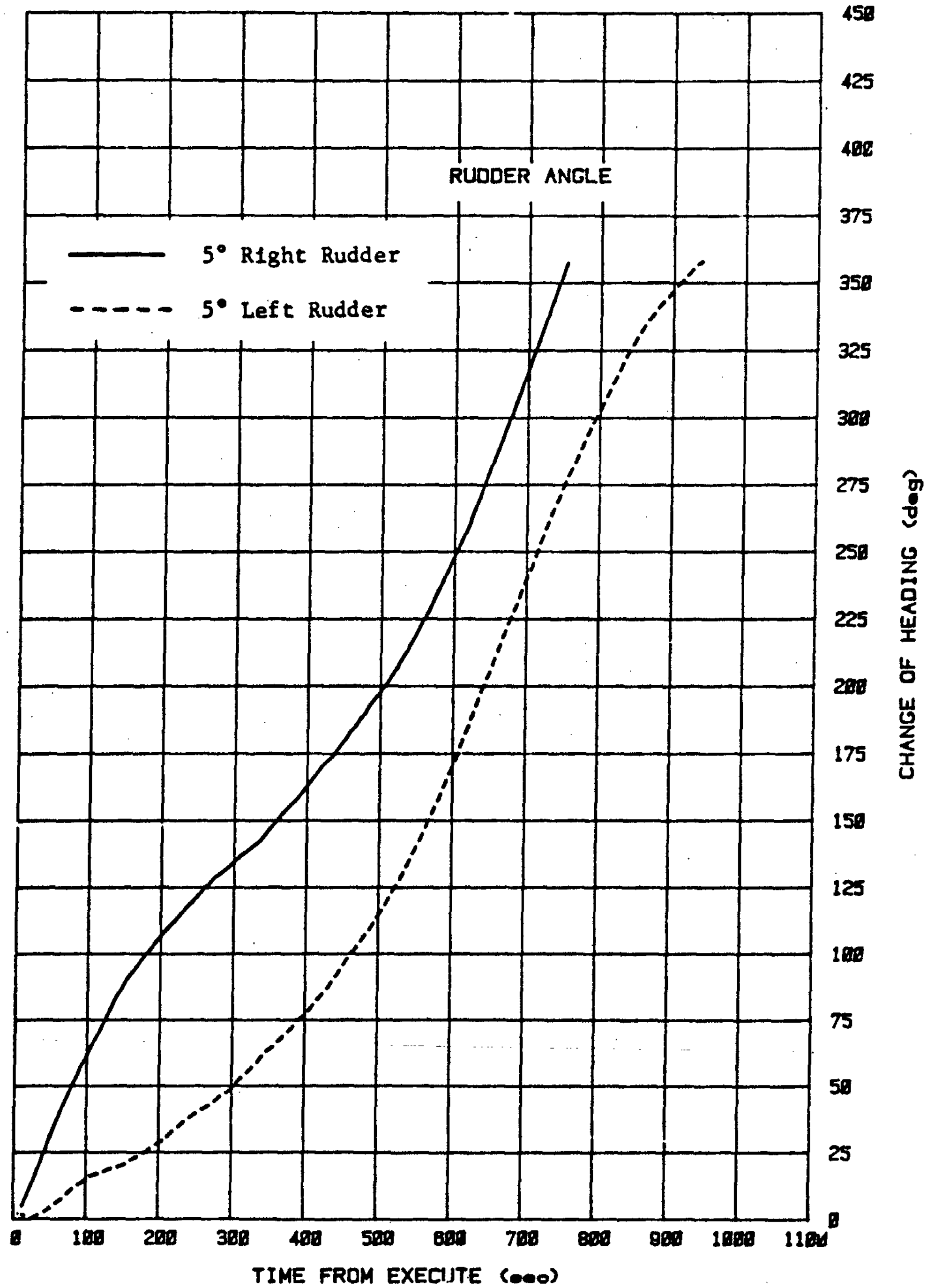


Figure 20 - Change of Heading versus Time for Two Tactical Turns at a Nominal Approach Speed of 10 Knots

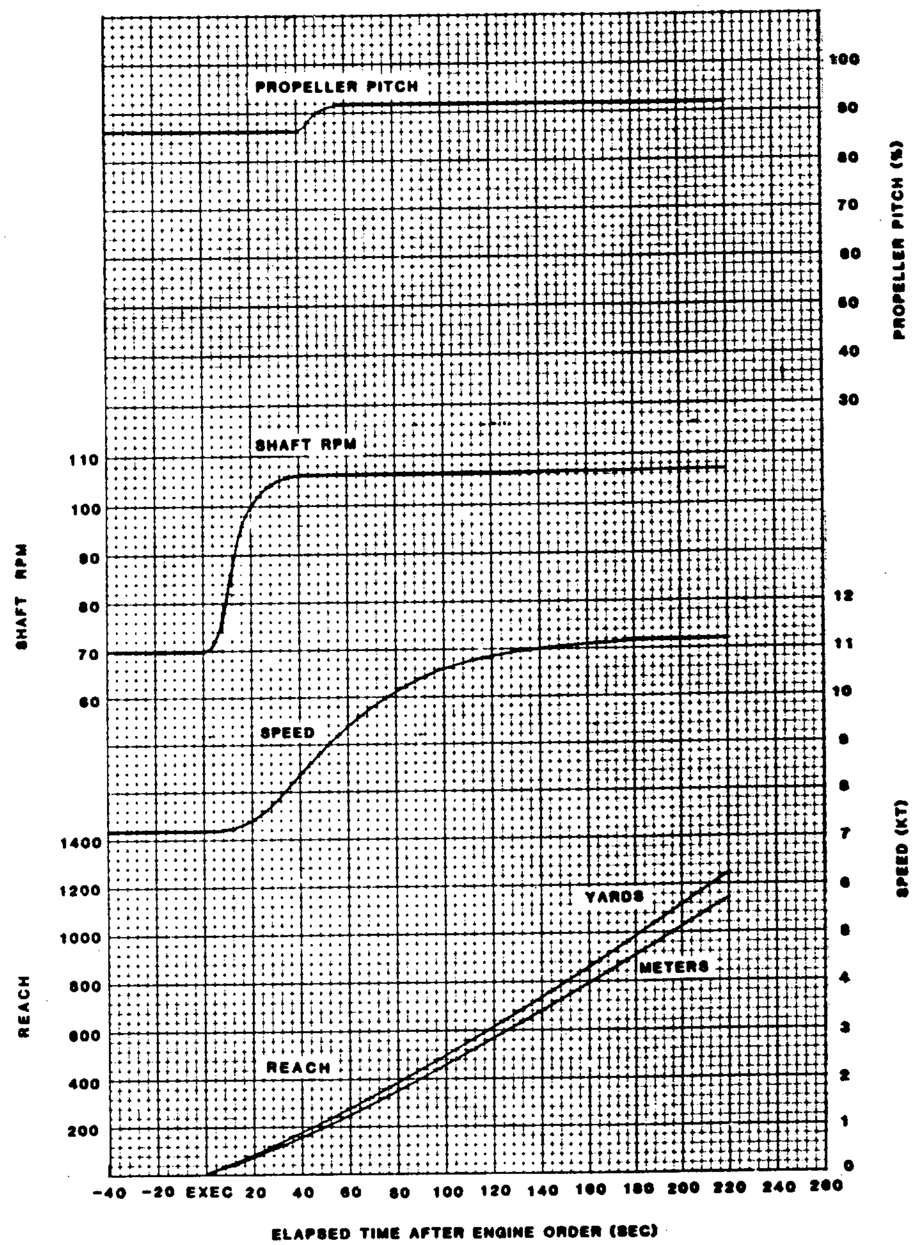


Figure 21 - Time History of an Acceleration Run
- Half Ahead to Full Ahead

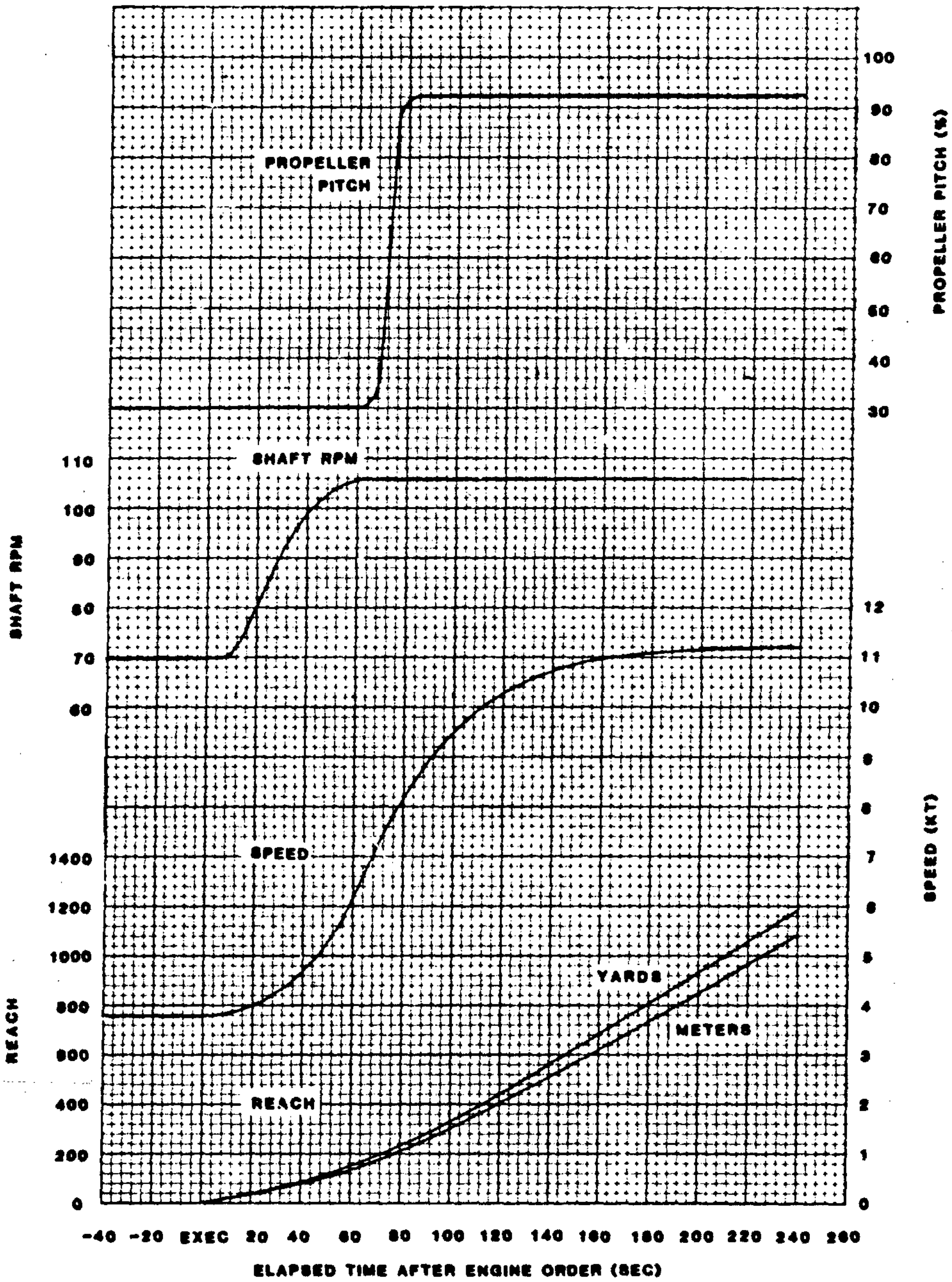


Figure 22 - Time History of an Acceleration Run
- Slow Ahead to Full Ahead

TABLE 1 - SHIP AND PROPELLER CHARACTERISTICS

Ship Characteristics	
Length Between Perpendiculars, feet (meters)	220.0 (67.06)
Length Overall, feet (meters)	246.4 (75.10)
Beam, Maximum, feet (meters)	75.0 (22.86)
Beam, Each Hull, feet (meters)	24.0 (7.32)
Distance Between Hulls, feet (meters)	27.0 (8.23)
Number of Rudders	2
Baseline Trial Displacement, tons (metric tons)	3634 (3692)
Towed Array Trial Displacement, tons (metric tons)	3600 (3658)
Baseline Trial Average Mean Draft, feet (meters)	21.3 (6.50)
Towed Array Trial Average Mean Draft, feet (meters)	21.0 (6.40)
Propeller Characteristics	
Number of Propellers	2
Number of Blades	4
Direction of Rotation	Outboard
Diameter, feet (meters)	12(3.66)
Design Pitch at the 0.7 Radius, degrees	27.3
Design Pitch at the 0.7 Radius, feet (meters)	13.64 (4.16)
Design Pitch Ratio, P/D	1.137
Propeller Manufacturer	LIPS, N.V. Drunen
Propeller Composition	Nickel-Aluminum Bronzez

TABLE 2 - SUMMARY OF TRIAL CONDITIONS

Date	Displacement		True Wind Average		*Air Temp		*Water Temp		*Water Specific Gravity	Sea State	Days From Last Hull Cleaning
	Ton	Metric Tons	Direction Deg.	Velocity Knots	°F	°C	°F	°C			
HECTOR RANGE											
5 Oct	3634	3692	190	18	75	23.9	74	23.3	1.024	2-3	14
6 Oct	3634	3692	210	18	72	22.2	75	23.9	1.024	2-3	15
7 Oct	3634	3692	23	15	79	26.1	74	23.3	1.024	2-3	16
AUTEC RANGE											
29 Oct	3600	3658	62	17	84	28.9	83	28.3	1.024	2	38
30 Oct	3600	3658	56	20	78	25.6	84	28.9	1.024	2-3	39

*The values of air and water temperatures and water specific gravity are actual values taken at the test sites. It should be noted that the values stated herein for the baseline trials conducted at HECTOR were not used to calculate ship displacement. The method used in calculating ship displacement is detailed in Appendix C.

TABLE 3.A - USNS HAYES (T-AGOR 16) 100% PROPELLER PITCH STANDARDIZATION TRIAL RESULTS, ENGLISH UNITS
HECTOR, 5 OCTOBER 1983

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM STBD	Shaft RPM PORT	Shaft RPM AVG	Shaft Torque (lbf-ft) STBD	Shaft Torque (lbf-ft) PORT	Shaft Torque (lbf-ft) TOTAL	Shaft Power (hp) STBD	Shaft Power (hp) PORT	Shaft Power (hp) TOTAL	Propeller Pitch (percent) STBD	Propeller Pitch (percent) PORT	Propeller Pitch (percent) AVG
S1220S	7.95	8.5	72.8	72.3	72.6	24,600	24,000	48,600	340	330	670	99.0	97.9	98.4
S1230N	8.53	9.2	72.7	72.3	72.5	22,500	21,500	44,000	310	300	610	99.0	97.9	98.4
AVG	8.24	8.8			72.6			46,300			640			98.4
S1060S	9.13	9.7	79.1	79.0	79.0	29,400	29,300	58,700	440	440	880	101.2	100.4	100.8
S1070N	9.25	10.3	79.0	79.0	79.0	27,800	28,300	56,100	420	420	840	101.3	100.0	100.6
S1080S	9.02	9.5	78.9	78.7	78.8	29,700	29,500	59,200	450	440	890	101.2	100.3	100.8
AVG	9.16	[illegible]			79.0			57,500			860			100.7
S1090S	10.45	10.9	88.6	90.0	89.3	36,300	38,600	74,900	610	660	1,270	101.1	100.3	100.7
S1100N	10.12	11.5	88.7	89.0	88.8	34,600	34,200	68,800	580	580	1,160	101.2	100.3	100.8
S110SS	10.27	10.8	88.5	88.8	88.6	36,900	37,300	74,200	620	630	1,250	101.2	100.3	100.8
AVG	10.24	11.2			88.9			71,600			1,210			100.8
S1120N	12.17	13.7	108.5	108.9	108.7	52,900	52,700	105,600	1,090	1,090	2,180	101.2	100.2	100.7
S1130S	12.48	13.2	108.6	108.8	108.7	55,600	55,900	111,500	1,150	1,160	2,310	101.2	100.2	100.7
AVG	12.32	13.4			108.7			108,600			2,240			100.7
S1160N	13.84	15.7	131.3	129.8	130.6	78,900	77,800	156,700	1,970	1,920	3,890	99.6	100.1	99.8
S1170S	14.22	15.2	131.3	129.8	130.6	81,800	81,200	163,000	2,040	2,010	4,050	99.4	100.2	99.8
S1171N	13.86	15.7	131.1	129.8	130.4	78,800	78,100	156,900	1,970	1,930	3,900	99.5	100.3	99.9
AVG	14.04	15.4			130.5			159,900			3,970			99.8
S1180N	14.82	16.5	138.9	137.4	138.2	87,600	86,400	[illegible]	2,320	2,260	4,580	99.4	100.2	99.8
S1190S	14.77	16.0	137.3	137.4	137.4	88,300	90,700	[illegible]	2,310	2,370	4,680	99.4	100.3	99.8
AVG	14.80	16.2			137.8			176,500			4,630			99.8

TABLE 3.B - USNS HAYES (T-AGOR 16) 100% PROPELLER PITCH STANDARDIZATION TRIAL RESULTS, METRIC UNITS
HECTOR, 5 OCTOBER 1983

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM			Shaft Torque (N-m)			Shaft Power (kW)			Propeller Pitch (percent)		
			STBD	PORT	AVG	STBD	PORT	TOTAL	STBD	PORT	TOTAL	STBD	PORT	AVG
S1120S	7.95	8.5	72.8	72.3	72.6	33,400	32,600	66,000	250	250	500	99.0	97.9	98.4
S1230N	8.53	9.2	72.7	72.3	72.5	30,500	29,100	59,600	230	220	450	99.0	97.9	98.4
AVG	8.24	8.8			72.6			62,800			480			98.4
S1060S	9.13	9.7	79.1	79.0	79.0	39,900	39,700	79,600	330	330	660	101.2	100.4	100.8
S1070N	9.25	10.3	79.0	79.0	79.0	37,700	38,400	76,100	310	320	630	101.3	100.0	100.6
S1080S	9.02	9.5	78.9	78.7	78.8	40,300	39,900	80,200	330	330	660	101.2	100.3	100.8
AVG	9.16	10.0			79.0			78,000			640			100.7
S1090S	10.45	10.9	88.6	90.0	89.3	49,200	52,300	101,500	460	490	950	101.1	100.3	100.7
S1100N	10.12	11.5	88.7	89.0	88.8	47,000	46,300	93,300	440	430	870	101.2	100.3	100.8
S1110S	10.27	10.8	88.5	88.8	88.6	50,000	50,600	100,600	460	470	930	101.2	100.3	100.8
AVG	10.24	11.2			88.9			97,200			900			100.8
S1120N	12.17	13.7	108.5	108.9	108.7	71,700	71,500	143,200	810	820	1,630	101.2	100.2	100.7
S1130S	12.48	13.2	108.6	108.8	108.7	75,400	75,700	151,100	860	860	1,720	101.2	100.2	100.7
AVG	12.32	13.4			108.7			147,200			1,680			100.7
S1160N	13.84	15.7	131.3	129.8	130.6	107,000	105,500	212,500	1,470	1,430	2,900	99.6	100.1	99.8
S1170S	14.22	15.2	131.3	129.8	130.6	111,000	110,100	221,100	1,530	1,500	3,030	99.4	100.2	99.8
S1171N	13.86	15.7	131.1	129.8	130.4	106,800	105,900	212,700	1,470	1,440	2,910	99.5	100.3	99.9
AVG	14.04	15.4			130.5			216,900			2,960			99.8
S1180N	14.82	16.5	138.9	137.4	138.2	118,800	117,100	235,900	1,730	1,690	3,420	99.4	100.2	99.8
S1190S	14.77	16.0	137.3	137.4	137.4	119,700	123,000	242,700	1,720	1,770	3,490	99.4	100.3	99.8
AVG	14.80	16.2			137.8			239,300			3,450			99.8

TABLE 4.A - USNS HAYES (T-AGOR 16) UNDER-DESIGN PITCH STANDARDIZATION TRIAL RESULTS,
ENGLISH UNITS
HECTOR, 5 - 6 OCTOBER 1983,
36%, 52% and 87% UNDER-DESIGN PITCH

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM STBD	Shaft RPM PORT	Shaft RPM AVG	Shaft Torque (lbf-ft) STBD	Shaft Torque (lbf-ft) PORT	Shaft Torque (lbf-ft) TOTAL	Shaft Power (hp) STBD	Shaft Power (hp) PORT	Shaft Power (hp) TOTAL	Propeller Pitch (percent) STBD	Propeller Pitch (percent) PORT	Propeller Pitch (percent) AVG
S1000N	4.45	4.8	73.0	72.5	72.8	5,800	5,700	11,500	81	79	160	36.0	*	36.0
S1010S	4.10	3.9	72.9	72.3	72.6	7,000	7,300	14,300	97	100	197	36.0	*	36.0
S1020N	4.31	4.7	73.0	72.4	72.7	6,000	5,900	11,900	83	81	164	36.0	*	36.0
AVG	4.24	4.3			72.7			13,000			180			36.0
S1030N	5.76	6.0	73.0	72.4	72.7	8,400	8,400	16,800	117	116	233	52.4	*	52.4
S1040S	5.06	5.2	73.0	72.5	72.8	9,900	10,100	20,000	138	139	277	52.4	*	52.4
S1050N	5.70	6.0	72.9	72.2	72.6	8,300	8,200	16,500	115	113	228	52.3	*	52.3
AVG	5.40	5.6			72.7			18,300			253			52.4
S1500S	8.33	8.9	80.6	80.0	80.3	24,400	24,700	49,100	370	380	750	88.3	86.7	87.5
S1510N	8.59	9.6	80.7	79.9	80.3	22,100	22,000	44,100	340	330	670	88.3	86.8	87.6
AVG	8.46	9.2			80.3			46,600			710			87.6
S1530S	9.38	9.9	90.5	89.4	90.0	30,100	30,000	60,100	520	510	1,030	88.1	86.6	87.4
S1540N	9.53	10.6	90.6	89.2	89.9	27,700	27,100	54,800	480	460	940	88.1	86.6	87.4
S1550S	9.35	9.9	90.5	89.1	89.8	30,200	30,200	60,400	520	510	1,030	88.1	86.6	87.4
AVG	9.45	10.2			89.9			57,500			990			87.4
S1560S	11.59	12.2	110.0	110.0	110.0	43,900	45,700	89,600	920	960	1,880	87.9	86.4	87.2
S1570N	11.38	12.8	110.0	110.0	110.0	41,400	43,000	84,400	870	900	1,770	87.9	86.5	87.2
S1580S	11.66	12.3	110.0	110.2	110.1	43,900	45,900	89,800	920	960	1,880	87.9	86.4	87.2
AVG	11.50	12.5			110.0			87,100			1,820			87.2
S1590N	13.37	15.1	135.9	134.3	135.1	67,400	66,200	133,600	1,740	1,690	3,430	87.7	86.2	87.0
S1600S	13.89	14.8	136.3	134.3	135.3	69,100	69,300	138,400	1,790	1,770	3,560	87.7	86.2	87.0
S1610N	13.36	15.1	136.1	134.6	135.4	67,000	66,500	133,500	1,740	1,700	3,440	87.8	86.2	87.0
AVG	13.63	15.0			135.3			136,000			3,500			87.0

NOTE: There was no port propeller pitch calibration at the lower speeds. The port and starboard rpms and torques were matched. Therefore the starboard propeller pitch value was used in lieu of the port pitch value.

TABLE 4.B - USNS HAYES (T-AGOR 16) UNDER-DESIGN PITCH STANDARDIZATION TRIAL RESULTS,
METRIC UNITS
HECTOR, 5 - 6 OCTOBER 1983,
36%, 52% and 87% UNDER-DESIGN PITCH

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM			Shaft Torque (N-m)			Shaft Power (kW)			Propeller Pitch (percent)		
			STBD	PORT	AVG	STBD	PORT	TOTAL	STBD	PORT	TOTAL	STBD	PORT	AVG
S1000N	4.45	4.8	73.0	72.5	72.8	7,800	7,700	15,500	60	59	119	36.0	*	36.0
S1010S	4.10	3.9	72.9	72.3	72.6	9,600	9,900	19,500	73	75	148	36.0	*	36.0
S1020N	4.31	4.7	73.0	72.4	72.7	8,100	8,000	16,100	62	60	122	36.0	*	36.0
AVG	4.24	4.3			72.7			17,600			134			36.0
S1030N	5.76	6.0	73.0	72.4	72.7	11,400	11,400	22,800	87	86	174	52.4	*	52.4
S1040S	5.06	5.2	73.0	72.5	72.8	13,400	13,700	27,100	103	104	207	52.4	*	52.4
S1050N	5.70	6.0	72.9	72.2	72.6	11,300	11,100	22,400	86	81	167	52.3	*	52.3
AVG	5.40	5.6			72.7			24,800			189			52.4
S1500S	8.33	8.9	80.6	80.0	80.3	33,000	33,500	66,500	280	280	560	88.3	56.7	87.5
S1510N	8.59	9.6	80.7	79.9	80.3	29,900	29,900	59,800	250	250	500	88.3	86.8	[illegible]
AVG	8.46	9.2			80.3			63,200			530			87.6
S1530S	9.38	9.9	90.5	89.4	90.0	40,900	40,600	81,500	390	380	770	88.1	86.6	87.4
S1540N	9.53	10.6	50.6	89.2	89.9	37,600	36,700	74,300	360	340	700	88.1	86.6	87.4
S1550S	9.35	9.9	90.5	89.1	89.8	41,000	40,900	81,900	390	380	770	88.1	86.6	87.4
AVG	9.45	10.2			89.9			78,000			730			87.4
S1560S	11.59	12.2	110.0	110.0	110.0	59,500	62,000	121,500	680	710	1,390	87.9	86.4	87.2
S1570N	11.38	12.8	110.0	110.0	110.0	56,200	58,200	114,400	650	670	1,320	87.9	86.5	37.2
S1580S	11.66	12.3	110.0	110.2	110.1	59,600	62,300	121,900	690	720	1,410	87.9	86.4	87.2
AVG	11.50	12.5			110.0			118,000			1,360			87.2
S1590N	13.37	15.1	135.9	134.3	135.1	91,400	89,800	181,200	1,300	1,260	2,560	87.7	86.2	87.0
S1600S	13.89	14.8	136.3	134.3	135.3	93,700	93,900	187,600	1,340	1,320	2,660	87.7	86.2	87.0
S1610N	13.36	15.1	136.1	134.6	135.4	90,900	90,200	181,100	1,300	1,270	2,570	87.8	86.2	87.0
AVG	13.63	15.0			135.3			184,400			2,610			87.0

NOTE: There was no port propeller pitch voltage calibration at the lower speeds. The port and starboard rpms and torques were matched. Therefore the starboard propeller pitch value was used in lieu of the port pitch value.

TABLE 5.A - USNS HAYES (T-AGOR 16) OVER-DESIGN PITCH STANDARDIZATION TRIAL RESULTS, ENGLISH UNITS

HECTOR, 5-6 OCTOBER 1983, 104%, 110% and 118% OVER-DESIGN PITCH

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM			Shaft Torque (lbf-ft)			Shaft Power (hp)			Propeller Pitch (percent)		
			STBD	PORT	AVG	STBD	PORT	TOTAL	STBD	PORT	TOTAL	STBD	PORT	AVG
S1390S	15.32	16.4	137.3	137.5	137.4	94,800	96,400	191,200	2,480	2,520	5,000	103.6	104.1	103.8
S1400N	15.00	16.9	137.4	137.6	137.5	91,000	92,500	183,500	2,380	2,420	4,800	103.7	104.1	103.9
S1410S	15.35	16.5	137.4	137.6	137.5	94,100	96,200	190,300	2,460	2,520	4,980	103.7	104.2	104.0
AVG	15.17	16.7			137.5			187,100			4,900			103.9
S1700N	11.43	13.3	100.0	99.4	99.7	51,600	53,400	105,000	980	1,010	1,990	109.7	113.6	111.6
S1710S	12.56	12.8	100.0	99.2	99.6	54,200	56,600	110,800	1,030	1,070	2,100	109.6	113.6	111.6
S1720N	11.39	13.3	100.0	99.3	99.6	51,700	53,400	105,100	980	1,010	1,990	109.6	113.6	111.6
AVG	11.98	13.0			99.6			107,900			2,050			111.6
S1730S	14.51	15.0	119.9	119.4	119.6	80,300	84,900	165,200	1,830	1,930	3,760	109.4	113.4	111.4
S1740N	13.28	15.3	120.1	119.3	119.7	77,400	81,700	159,100	1,770	1,860	3,630	109.4	113.4	111.4
S1750S	14.32	15.0	120.1	119.6	119.8	80,960	85,900	166,800	1,850	1,960	3,810	109.4	113.4	111.4
AVG	13.85	15.2			119.7			162,600			3,710			111.4
S1760S	15.89	16.2	131.4	131.3	131.4	95,600	102,300	197,900	2,390	2,560	4,950	109.3	113.3	111.3
S1770N	14.34	16.9	131.4	131.0	131.2	91,300	95,900	187,200	2,280	2,390	4,670	109.4	113.3	111.4
S1780S	15.75	16.2	131.4	130.5	131.0	96,300	101,600	197,900	2,410	2,520	4,930	109.3	113.3	111.3
AVG	15.08	16.6			131.2			192,500			4,800			111.4
S1300N	10.18	11.4	80.7	80.1	80.4	38,200	36,100	74,300	590	550	1,140	117.6	119.2	118.4
S1310S	10.24	10.7	80.8	80.1	80.4	40,700	39,000	79,700	630	590	1,220	117.6	119.1	118.4
S1320N	10.10	11.3	80.8	79.9	80.4	38,500	36,100	74,600	590	550	1,140	117.6	119.1	118.4
AVG	10.19	11.0			80.4			77,100			1,180			118.4
S1330N	11.32	12.8	91.1	91.3	91.2	49,100	48,000	97,100	850	830	1,680	117.5	118.9	118.2
S1340S	11.45	12.0	91.2	91.2	91.2	52,700	51,800	104,500	920	900	1,820	117.5	118.9	118.2
AVG	11.38	12.4			91.2			100,800			1,750			118.2
S1360N	13.30	15.0	110.9	111.3	111.1	75,300	75,000	150,300	1,590	1,590	3,180	117.3	118.7	118.0
S1370S	13.61	14.5	110.9	111.1	111.0	79,000	78,900	157,900	1,670	1,670	3,340	117.3	118.7	118.0
AVG	13.46	14.8			111.0			154,100			3,260			118.0

TABLE 5.B - USNS HAYES (T-AGOR 16) OVER-DESIGN PITCH STANDARDIZATION TRIAL RESULTS,
METRIC UNITS
HECTOR, 5 - 6 OCTOBER 1983
104%, 110% and 118% OVER-DESIGN PITCH

Run No.	Mini-Ranger Speed (knot)	EM Log Speed (knot)	Shaft RPM			Shaft Torque (N-m)			Shaft Power (kW)			Propeller Pitch (percent)		
			STBD	PORT	AVG	STBD	PORT	TOTAL	STBD	PORT	TOTAL	STBD	PORT	AVG
S1390S	15.32	16.4	137.3	137.5	137.4	128,500	130,700	259,200	1,850	1,880	3,730	103.6	104.1	103.8
S1400N	15.00	16.9	137.4	137.6	137.5	123,400	125,400	248,800	1,780	1,810	3,590	103.7	104.1	103.9
S1410S	15.35	16.5	137.4	137.6	137.5	127,600	130,500	258,100	1,840	1,880	3,720	103.7	104.2	104.0
AVG	15.17	16.7			137.5			253,700			3,650			103.9
S1700N	11.43	13.3	100.0	99.4	99.7	69,900	72,400	142,300	730	750	1,480	109.7	113.6	111.6
S1710S	12.56	12.8	100.0	99.2	99.6	73,400	76,800	150,200	770	800	1,570	109.6	113.6	111.6
S1720N	11.39	13.3	100.0	99.3	99.6	70,100	72,400	142,500	730	750	1,480	109.6	113.6	111.6
AVG	11.98	13.0			99.6			146,300			1,530			111.6
S1730S	14.51	15.0	119.9	119.4	119.6	108,900	115,100	224,000	1,370	1,440	2,810	109.4	113.4	111.4
S1740N	13.28	15.3	120.1	119.3	119.7	104,900	110,800	215,700	1,320	1,380	2,700	109.4	113.4	111.4
S1750S	14.32	15.0	120.1	119.6	119.8	109,700	116,500	226,200	1,380	1,460	2,840	109.4	113.4	111.4
AVG	13.85	15.2			119.7			220,400			2,760			111.4
S1760S	15.89	16.2	131.4	131.3	131.4	129,600	138,700	268,300	1,780	1,910	3,690	109.3	113.3	111.3
S1770N	14.34	16.9	131.4	131.0	131.2	123,700	130,000	253,700	1,700	1,780	3,480	109.4	113.3	111.4
S1780S	15.75	16.2	131.4	130.5	131.0	130,500	137,800	268,300	1,800	1,880	3,680	109.3	113.3	111.3
AVG	15.08	16.6			131.2			261,000			3,580			111.4
S1300N	10.18	11.4	80.7	80.1	80.4	51,900	49,000	100,900	440	410	850	117.6	119.2	118.4
S1310S	10.24	10.7	80.8	80.1	80.4	55,200	52,900	108,100	470	440	910	117.6	119.1	118.4
S1320N	10.10	11.3	80.8	79.9	80.4	52,100	48,900	101,000	440	410	850	117.6	119.1	118.4
AVG	10.19	11.0			80.4			104,500			880			118.4
S1330N	11.32	12.8	91.1	91.3	91.2	66,600	65,100	131,700	630	620	1,250	117.5	118.9	118.2
S1340S	11.45	12.0	91.2	91.2	91.2	71,500	70,300	141,800	680	670	1,350	117.5	118.9	118.2
AVG	11.38	12.4			91.2			136,700			1,300			118.2
S1360N	13.30	15.0	110.9	111.3	111.1	102,100	101,700	203,800	1,190	1,190	2,380	117.3	118.7	118.0
S1370S	13.61	14.5	110.9	111.1	111.0	107,100	107,000	214,100	1,240	1,240	2,480	117.3	118.7	118.0
AVG	13.46	14.8			111.0			209,000			2,430			118.0

TABLE 6.A - USNS HAYES (T-AGOR 16) TOWED ARRAY STANDARDIZATION TRIAL RESULTS, ENGLISH UNITS
AUTEC RANGE, 29-30 OCTOBER 1983

Run No.	AUTEC-Range Speed (knot)	EM Log Speed (knot)	Shaft RPM STBD	Shaft RPM PORT	Shaft RPM AVG	Shaft Torque (lbf-ft) STBD	Shaft Torque (lbf-ft) PORT	Shaft Torque (lbf-ft) TOTAL	Shaft Power (hp) STBD	Shaft Power (hp) PORT	Shaft Power (hp) TOTAL	Propeller Pitch (percent) STBD	Propeller Pitch (percent) PORT	Propeller Pitch (percent) AVG
A1040S	5.53	5.4	70.4	69.8	70.1	9,900	9,300	19,200	130	120	250	54.0	*	54.0
A1030N	4.90	4.8	70.5	69.9	70.2	10,900	10,200	21,100	150	140	290	53.7	*	53.7
A1050S	5.46	5.4	70.3	69.7	70.0	9,900	9,300	19,200	130	120	250	53.8	*	53.8
AVG	5.20	5.1			70.1			20,200			270			53.8
A1060N	10.38	10.5	89.6	89.9	89.8	41,800	43,500	85,300	710	740	1,450	100.8	*	100.8
A1070S	10.71	11.3	89.6	90.1	89.8	40,100	40,000	80,100	680	690	1,370	100.8	*	100.8
A1080N	10.52	10.8	89.2	89.7	89.4	41,600	41,500	83,100	710	710	1,420	100.9	*	100.9
AVG	10.58	11.0			89.7			82,200			1,400			100.8
A1101N	12.92	13.4	109.1	109.4	109.2	62,400	64,100	126,500	1,300	1,340	2,640	100.8	*	100.8
A1090S	12.61	13.6	108.8	109.8	109.3	61,000	62,700	123,700	1,260	1,310	2,570	100.8	*	100.8
A1111N	12.77	13.3	109.1	109.5	109.3	62,900	64,400	127,300	1,300	1,340	2,640	100.9	*	100.9
AVG	12.73	13.5			109.3			125,300			2,610			100.8

NOTE: There was a port propeller pitch voltage shift. The port and starboard rpms and torques were matched. Therefore the starboard propeller pitch value was used in lieu of the port propeller pitch value.

TABLE 6.B - USNS HAYES (T-AGOR 16) TOWED ARRAY STANDARDIZATION TRIAL RESULTS, METRIC UNITS
AUTEC RANGE, 29-30 OCTOBER 1983

Run No.	AUTEC-Range Speed (knot)	EM Log Speed (knot)	Shaft RPM			Shaft Torque (N-m)			Shaft Power (kW)			Propeller Pitch (percent)		
			STBD	PORT	AVG	STBD	PORT	TOTAL	STBD	PORT	TOTAL	STBD	PORT	AVG
A1040S	5.53	5.4	70.4	69.8	70.1	13,400	12,700	26,100	100	90	190	54.0	*	54.0
A1030N	4.90	4.9	70.5	69.9	70.2	14,800	13,900	28,700	110	100	210	53.7	*	53.7
A1050S	5.46	5.4	70.3	69.7	70.0	13,400	12,600	26,000	100	90	190	53.8	*	53.8
AVG	5.20	5.1			70.1			27,400			200			53.8
A1060N	10.38	10.5	89.6	89.9	89.8	56,600	59,000	115,600	530	560	1,090	100.8	*	100.8
A1070S	10.71	11.3	89.6	90.1	89.8	54,500	54,200	108,600	510	510	1,020	100.8	*	100.8
A1080N	10.52	10.8	89.2	89.7	89.4	56,500	56,300	112,800	530	530	1,060	100.9	*	100.9
AVG	10.58	11.0			89.7			111,400			1,050			100.8
A1101N	12.92	13.4	109.1	109.4	109.2	84,600	87,000	171,600	970	1,000	1,970	100.8	*	100.8
A1090S	12.61	13.6	108.8	109.8	109.3	82,700	85,000	167,700	940	980	1,920	100.8	*	100.8
A1111N	12.77	13.3	109.1	109.5	109.3	85,300	87,300	172,600	970	1,000	1,970	100.9	*	100.9
AVG	12.73	13.5			109.3			169,900			1,950			100.8

NOTE: There was a port propeller pitch voltage shift. The port and starboard rpms and torques were matched. Therefore the starboard propeller pitch value was used in lieu of the port propeller pitch value.

TABLE 7 - SUMMARY OF BASELINE HORIZONTAL OVERSHOOT TRIALS

Run Number	H1002	H1011	H1020	H1031	H1041	H1050	H1060	H1071
Nominal Approach Speed (knot)	5.0	5.0	5.0	5.0	10.0	10.0	10.0	10.0
Nominal Rudder Angle Ordered at Initial Execute (deg)	20R	20L	10R	10L	20R	20L	10R	10L
Change of Course	±20	±20	±10	±10	±20	±20	±10	±10
Overshoot after 2nd Execute (deg)	11.3	9.7	4.5	5.3	15.2	14.2	6.9	7.0
Overshoot after 3rd Execute (deg)	8.0	10.2	3.5	3.9	15.0	13.7	5.2	9.1
Overshoot after 4th Execute (deg)	10.5	10.4	6.3	6.1	14.9	15.1	9.0	6.9
Overshoot after 5th Execute (deg)	8.5	12.2	4.5	5.7	13.7	12.8	5.0	7.8
Overshoot after 6th Execute (deg)	12.8	10.6	6.6	5.5	16.7	14.6	9.1	8.7
Overshoot after 2nd Execute (s)	20.0	19.0	19.0	20.0	13.0	13.0	11.0	11.0
Overshoot after 3rd Execute (s)	17.0	20.0	12.0	16.0	13.0	14.0	11.0	18.0
Overshoot after 4th Execute (s)	21.0	20.0	23.0	21.0	14.0	15.0	15.0	11.0
Overshoot after 5th Execute (s)	17.0	24.0	13.0	19.0	12.0	13.0	10.0	11.0
Overshoot after 6th Execute (s)	22.0	19.0	19.0	17.0	14.0	13.0	16.0	15.0
Time between 1st and 2nd Execute (s)	23.0	41.0	28.0	30.0	23.0	20.0	19.0	23.0
Time between 2nd and 3rd Execute (s)	85.0	89.0	102.0	91.0	53.0	50.0	56.0	45.0
Time between 3rd and 4th Execute (s)	81.0	90.0	66.0	76.0	54.0	56.0	40.0	56.0
Time between 4th and 5th Execute (s)	101.0	89.0	108.0	91.0	57.0	54.0	59.0	49.0
Time between 5th and 6th Execute (s)	81.0	94.0	67.0	85.0	52.0	55.0	38.0	52.0
Reach (s)	86.0	108.0	104.0	101.0	65.0	64.0	65.0	60.0
Average Period (s)	185.0	180.0	172.0	170.0	109.0	110.0	95.0	102.0

TABLE 8 - SUMMARY OF TOWED ARRAY HORIZONTAL OVERSHOOT TRIALS

Run Number	Z1262	Z1251	Z1210	Z1230	Z1240	Z1211	Z1220
Nominal Approach Speed (knot)	5.0	5.0	10.0	10.0	10.0	10.0	10.0
Nominal Rudder Angle Ordered at Initial Execute (deg)	20R	20L	15R	10R	10L	20R	20L
Change of Course	±20	±20	±15	±10	±10	±20	±20
Overshoot after 2nd Execute (deg)	10.2	8.8	8.0	4.4	5.0	14.5	11.7
Overshoot after 3rd Execute (deg)	8.9	10.2	12.7	7.8	10.0	16.2	14.5
Overshoot after 4th Execute (deg)	10.5	11.0	8.9	5.6	4.5	16.0	11.5
Overshoot after 5th Execute (deg)	11.8	8.2	10.3	9.8	10.9	16.0	14.2
Overshoot after 6th Execute (deg)	7.7	10.9	11.4	4.8	5.4	16.4	13.7
Overshoot after 2nd Execute (s)	19.0	19.0	9.0	9.0	8.0	13.0	12.0
Overshoot after 3rd Execute (s)	18.0	18.0	13.0	13.0	14.0	16.0	14.0
Overshoot after 4th Execute (s)	21.0	20.0	11.0	10.0	9.0	16.0	12.0
Overshoot after 5th Execute (s)	23.0	18.0	12.0	15.0	15.0	13.0	14.0
Overshoot after 6th Execute (s)	19.0	21.0	12.0	10.0	9.0	16.0	15.0
Time between 1st and 2nd Execute (s)	34.0	40.0	20.0	20.0	23.0	33.0	23.0
Time between 2nd and 3rd Execute (s)	82.0	82.0	43.0	38.0	35.0	49.0	47.0
Time between 3rd and 4th Execute (s)	85.0	87.0	53.0	53.0	59.0	55.0	57.0
Time between 4th and 5th Execute (s)	87.0	92.0	46.0	39.0	35.0	52.0	47.0
Time between 5th and 6th Execute (s)	93.0	85.0	54.0	55.0	59.0	55.0	57.0
Reach (s)	97.0	98.0	54.0	50.0	52.0	59.0	59.0
Average Period (s)	173.0	175.0	98.0	93.0	94.0	105.0	104.0

TABLE 9 - SUMMARY OF TOWED ARRAY TACTICAL TURN TRIALS

Run No.	Nominal Approach Speed (kt)	Approach RPM	Nominal Execute Rudder Angle (deg)	Advance yd(m)	Transfer yd(m)	Tactical Diameter yd(m)	Steady Turning Diameter yd(m)	Steady Speed In-Turn
T1060	10	106.7	5R	615(562)	430(393)	1093(999)	1125(1029)	8.4
T1070	10	106.4	5L	841(769)	1007(921)	1240(1134)	1214(1110)	7.6

L=Left, R=Right

APPENDIX A - DESCRIPTION OF HECTOR

(Figure A.1)

APPENDIX A - DESCRIPTION OF HECTOR

The Hatteras East Coast Tracking Offshore Range (HECTOR) is located 50 nautical miles (92.6 kilometers) northeast of Cape Hatteras, North Carolina and 87 nautical miles (161 kilometers) southeast of Norfolk, Virginia. The range site makes use of two of four offshore towers which are used for Navy pilot training. The North tower, the most easterly of the four towers, is located at 36°03'52" latitude north and 74°59'00" longitude west. The South tower is located at 35°47'11" latitude north and 75°05'42" longitude west. These unmanned towers are 75 feet (22.9 meters) high and 17.54 nautical miles (32.5 kilometers) apart and are utilized as platforms for permanently mounted tracking instrumentation.

The primary means of determining ship position is the Motorola Mini-Ranger III (MRS III) pulse tracking system. A transmitter located on the ship was used to interrogate two reference station transponders. These transponders were mounted on towers which are separated by a known distance. The elapsed time between the transmitted interrogation produced by the MRS III transmitter and the reply received from each transponder was used as the basis for determining the distance to each transponder. This range information, together with the known location of each transponder, was triangulated to provide a position fix of the ship. Successive positional fixes enable the calculation of ship speed as well as its turning and maneuvering capabilities.

Since tracking accuracy is related to system geometry, ship trials are normally conducted with a 13.9 nautical square mile (25.7 square kilometer) area as shown in Figure A.1. The center of this area (35°52.5' latitude north and 74°51.0' longitude west) is approximately 9.6 nautical miles (17.8 kilometers) from the midpoint of the distance between the towers in a direction perpendicular to the baseline determined by the two towers. The approach for each trial run is generally conducted near the center of the tracking area on a course parallel with the baseline determined by the towers. Thus, a heading of 018°T is used for north runs and a heading of 198°T is used for south runs. Water depth is in excess of 300 feet (91.4 meters).

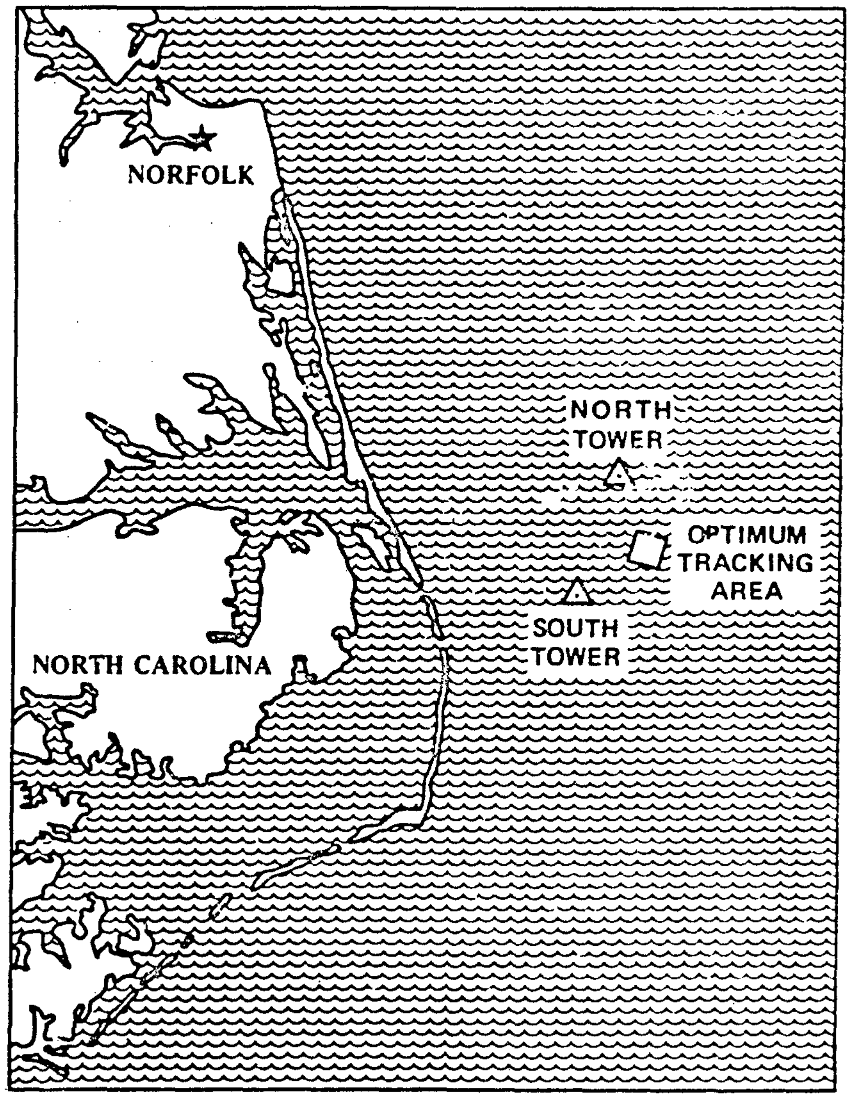


Figure A.1 - Hatteras East Coast Tracking Offshore Range (HECTOR)

APPENDIX B - DESCRIPTION OF THE AUTEC RANGE

(Figure B.1)

APPENDIX B - DESCRIPTION OF THE AUTEC RANGE

The Atlantic Undersea Test and Evaluation Center (AUTEC) is located on Andros Island, Bahamas which is approximately 29 miles (47 kilometers) southwest of Nassau and about 150 miles (241 kilometers) southeast of Miami, Florida. The towed array trials were conducted on the Weapons Range which is an underwater, three-dimensional tracking range. Range positional data were used to calculate ship speed, ship turning characteristics (advance, transfer, tactical diameter, speed in the turn), and acceleration characteristics (reach and time to attain the steady state powering characteristics associated with the requested engine order).

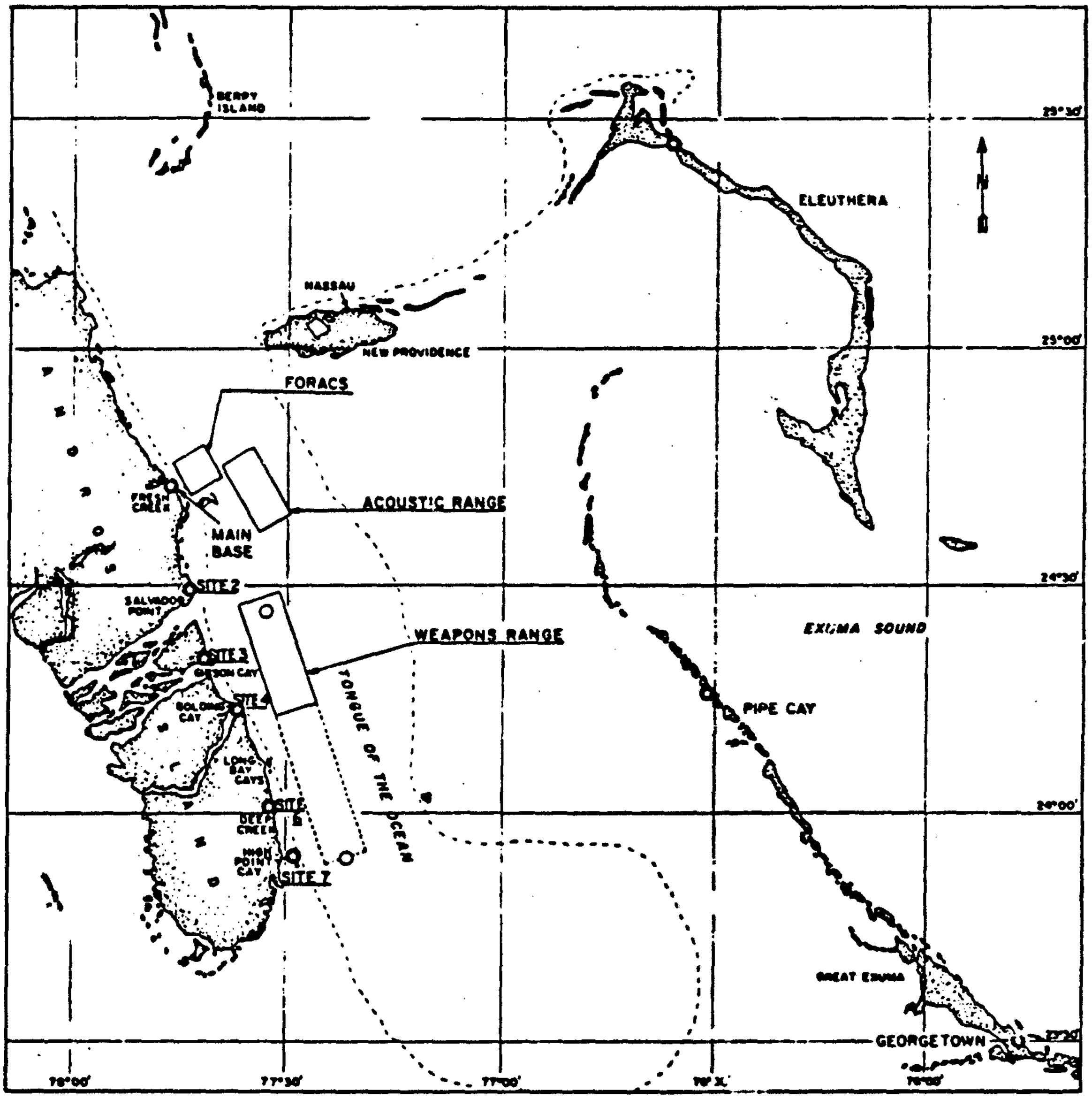


Figure B.1 - Atlantic Undersea Test and Evaluation Center (AUTEC), Underwater Range, Andros Island, Bahamas

APPENDIX C - CALCULATION OF DISPLACEMENT OF USNS HAYES (T-AGOR 16)

Displacement is calculated from the draft readings. The most accurate draft readings were taken in brackish water, pierside at Cheatham Annex, Virginia just prior to the HECTOR trials. Due to the high sea state accurate draft readings could not be taken on the HECTOR range.

Pierside Draft Readings

	Port	Starboard	Average
Inboard Stern	21.33 ft (6.50 m)	21.17 ft (6.45 m)	21.25 ft (6.48 m)
Inboard Bow	21.58 ft (6.58 m)	21.33 ft (6.50 m)	21.46 ft (6.54 m)
			21.36 ft (6.51 m)

From the HAYES' Hydrostatic Properties Chart, the ship's displacement equaled 3,680 tons (3,739 metric tons) for a mean draft of 21.36 ft (6.51 m) in salt water at 59 degrees F (15 degrees C) and a density of 1.9905. This displacement must be corrected for brackish water readings. All specific gravity readings were taken with a 60/60 hydrometer.

$$(1) \quad \text{Specific Gravity} = \frac{\text{Density of Water @ Observed Temperature °F}}{\text{Density of Fresh Water @ 60°F (15.6 °C)}}$$

Pierside brackish water readings were:

Specific Gravity = 1.014

Temperature = 74 degrees F (23.3 degrees C)

From Equation (1),

$$1.014 = \frac{\text{Density of Brackish Water at 74°F (23.3°C) Pierside}}{1.9383}$$

Therefore:

Density of pierside water at 74 degrees (23.3 degrees C) = 1.014 x 1.9383=1.9654

(2) $$\frac{\text{Density of Brackish Water @ 74°F (23.3°C)}}{\text{Density of Sea Water @ 59°F (15.0°C)}} = \frac{1.9654}{1.9905} = 0.9874$$

(3) $$\text{Corrected Ship Displacement} = \left[\begin{array}{l}\text{Displacement at 21.36 ft (5.51 m)} \\ \text{draft from Hydrostatic Properties} \\ \text{Chart.}\end{array}\right] \times \left[\frac{\text{Density of Brackish Water @ 74°F (23.3°C)}}{\text{Density of Sea Water @ 59°F (15.0°C)}}\right]$$

= 3680 tons (3739 metric tons) x 0.9874

Therefore:

Corrected Ship Displacement = 3634 tons (3692 metric tons) for HECTOR trials.

AUTEC TRIALS

Draft Readings at Beginning of Trial

	Port	Starboard	Average
Inboard Stern	21.00 ft (6.40 m)	20.50 ft (6.25 m)	20.75 ft (6.32 m)
Inboard Bow	21.25 ft (6.48 m)	21.00 ft (6.40 m)	21.13 ft (6.44 m)
			20.94 ft (6.38 m)

Draft Readings at End of Trial

	Port	Starboard	Average
Inboard Stern	21.00 ft (6.40 m)	20.75 ft (6.32 m)	20.88 ft (6.36 m)
Inboard Bow	21.50 ft (6.55 m)	21.00 ft (6.40 m)	21.25 ft (6.48 m)
			21.06 ft (6.42 m)

Trial Average = 21.00 ft (6.40 m)

From the Hydrostatic Properties Chart, displacement equaled 3610 tons (3668 metric tons) for a mean draft of 21.00 ft (6.40 m) in salt water at 59 degrees F (15 degrees C) and a density of 1.9905.

This displacement must be corrected for the specific gravity reading taken on the range.

Specific Gravity = 1.024

Temperature = 83 degrees F (28.3 degrees C)

From Equation (1),

1.024 = Density of Seawater at 83°F (28.3°C)/1.9383

Therefore:

Density of Seawater at 83°F (28.3°C) = 1.024 x 1.9383=1.9848

From Equation (2),

$$\frac{\text{Density of Sea Water @ 83°F(28.3°C)}}{\text{Density of Sea Water @ 59°F (15.0°C)}} = \frac{1.9848}{1.9905} = 0.9971$$

From Equation (3),

Displacement x 0.9971=3610 tons (3668 metric tons) x 0.9971

Therefore:

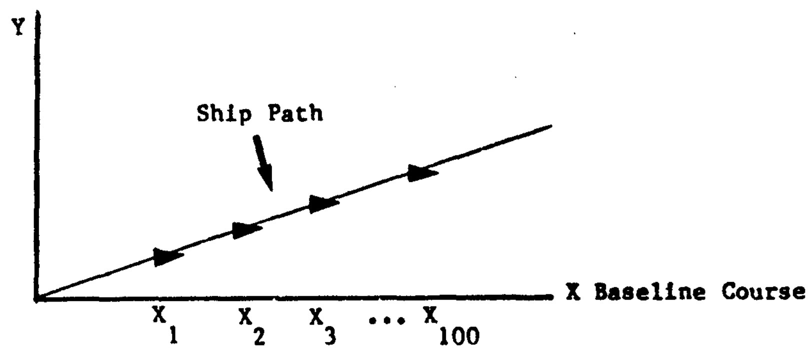
Corrected ship displacement = 3,600 tons (3,658 metric tons) for the AUTEC trials.

APPENDIX D - DISCUSSION OF SHIP'S EM LOG AND RANGE SPEED

(Figure D.1)

APPENDIX D - DISCUSSION OF SHIP'S EM LOG AND RANGE SPEED

The Motorola Mini-Ranger III pulse tracking system was used to obtain actual ship speed at HECTOR. As discussed in the text, the successive positional fixes obtained by MRS III were used to determine ship speed. This system was accurate to within ±10 feet (±3 meters). A baseline course was determined (X axis) and speed along it was derived using X positional data. The component of speed due to wind and sea (Y axis) was eliminated. Speed was determined using an average of pairs of X positional data (see below). For example, if there are 100 data points, the speed is calculated between X_1 and X_{50}, X_2 and X_{51}, etc. An average of all these speeds is the final speed.



$$V = \frac{\frac{X_{50} - X_1}{t_{1-50}} + \frac{X_{51} - X_2}{t_{2-51}} + \ldots + \frac{X_{100} - X_{51}}{t_{51-100}}}{51}$$

Two or three runs, alternating 180 degrees in direction and of three minutes duration, were made at HECTOR. An average was applied to take into account the effects of current. For a two-pass spot, a simple average of the data from the two passes were used. For a three-pass spot, the data for the odd direction was weighted twice and the four passes were then averaged.

The average baseline trial speed for each test spot at HECTOR, as determined by MRS III, was compared to the ship's 10-knot EM log. As shown in Figure D.1, for speeds below 7 knots, the log was comparable to the range speed though slightly higher. Above 7 knots, the log was 0.6 to 1.7 knots higher than the range speed.

For the towed array trials, actual ship speed at AUTEC was determined from range positional data. Range track was obtained by an AUTEC shipboard mounted pinger and various sea bottom mounted hydrophone arrays. The pinger emitted a signal which took a distinct time to reach a hydrophone array. By measuring the time to 3 or more arrays and knowing the distances between arrays, a positional fix can be obtained. Actual ship speed was then calculated after manipulating the positional data in the same manner as on HECTOR.

Shipboard speed for these AUTEC towed array trials was obtained from the 40-knot EM log which was not available for the HECTOR trials. This log speed ranges from 0.1 to 0.6 knots higher than the AUTEC range speed. As is evident from Figures D.1, the 40-knot log was more consistent with range speed than the 10-knot log.

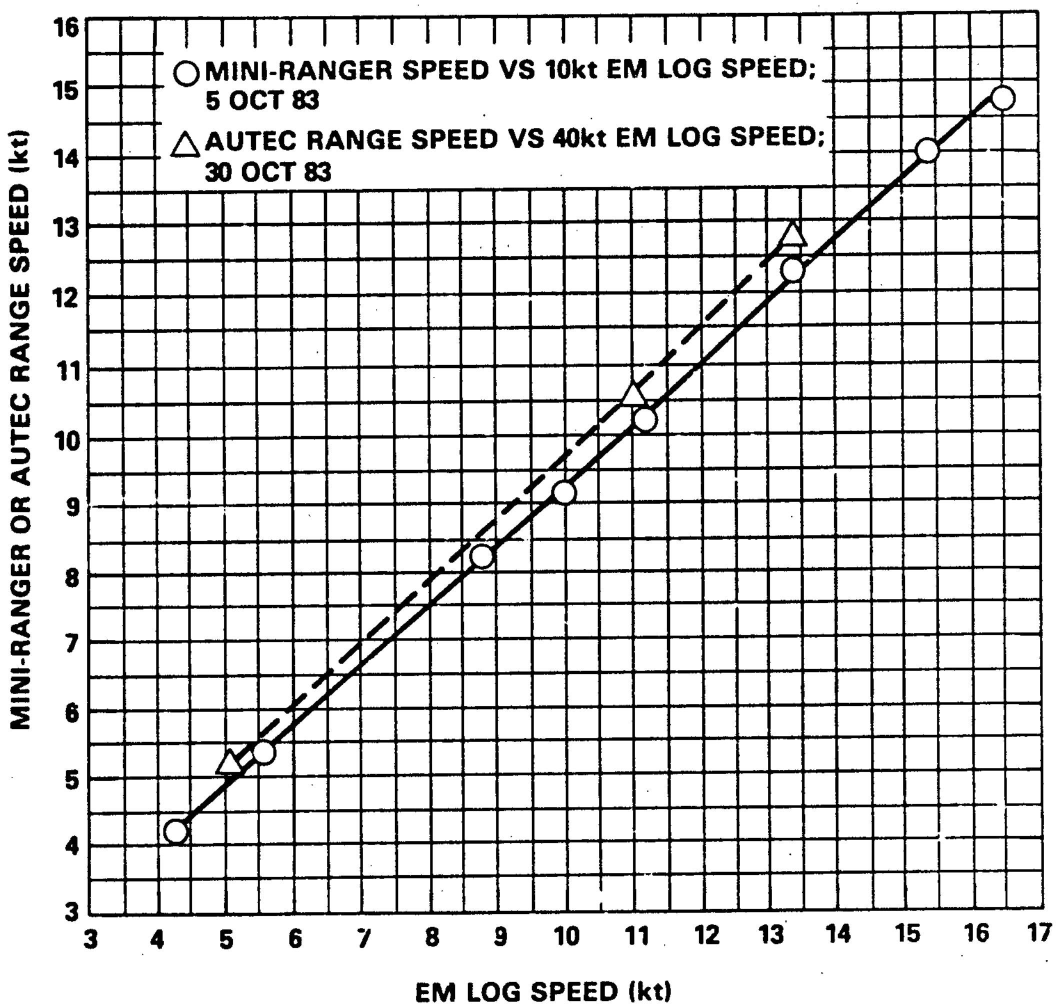


Figure D.1 - Comparison of Mini-Ranger and AUTEC Speeds versus Ship's EM Log Speed in the Design Control Mode

APPENDIX E - DIAGRAM OF A TYPICAL HORIZONTAL OVERSHOOT MANEUVER

(Figure E.1)

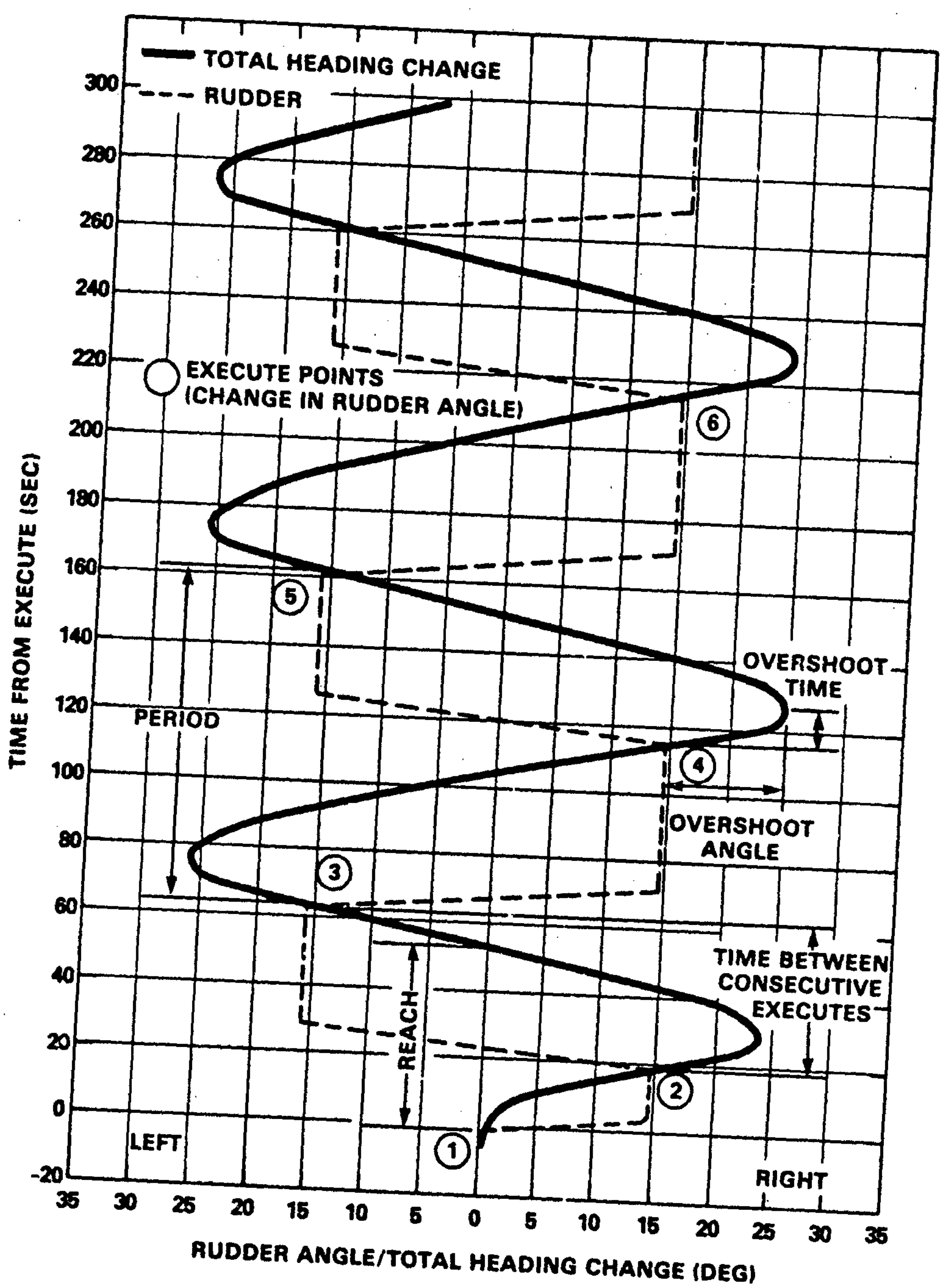


Figure E.1 - Example of a Typical Horizontal Overshoot Maneuver

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