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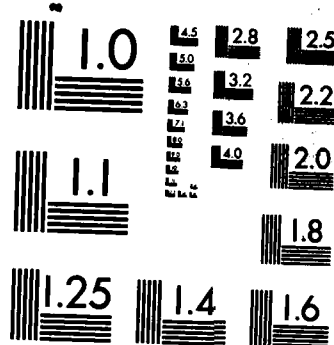
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SHIP NAVIGATION SIMULATOR STUDY
UPPER MOBILE BAY CHANNEL

by

Carl Huval

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39180-0631

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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

Mobile Harbor navigation channel presently can accommodate ship drafts up to the authorized channel depth of 40 ft, depending on tide levels, dredging overdraft amount, and rate of channel shoaling. Many of the larger dry bulk carriers, such as coal colliers, are entering or leaving Mobile Harbor in a light loaded condition. This makes the movement of cargo more expensive and lowers transportation efficiency that could be possible by fully utilizing the larger vessels and their economies of scale.

The relatively narrow channel width of 400 ft causes navigation problems, especially in the upper Mobile Bay channel reach where overbank depths become very small. In addition, ship steering problems have been reported by pilots in the vicinity of the Arlington Channel and when meeting a docked ship at the

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20. ABSTRACT (Continued).

McDuffie Island Coal Terminal. Mobile District is considering a plan to deepen and widen the Mobile Harbor navigation channel in phases to ultimately provide a 55- by 650-ft channel.

The presently authorized Mobile Harbor Navigation Project does not include a turning basin in the lower part of Mobile River or the upper part of Mobile Bay. There is no provision for a safe anchorage area for deep-draft vessels while awaiting berths. A turning basin and an anchorage area in the upper bay region has been proposed by the District.

This report presents the results of a navigation study conducted on the US Army Engineer Waterways Experiment Station (WES) Ship Simulator. The purpose of the study was to investigate navigation improvements due to channel widening in the upper bay area. The impact of the proposed anchorage area and turning basin was also investigated. The effect of channel depth increases on navigation conditions was investigated separately, and was not considered in this study.

As a part of the investigation a reconnaissance trip aboard a typical bulk carrier was conducted to observe pilot maneuvers and to record the inbound ship transit with video tape equipment and still photographs. Special tests were conducted on the Mobile Bay scale model to record current patterns in the upper bay study region. The study area navigation channel was schematized on the simulator using available navigation charts and topographic maps, and the District furnished hydrographic survey data. Ebb tide current data from the physical model were used to give realistic inbound test conditions on the simulator. The simulator visual scene was created using the data recorded during the inbound ship transit, maps, and charts.

The simulations consisted of a series of inbound base tests using a 63,000-dwt bulk carrier fully loaded to a draft of 36 ft in the present channel depth of 40 ft. The proposed turning basin, anchorage area, and widened channel (from 400 to 650 ft) was then schematized and another series of tests was conducted. A total of 32 tests were run with three WES engineer-pilots and one active Mobile Bay pilot. The tests by the active bay pilot were particularly important because they validated the simulator visual scene, the method of schematizing the channel, and the strong bank-suction and crosscurrent effects on ship handling in the study area.

The study showed that careful pilot control was required to maneuver the simulated ship in the 400-ft-wide channel in the upper bay reach. Anticipating the ship response at the Arlington Channel and the docked ship was necessary to prevent ship grounding or collision. The 650-ft-widened channel, the anchorage area, and the turning basin increase the safety margin in the upper bay reach by greatly decreasing the bank-suction forces at Arlington Channel and the docked ship. The proposed project will provide greatly improved navigation conditions in the upper bay.

PREFACE

This investigation was performed by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, Mobile (SAM). The study was conducted with the WES Research Ship Simulator. Authority for the investigation was given by letter of 3 March 1982. SAM provided the essential field data required. The study was conducted during the period March 1982–December 1984. The study results were provided to SAM by means of a draft report on 14 December 1984.

Substantial financial support for this project was also received from the Office, Chief of Engineers (OCE), Research and Development Program in Navigation Hydraulics. Mr. Bruce L. McCartney, OCE, Technical Monitor for this program, has provided invaluable assistance to the WES Ship Simulator from its inception.

The investigation was conducted by Mr. Carl J. Huval with the help and support of Dr. Larry L. Daggett and Messrs. Bradley M. Comes and Robert T. Garner III of the Mathematical Modeling Group, under the general supervision of Messrs. Henry B. Simmons and Frank A. Herrmann, Jr., former and successive Chiefs of the Hydraulics Laboratory, and Marden B. Boyd, Chief of the Hydraulic Analysis Division. This report was edited by Mrs. Beth F. Vavra, Publications and Graphic Arts Division.

Mr. Rick Champion provided liaison with SAM during the majority of the study period. The author would like to express his appreciation to Captain Doug McColl, Mobile Harbor Pilot, for his help in the study both onboard the inbound bulk carrier in Mobile Bay and later at WES on the ship simulator.

Director of WES was COL Allen F. Grum, USA. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
deadweight tons (English or long)	1.01605	tonnes (kilograms)
feet	0.3048	metres
knots (international)	0.5144444	metres per second
miles (US statute)	1.609347	kilometres
square miles (US statute)	2.589998	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

SHIP NAVIGATION SIMULATOR STUDY

UPPER MOBILE BAY CHANNEL

PART I: INTRODUCTION

1. The Mobile District has proposed a navigation improvement plan for Mobile Harbor to accommodate the larger bulk carriers engaged in international coal trade. The proposed project is to be implemented in phases, initially involving the upper Mobile Bay region only. The District requested the US Army Engineer Waterways Experiment Station (WES) to investigate the proposed channel, the turning basin, and the anchorage with respect to safe navigation conditions.

2. The principal tool used for the study described in this report was the WES Ship Simulator. Special tests were conducted on the Mobile Bay scale model at WES to measure and record the currents occurring in the study area for input into the simulator. A 63,000-dwt bulk carrier type ship typical of the size vessel presently using the coal loading facility was used in the simulator study. A reconnaissance trip aboard a bulk carrier inbound into Mobile Harbor was taken to study real world piloting conditions. A number of inbound ship transit simulator tests were conducted with a professional Mobile Bay pilot as well as several WES engineers.

3. This report presents a brief overview of Mobile Harbor, some of the navigation problems in the study area, and the proposed channel modifications. The ship simulator is next described and the methodology of data base creation. The test results are then presented and discussed; and finally, study conclusions and recommendations are drawn. Appendix A gives plotted results of all the test runs used in the analysis of results.

PART II: PORT OF MOBILE

4. Mobile Harbor is the only seaport in Alabama and is one of the Nation's major ports of entry, ranking about twelfth in total traffic. Harbor facilities include large oil terminals, the Alabama State Docks with numerous general cargo handling berths, a large public grain elevator, and several other smaller facilities. In 1975, the McDuffie Coal Terminal was placed in operation by the Alabama State Docks. This facility is designed to handle coal for export from barges and rail cars to large dry-bulk carriers and coal colliers. The capacity of this terminal was recently increased to 25 million tons* annually. It is anticipated that coal movements through Mobile Harbor will increase from about ? million tons in 1975 to about 20 million tons by the year 2000.

Description

5. Mobile Bay (Figure 1) is located on the Gulf of Mexico and covers an area of nearly 400 square miles. The bay is about 30 miles long and is relatively shallow with natural depths of 8 to 10 ft. The entrance to the bay from the Gulf is about 3 miles wide. The prima.y inflow into the bay is the Mobile River with a mean discharge of 63,500 cfs. Tides in Mobile Bay are diurnal and consist of one tide daily. Tidal fluctuations vary during the lunar month from less than 1 ft to as much as 2.5 ft during spring tides. The mean range increases from 1.2 ft near the bay entrance to 1.5 ft at the head of the bay. Wind effects are very important in the bay and often dominate the tidal fluctuations.

6. Tidal currents in the shallow part of the bay are typically less than 1 fps but are much larger in the navigation channels. Near the bay entrance, the maximum currents occur with a magnitude up to 4.5 fps on both flood and ebb. In the navigation channel at the upper bay project area (Figure 2), the surface currents are about 0.5 fps on flood and 2.5 fps on ebb. The Mobile River inflow does have an effect on tidal currents in the upper bay, tending to cause a decrease in flood currents and an increase in the ebb currents. There is also a variation in current velocities with

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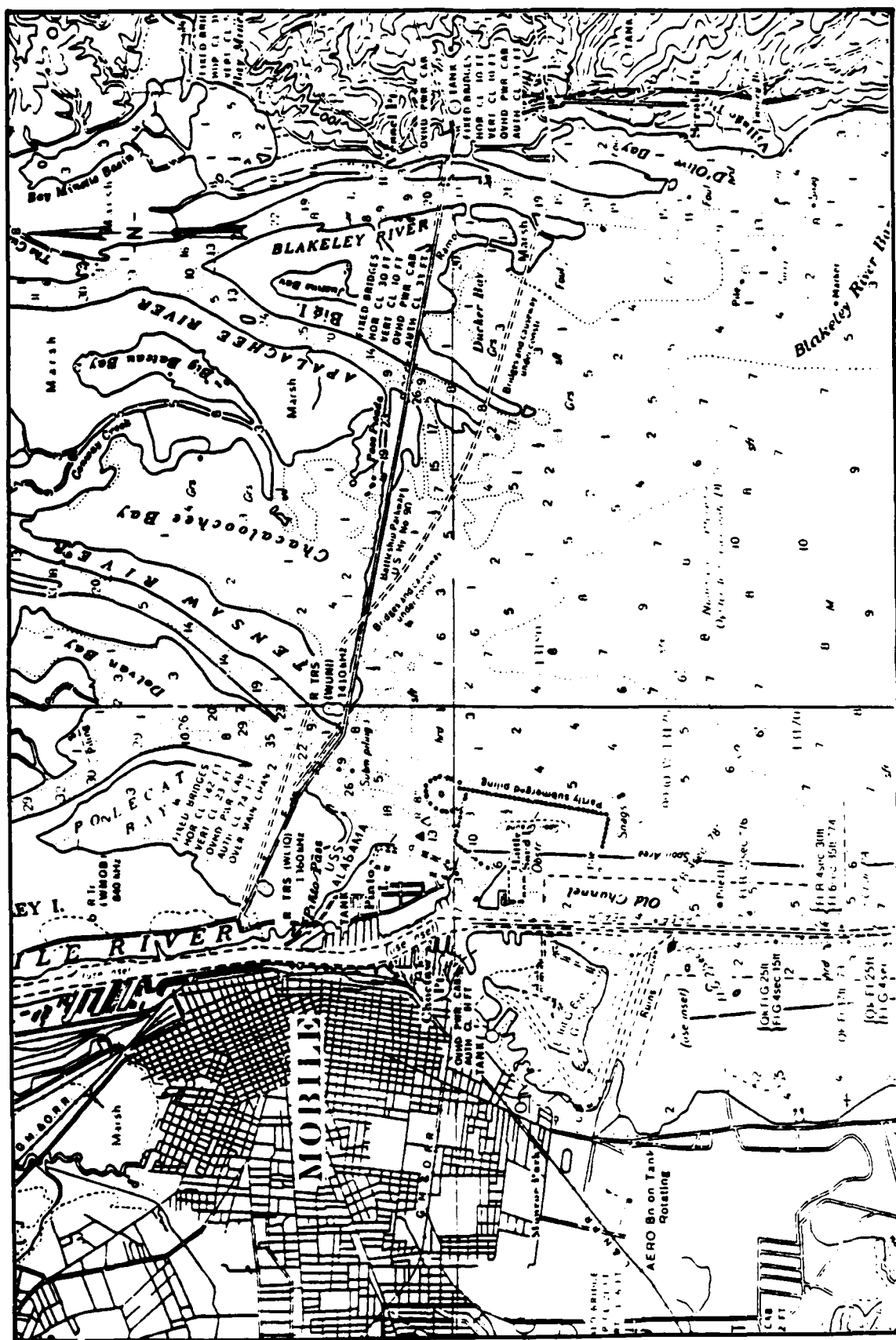* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.
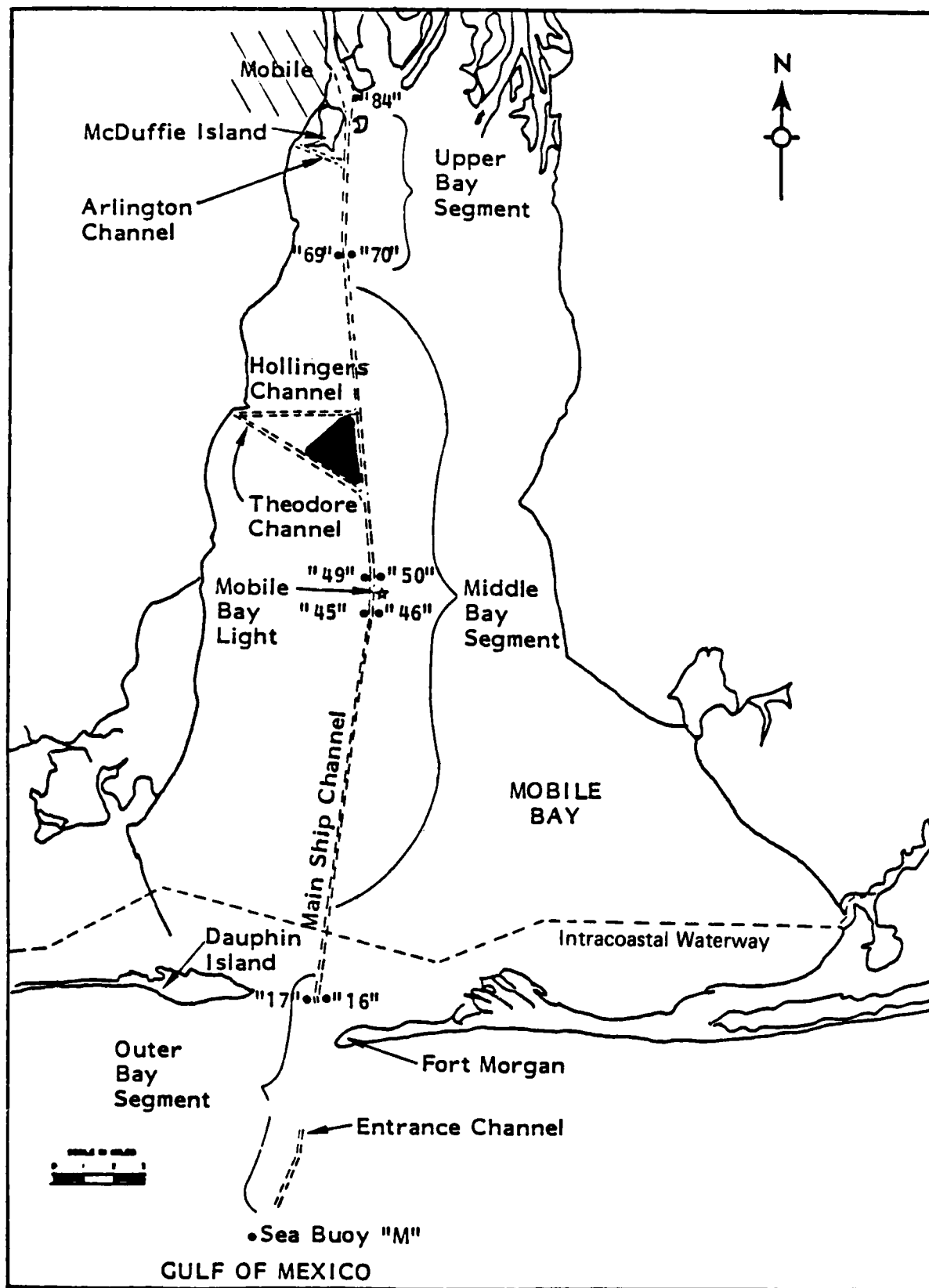
Figure 1. Mobile Harbor channels

Figure 2. Detail map of upper bay segment

respect to the depth, giving an increase on the channel bottom in flood and a decrease on the channel bottom in ebb. The currents are fairly well lined up to the channel alignment, except in the vicinity of Choctaw Pass and Little Sand Island, and near the Arlington Channel junction (Figure 3).

7. The authorized navigation project for Mobile Harbor consists of the following main features:

a. A 42- by 600-ft channel about 1.5 miles long across the bar near the entrance to the bay.

b. A 40- by 400-ft channel in Mobile Bay about 30 miles long to the mouth of Mobile River at Choctaw Pass.

c. A 40-ft channel in Mobile River about 4.5 miles long to the US 90 Highway Bridge, the width varying from 500 to 775 ft.

Table 1 gives pertinent details of the navigation channel data in the study area.

8. The aids to navigation in the upper bay study area consist of buoys and beacons generally located on the channel edges. The channel marker gate at the 7-degree right turn (beacons 73 and 74) marks the first navigation aid during an inbound test run in the study area. As Figure 2 indicates, buoy 76 is located well to the east of the channel edge, which differs considerably from the other channel markers. The beginning of Mobile River and the end of the study segment is marked by buoy 84 located at Choctaw Pass (Figure 3).

Navigation Problems

9. Navigation problems in the study area (Figure 3) are due, in part, to strong ebb tide currents, especially at high Mobile River flows. The high bank-suction forces are also a problem and this is aggravated by the presence of a docked ship at the coal loading terminal on McDuffie Island. The pilots report that ships have had controllability problems in the study area, especially at the Arlington Channel opening on the west side of the main ship channel. This is attributed to the unbalanced bank-suction forces on each side of the ship. Steering problems are also noted at the coal terminal dock, especially when a coal collier is docked and being loaded. The high bank-suction forces from the docked ship and the need to steer well away from the docked ship have prompted the Mobile harbormaster to issue an advisory to the pilots suggesting one-way traffic in this reach of the channel. Inbound ships tend to have greater control problems than outbound vessels.

8

Figure 3. Large-scale map of study area

10. The increased coal ship traffic in the study area has created a need for a turning basin in the upper bay. The existing Mobile Harbor project provides for two turning basins in the Mobile River reach about 2 miles north of the coal terminal and in a highly congested area. In addition to the lack of an efficient turning basin, Mobile Harbor does not have an anchorage area for vessels awaiting a berth or cargo loading. At present, this requires vessels to anchor in the Gulf of Mexico 40 miles away while awaiting a berth.

Proposed Channel Improvements

11. The navigation channel improvements to Mobile Harbor are to be developed in phases. The first phase will include the construction of a turning basin and an anchorage area near the McDuffie Island Coal Terminal in upper Mobile Bay. As a part of the first phase, the channel would be widened in the upper bay reach of the ship channel from 400 to 650 ft. The second phase of the project involves deepening the present channel from 40 to 55 ft to accommodate the larger 150,000-dwt coal colliers at full loaded draft of 52 ft. The third phase of the project would then provide a wider channel from the Gulf to the upper bay.

12. A drawing of the proposed project features as modeled in the ship simulator is shown in Figure 4. The turning basin is planned to be 1,500 ft wide (including the 650-ft channel) and 1,500 ft long. The anchorage area is sized to accommodate four ships at anchor and is designed to be 4,000 ft long and 950 ft wide (including the 650-ft channel). For the first phase, the widened 650-ft channel extends from Choctaw Pass to slightly south of the 7-degree right turn near channel markers 73 and 74. All transitions in channel widths at the anchorage area and the turning basin are designed to be 45 degrees.

Purpose and Scope of Study

13. Only the first phase of the channel improvement project in the upper bay region was simulated for this investigation. This included the 650-ft-wide channel, the turning basin, and the anchorage area. The purpose of the study was to determine the navigation conditions in the existing and proposed channels. The impact on navigation of the proposed turning basin and anchorage area was also investigated.
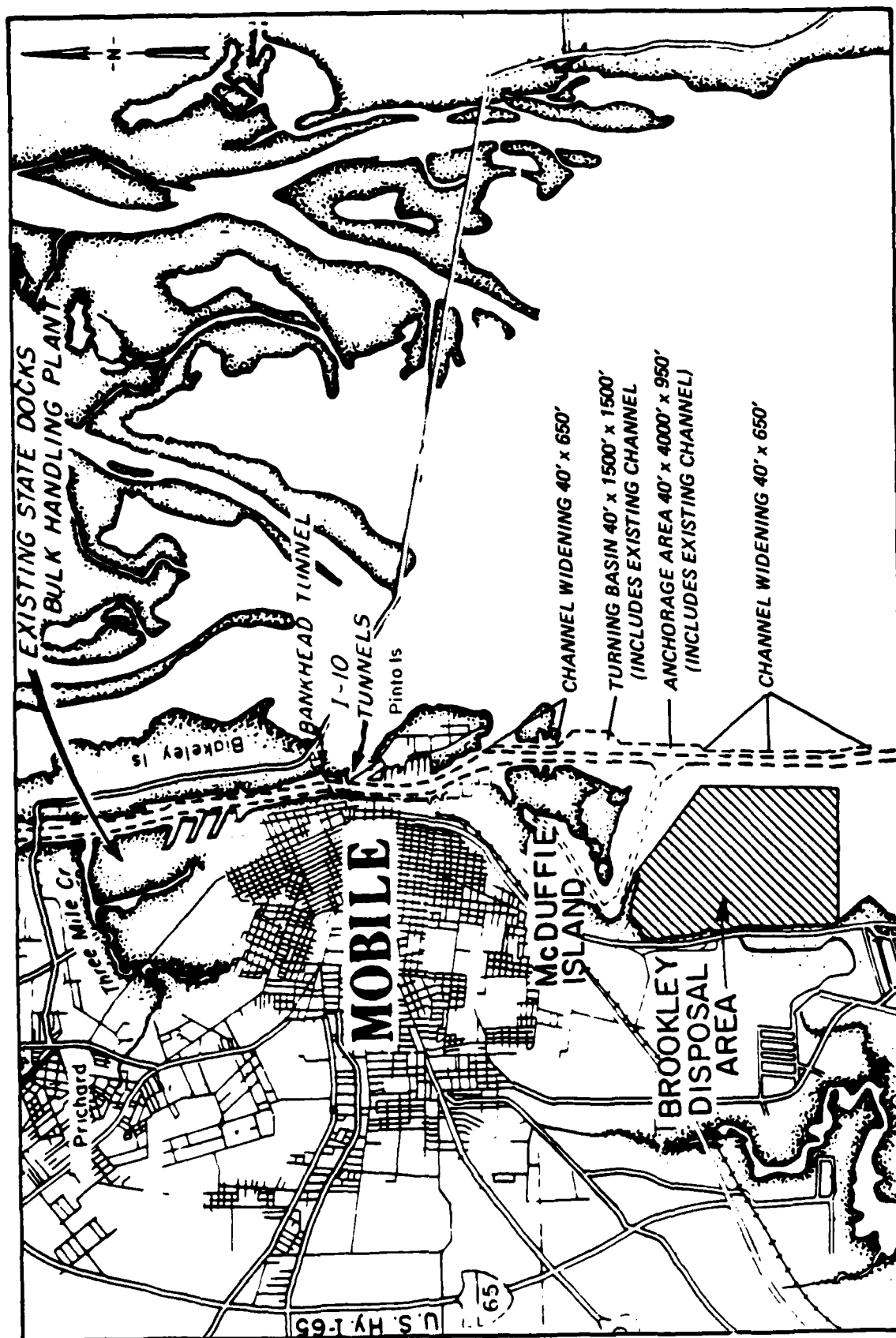
Figure 4. Upper bay channel improvement plan

PART III: FIELD RECONNAISSANCE

14. An inbound ship transit was made aboard the 50,350-dwt bulk carrier M/S EEKLO (Belgium registry) on the morning of 20 June 1982. The ship was carrying iron ore pellets from Canada to Mobile and was loaded to a draft of 40 ft. Table 2 gives details of some of the pilot commands through the simulated study area, based on notes taken on the transit. The sequence was videotaped from the ship bridge and still-color photographs were made to provide the basis for creating the visual scene for the simulations.

15. The pilot controlling the ship was the same pilot who later participated in validation tests on the WES Ship Simulator. Ship speed during the transit was very slow due to the large ship draft compared with the channel depth. The ship speed in open, deep water (taken from a chart posted on the ship bridge) was rated as about 5 knots at "dead slow" and 7 knots at "slow." Between channel markers 76 and 82, for example, the ship speed was calculated based on the 1-n.m. distance covered in 13 min to be about 4-1/2 knots. While engine settings did change between "dead slow" and "slow" during this interval, the bottom and channel bank conditions also have an effect on ship speed. The use of increased engine rpm settings to help turn the ship is evident at the two channel turns and near Arlington Channel. The pilot's preference for the right side of the channel is apparent from the predominant use of right rudder during the transit.

PART IV: UPPER MOBILE HARBOR SHIP NAVIGATION SIMULATION

Simulator Description

16. The WES Ship Simulator is described in detail in Engineer Technical Letter 1110-2-289* and will not be repeated here. However, for the benefit of the reader and as a matter of completeness, a few significant features of the simulator will be described.

17. The purpose of the WES simulator is to provide reasonably realistic operating conditions for testing and optimizing navigation channels and ancillary features to aid project design. The simulator operates in real-time (i.e. no physical model time-scale contraction) and tests can be conducted with an autopilot or with human pilots in control. Once a test scenario is developed for a study area, a series of trial runs can be conducted through the simulated environment. As the ship is maneuvered through the study area, the vessel is subjected to the environmental forces previously built into the scenario. The human pilot navigates the ship using a steering wheel and engine controls very similar to those available on a ship bridge. As the vessel is navigated through the scene, a computer-generated, perspective view from the ship bridge is displayed in color on a large television screen. This provides the pilot with some of the necessary ship motion cues that are used in conning a ship. As the vessel moves through the study area, the scene is updated periodically.

18. The simulator hardware consists of a DEC PDP-11/60 minicomputer, Genisco color generator hardware, simulated radar and precision navigation CRT display units, and a ship steering console. The simulator software consists of a system of computer programs that computes the ship hydrodynamics and vessel response to external forces and vessel control. Another set of codes keeps track of input/output to the ship console and updates the simulated radar and precision navigation displays. A third part of the system software generates the color scene out of the pilot's window as the ship moves through the study area.

19. The mathematical ship hydrodynamic model includes the capability to simulate the effects of crosscurrents, channel bottom effects, and

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* Office, Chief of Engineers. 1983. "Ship and Tow Simulators," Engineer Technical Letter 1110-2-289, 5 Dec 1983, Washington, DC.

bank-suction forces. The effects of wind and waves can also be simulated. A large fleet of ships and push towboats is available in a variety of sizes to meet the needs of many channel design projects.

Scenario Development

20. In order to simulate a study area, it is necessary to develop information relative to three types of input data:

   a. Channel dimensions for the existing and any planned channel modifications.

   b. Current pattern data in the channels, including magnitude and direction.

   c. Visual scene data base composed of heights of principal features in a horizontal grid.

Each of these data types is dealt with in the following three sections.

Channel schematization

21. The information used to develop the channel data base came from Mobile Bay navigation chart No. 11376 published by National Oceanic and Atmospheric Administration (Figures 2 and 3 show excerpts from that chart), US Geological Survey quadrangle maps of the study area, District-furnished hydrographic data, and existing and proposed channel configurations. Channel depths for both test conditions were uniformly set to the presently authorized depth of 40 ft. This was done rather than setting depths to the measured hydrography because of variable bottom conditions from shoaling effects, dredging inaccuracies, and to concentrate the study on the relative impact of the existing and proposed channel geometry. A study of available hydrography was used to set the overbank depths on each side of the channel and the channel side slopes. Both of these parameters are crucial for accurate representation of bank-suction forces. Figure 5 presents a contour map of the channel hydrography south of Arlington Channel and Figure 6 shows two cross-section plots from the map. Channel side slopes are generally about 1 on 5. The channel data used in the simulations are tabulated in Table 3.

22. Channel schematization at the Arlington Channel and the docked coal collier at the McDuffie Island terminal required special treatment to ensure realistic bank-suction effects. The method used at Arlington Channel west bank opening was to widen the channel to 1,150 ft and to increase the left overbank depth to 22 ft. The docked ship was schematized as a vertical channel bank on the left side with no overbank depth. Similar techniques were

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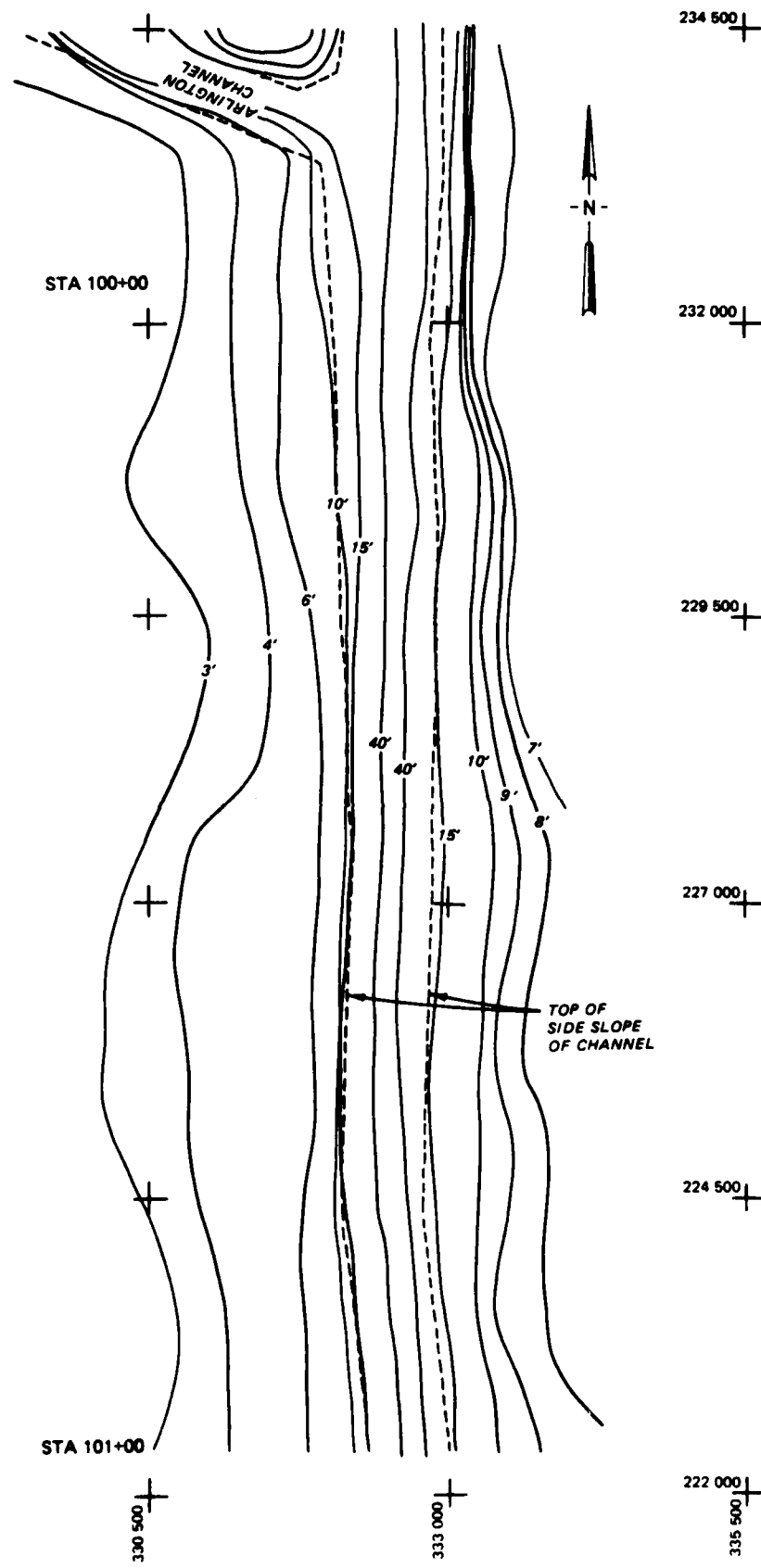
Figure 5. Contoured map of hydrography of channel and overbank
area south of Arlington Channel

DISTANCE ACROSS CROSS-SECTION VS DEPTH (IN FEET)
MOBILE HARBOR

.... STATION 100+00
—·—· STATION 101+00

X STATE PLANE COORDINATE (THOUSANDS OF FEET)
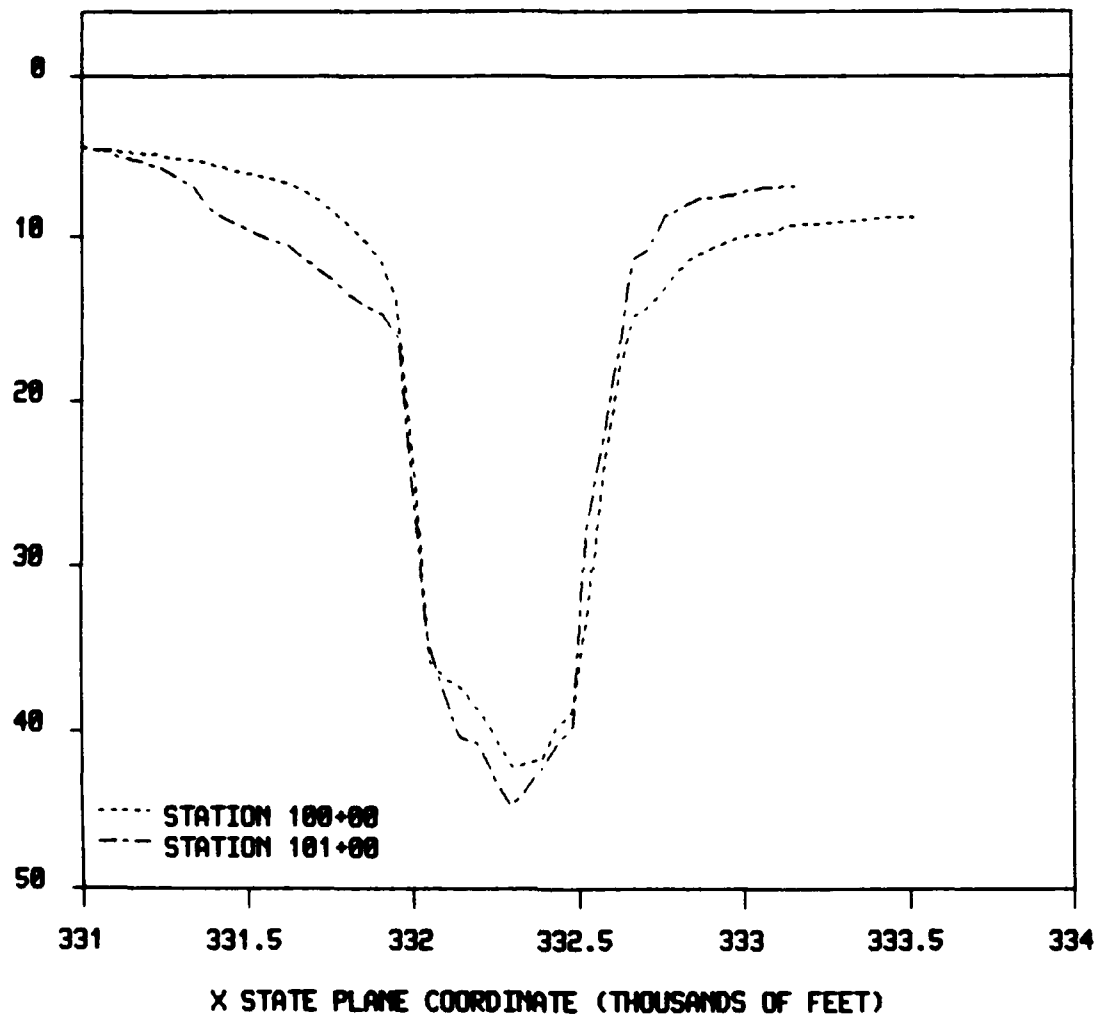
Figure 6. Channel cross sections

used for the anchorage area and turning basin in the proposed channel scenario. Sketches detailing the channel definition of terms and showing the method of schematizing are given in Figure 7. Results of the channel data base setup are shown in Figure 8 for both the existing and proposed channel configurations.

Current data

23. Currents are among the most important scenario input data because of the strong influence of those forces on ship controllability in Mobile Harbor. The Mobile Bay scale model at WES was used to generate a number of surface tide current patterns using overhead cameras located over the study area. Time-exposure photographs were made of floating confetti with a strobe flash at the end of the exposure to indicate current direction and magnitudes. Figure 9 presents the photographs that were used to develop the current magnitudes and direction for input into the simulator data base. The model test runs were conducted with mean Gulf tide (2.3-ft range at Dauphin Island) and a high Mobile River flow of 116,000 cfs. Test runs were made for both the existing and proposed channel conditions. The resulting current data used in the simulations are shown in Figure 10.

24. An inbound ship transit was used for the simulations because pilots indicated that ship control problems were much more severe during inbound transits, especially in cases when ships have maximum loads. An ebb tide current was selected for ship simulations since flood currents in the project area were only about 0.5 fps or less. A study of hourly tide current magnitudes from the confetti photographs as well as data from previously published scale-model study reports showed that maximum ebb current occurred at about tidal hour 18 over the study area. Current magnitude and direction data were obtained at a number of channel locations from the photographs at maximum ebb current conditions. These data were used as the input current data for all ship simulations.

Visual scene

25. The visual scene data base was created from the same maps and charts noted in the discussion of the channel data source. In addition, the location and height of the three highest buildings in downtown Mobile and the cranes and water towers located on Pinto Island were obtained from the District. Color photographs taken during the reconnaissance trip aboard a bulk carrier on the inbound transit into Mobile Harbor were invaluable in visual

17

SAILING
DIRECTION

€ CHANNEL

CHANNEL TOP WIDTH

OVERBANK
DEPTH

CHANNEL DEPTH

OVERBANK
DEPTH

PORT BANK

SLOPE
ANGLE

SLOPE
ANGLE

STARBOARD BANK

CHANNEL BOTTOM WIDTH

NAVIGATION CHANNEL DEFINITION SKETCH

MAIN SHIP CHANNEL

ARLINGTON
CHANNEL

DOCKED
SHIP

PORT

STARBOARD

MCDUFFIE
ISLAND
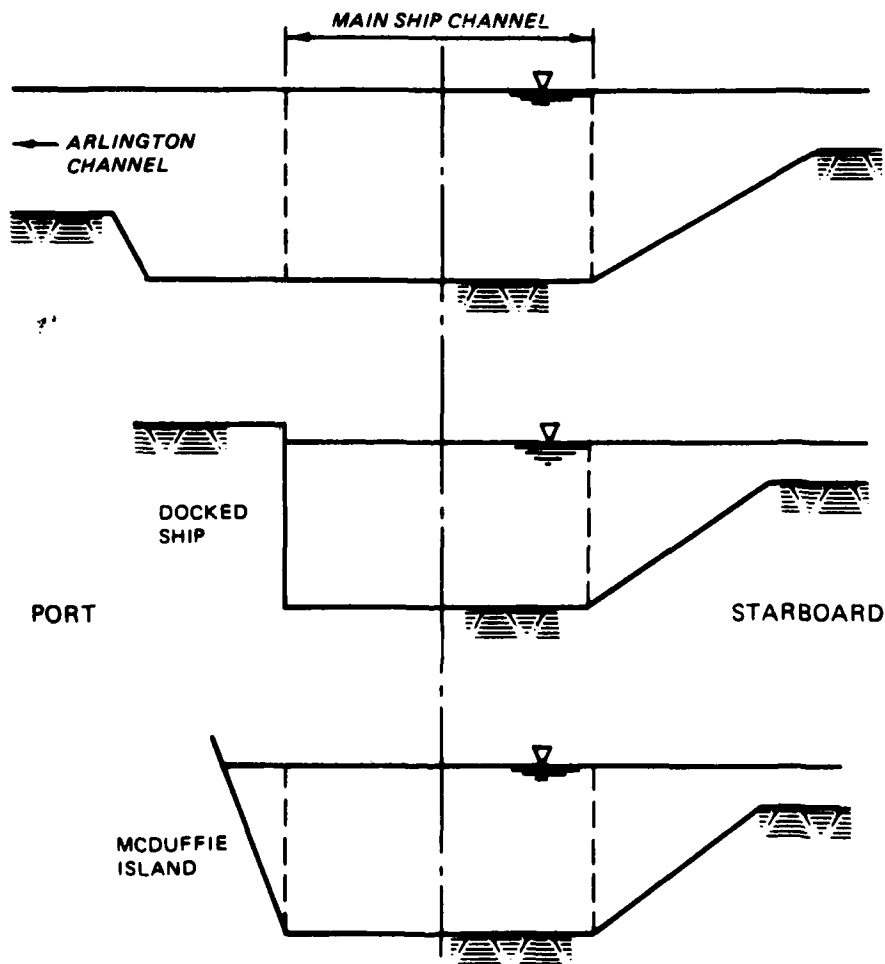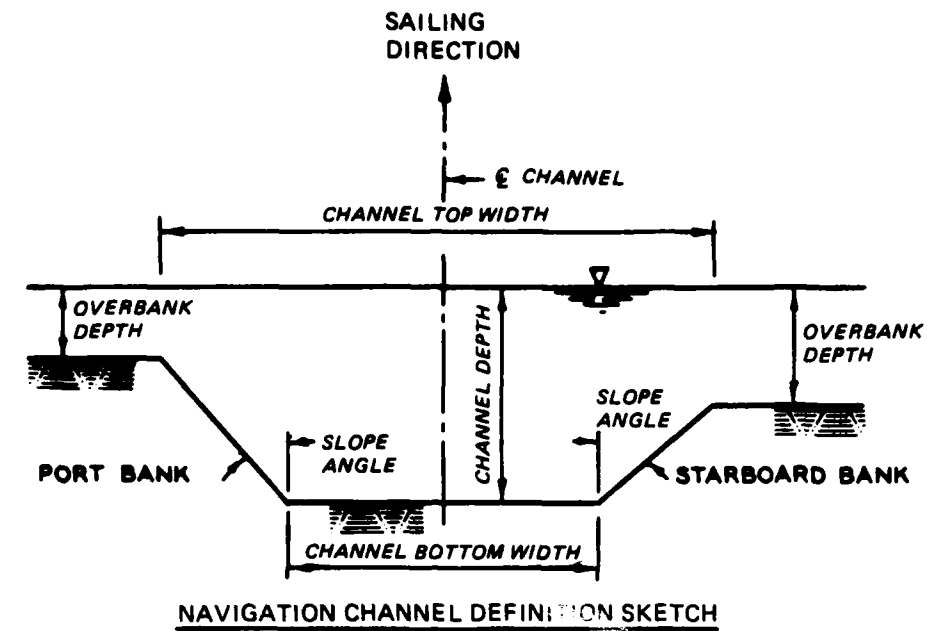
EXAMPLES OF SCHEMITIZATION

Figure 7. Channel cross-section schematization

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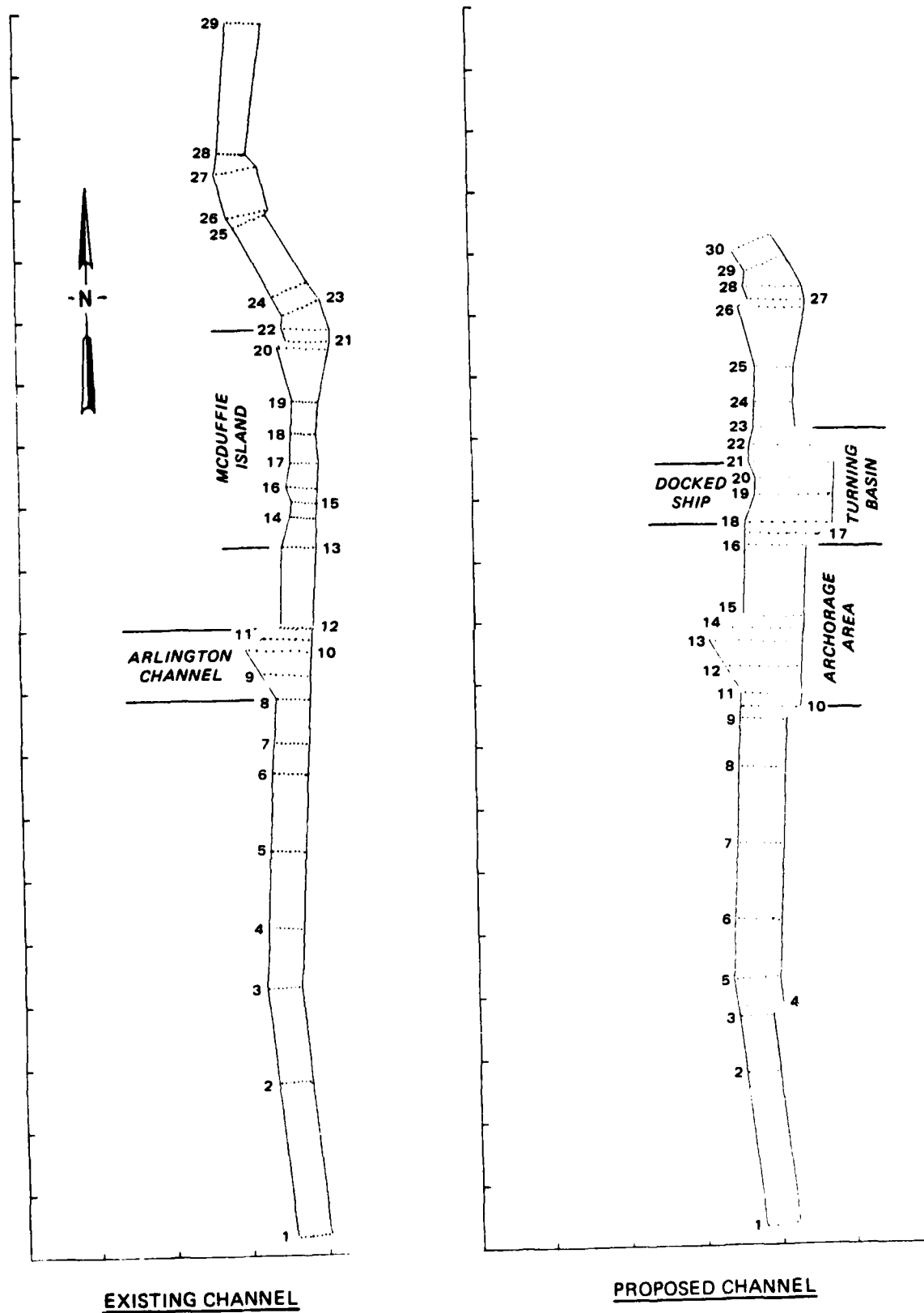
Figure 8. Channel definition and cross sections

EXISTING CHANNEL

PROPOSED CHANNEL

19

EXISTING CHANNEL

PROPOSED CHANNEL

Figure 9. Tide currents in navigation channel; flow 116,000 cfs, maximum ebb tide

20

EXISTING CHANNEL   PROPOSED CHANNEL
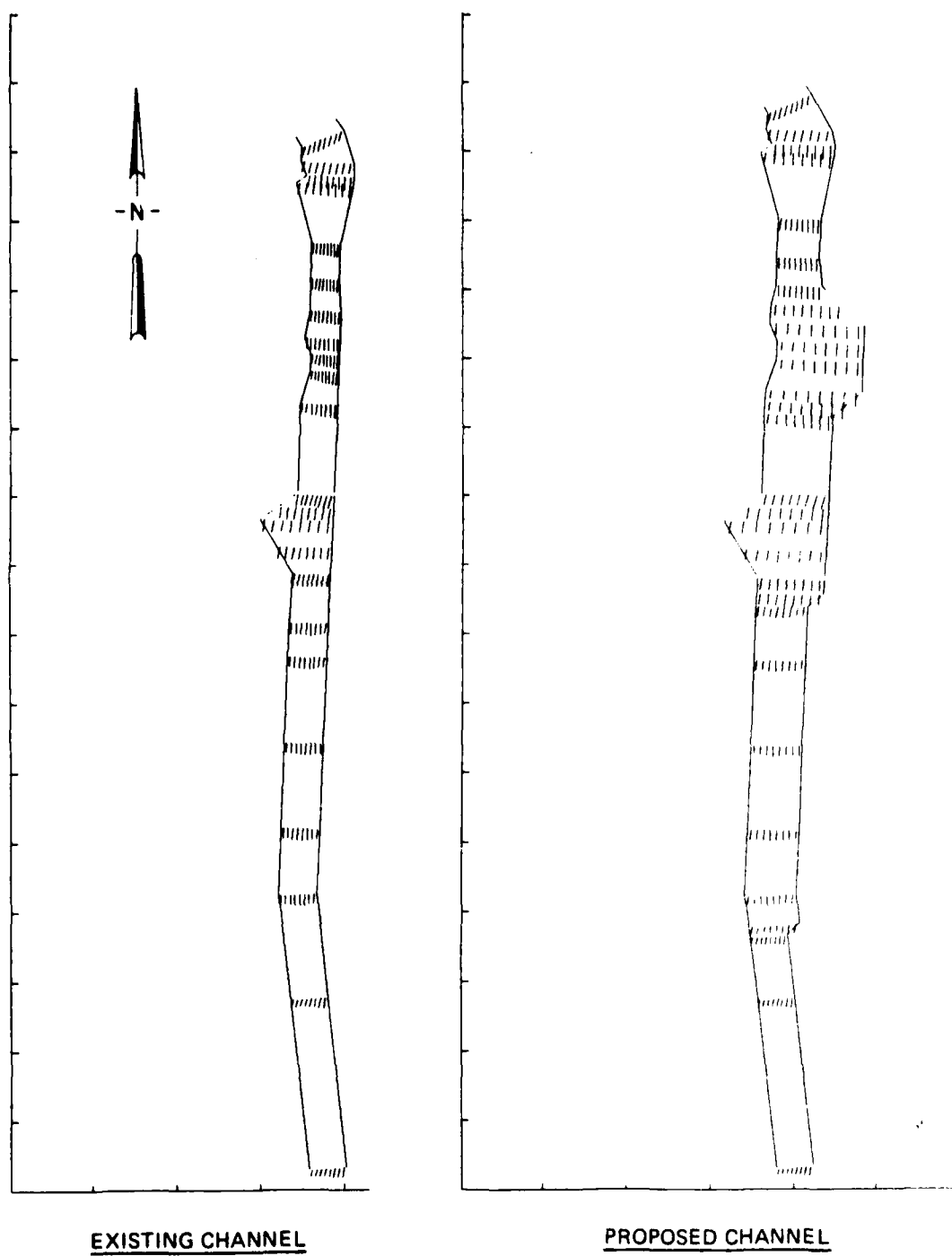
Figure 10. Channel current conditions used for simulation

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scene development. The video taping of that same trip from the bulk carrier
bridge was used extensively to check the validity of the visual data base.
Figure 11 shows one of the photographs obtained during the inbound trip that
was used to create the visual data base.

26. All aids to navigation such as buoys, channel markers, and beacons
were included in the visual scene. Other data included the docked ship at the
McDuffie Island terminal, the main coal loading equipment, the coal pile on
the island, and the previously noted buildings and cranes.

27. It may be noted that the creation of a scenario for a project area
is very demanding in terms of ship hydrodynamics and hydraulic engineering
judgment. The visual scene portion of the scenario is especially time-
consuming, since much of that development can only be done by trial and error.
The goal of the scenario is to provide all the required data without excessive
hydraulic or visual clutter, bearing in mind the finite memory storage and
computational resources available on the minicomputer. A photograph of the
resulting visual scene from the simulated ship bridge is presented as Fig-
ure 12, and a plan view of the visual representation of the area is shown in
Figure 13.

Test Ship

28. The ship used in the simulations was a bulk carrier sized to a
draft of 36 ft for transiting the existing channel and the proposed widened
channel, both with the existing 40-ft depth. The ship used for this study was
actually a modification of a ship used in a previous study and for which the
required characteristics and coefficients had been determined. The base ship
used to develop the 63,000-dwt bulk carrier was an available 87,000-dwt oil
tanker with a full loaded draft of 40 ft. It was quite feasible to develop
the bulk carrier test ship from a tanker because of the close similarity of
the design fairing lines of both ship types. The bulk carrier test ship
dimensions were calculated using the geosim methodology of reducing the ship's
physical dimensions by the proportion of the ship's draft (i.e. 36 to 40 ft).
This preserves the main geometrical ratios of the ship and ensures the simi-
larity of hydrodynamic coefficients and thus ship behavior. In addition to
the ship dimensions, the ship mass and moment of inertia were modified to
properly reflect the change in ship size. The table below presents the

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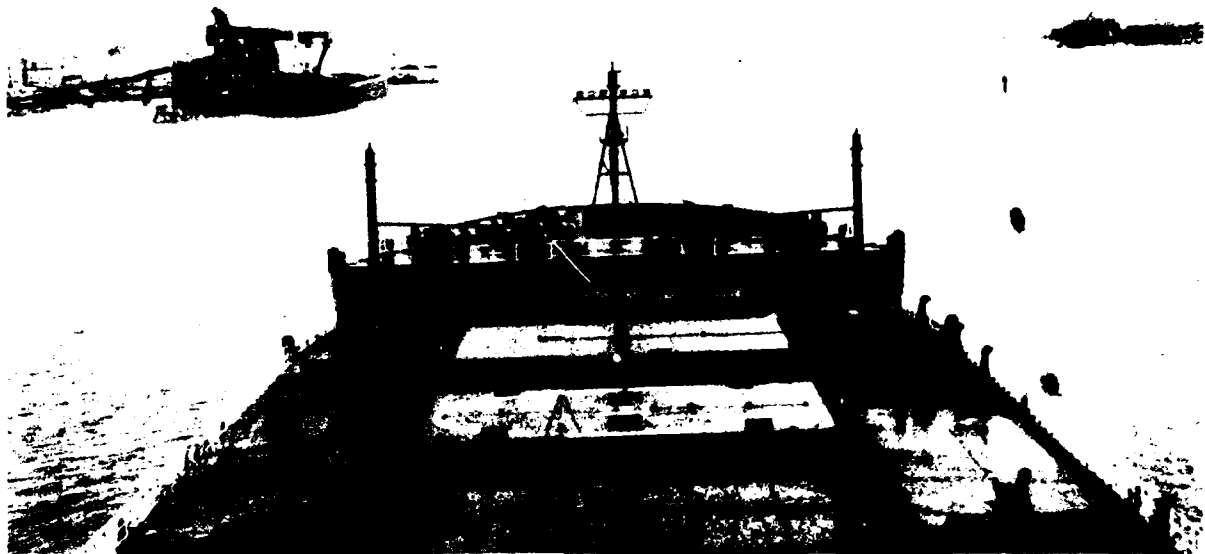
Figure 11. View from bulk carrier ship bridge
approaching docked coal collier at McDuffie Island
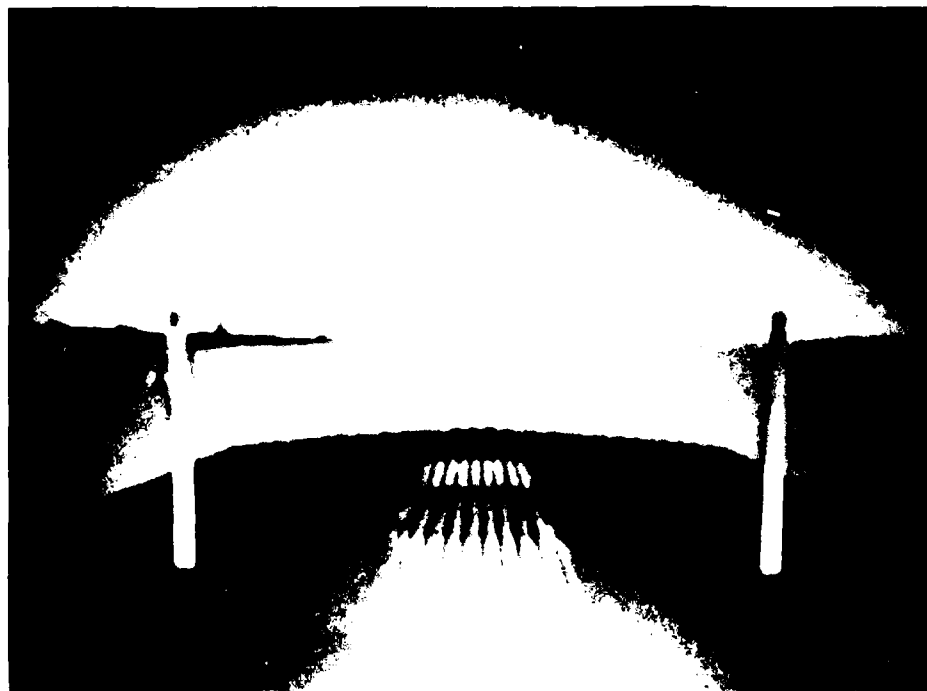
Figure 12. Ship simulator view

23
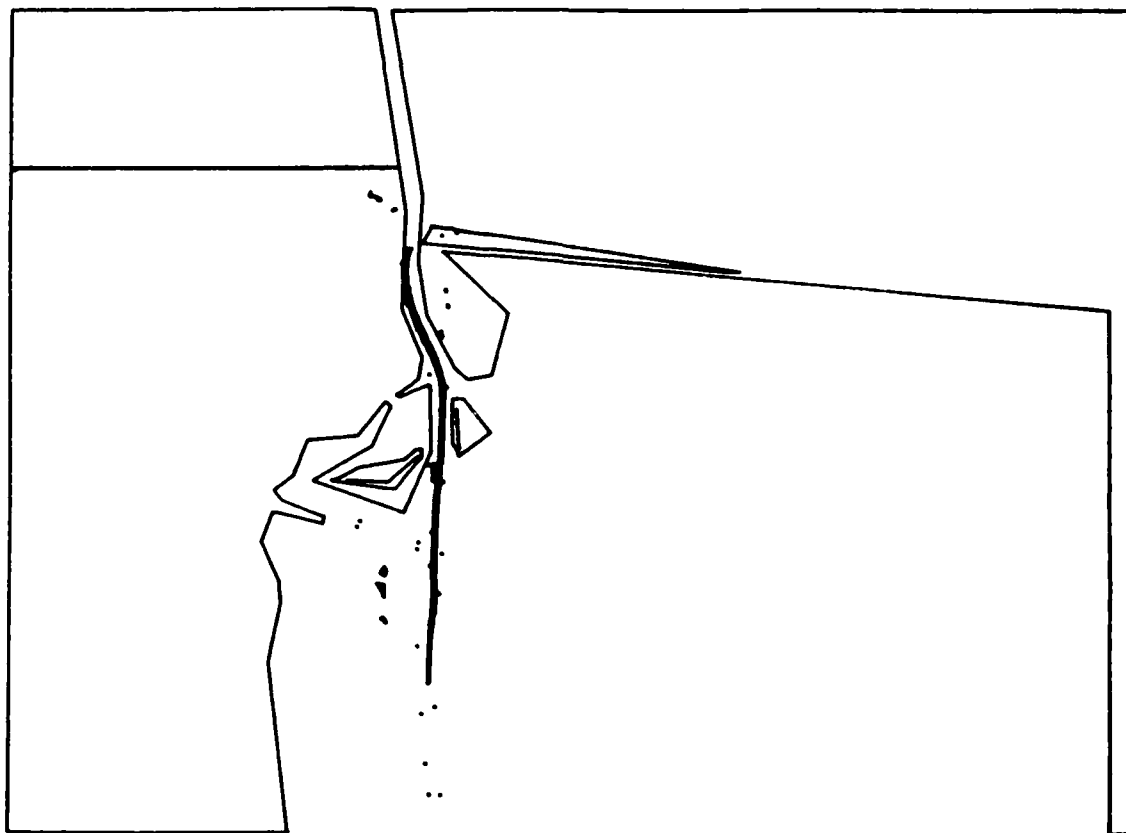
Figure 13. Study area limits of visual scene showing
main features and typical ship path

results of this analysis and the derived ship particulars of the simulated
test ship.

Characteristics	Ratio	Displacement, dwt	
		87,000	63,000
Length, ft	36/40	763	685
Beam, ft	36/40	125	112
Draft, ft	36/40	40	36
Mass slugs	$(36/40)^3$	0.60627E+07	0.43892E+07
Inertia, sq-ft slugs	$(36/40)^5$	1.867E+11	1.0894E+11
Length/beam	1.00	6.10	6.10
Beam/draft	1.00	3.12	3.12
Length/draft	1.00	19.08	19.08
Block coefficient	1.00	0.802	0.802

Test Procedure

29. Each simulator trial consisted of an inbound test run with the 63,000-dwt bulk carrier against a mean peak ebb tide current. At the start of the test, the ship was located at midchannel and was proceeding on the course of the channel at about 6 knots. Most of the runs were initiated at the southern extremity of the scenario and involved hands-on steering of the ship past the docked ship at the coal loading terminal. About one-fourth of the tests were initiated about halfway into the scenario 4,000 ft south of the most critical part of the study area (the area around the Arlington Channel and McDuffie Island Dock) in order to save on simulation time. All WES engineer-pilots required some practice runs before recording data. Data accumulation was started and test trials repeated so as to provide at least five test runs per pilot.

30. A total of 32 trials were conducted with 5 pilots. The pilots are identified as follows:

   a. An autopilot that controlled the ship rudder based on course deviation, distance from channel center line, and other similar control parameters.

   b. An active professional Mobile Bay pilot with a number of years of piloting experience into Mobile Bay onboard a variety of ship types and sizes.

   c. WES2 was an experienced engineer with a good comprehension of ship hydrodynamics but no ship piloting experience.

   d. WES4 was a new engineer familiar with hydrodynamics without any pilot experience.

   e. WES3 was a computer programmer with a good overall knowledge of the ship simulator, but naive about ship piloting.

PART V: VALIDATION TESTS

31. On 31 August 1983, the Mobile Bay scenario as set up on the WES Ship Simulator was checked out with the help of an experienced bay pilot. These tests were especially critical because the simulator had not been previously validated for ship simulations. The tests were made to ensure the integrity of the visual scene, that the channel was correctly schematized to properly simulate bank-suction forces, and that the crosscurrent effects gave correct ship response.

32. Three full test runs were completed which consisted of two base channel conditions and one test with the widened channel and the anchorage area and turning basin in place. Two other tests were partially completed but equipment failures aborted these runs prematurely. The first test was terminated after running aground north of Arlington Channel and was considered to be a training run.

33. During the test runs, the bay pilot observed that the simulator seemed to respond the same way as a real ship in the Mobile Harbor channel. Bank suction "felt" realistic during the inbound run as the channel overbank depths decreased to only about 3 ft. According to the pilot, the effect from Arlington Channel and the docked ship at the coal terminal was very similar to the real ship. Crosscurrent effects near Little Sand Island caused the ship to respond as expected. The visual scene had all the essential cues without excessive information.

34. Several suggestions were made to improve the simulator as follows:

   a. The ship engine control should be on or near the ship steering stand. The engine settings should be unique and similar to those of a typical ship (full ahead, corresponding to 80 rpm, etc.).

   b. The rudder indicator response was slow. It should be rewired so as to correspond to the rudder command, rather than the actual rudder position.

35. The pilot concluded that "The ship simulator that [WES has] built is very impressive and I wholeheartedly agree that it will be a great asset in channel design."

PART VI: TEST RESULTS

36. A summary of all tests analyzed is shown in Table 4. Plotted output data for each test are presented in Appendix A. Five plots are presented for each test:

a. A ship track plot of the upper part of the scenario with channel edge boundaries, shorelines, and channel markers.

b. Four data plots of the ship parameters resulting from the tests as a function of distance along the channel, including rudder setting (also labeled as rudder position in the plots), distance off channel center line, ship starboard and port clearance to the channel edges, ship speed and engine rpm settings, and ship heading.

c. Each plot also shows four small circular location markers along the horizontal grid depicting the scenario start, the channel right turn, the entrance to the Arlington (side) Channel, and the docked ship at the coal terminal.

The plots in Appendix A are grouped according to test sequence and by individual pilots controlling the ship. In addition, selected comparative graphs of base and proposed channel test results will be presented as figures in the report and discussed below.

37. Table 4 also presents a key for test condition identification and a cryptic summary of test outcome. Of the 30 human-piloted runs, 15 were classed as OK, i.e. could be considered satisfactory. As the table shows, two runs were aborted by equipment failure. The 13 unsatisfactory runs were classified as to severity of failure with 4 runs banked where the ship strayed a slight amount out of the channel boundary. The remaining nine tests showed the ship either went aground and the test terminated or went substantially out of the channel boundaries (grounded). A study of each of the pilot's test sequences showed evidence of substantial elements of learning or of ship control improvement. In the following discussion of test results, the tests conducted by each pilot will be summarized. These summaries will then be followed by a comparative narrative of base tests and the proposed channel test conditions.

Autopilot Tests

38. The base test results with the existing channel (Test 1) show that the autopilot keeps very tight control of the ship so that distances off

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channel center line do not exceed 50 ft (Figure A1b). The greatest deviation from the center line occurs immediately north of the Arlington Channel and tends to draw the ship to the left side of the main channel. The docked ship at the coal terminal causes ship interaction forces which tend to push the inbound ship toward the right side of the main channel. Channel edge port and starboard clearances (Figure A1c) are generally equal to or greater than one ship beam (112 ft), with two locations where the clearance drops to about 75 ft. The rudder settings used by the autopilot are typically 20 degrees or less. The ship engine setting (Figure A1d) is constant at 60 rpm with a resulting speed of 6 knots. Results from the four perturbations at the beginning of the scenario, at the small right turn, at Arlington Channel, and at the docked ship at the coal terminal are all clearly apparent from the data.

39. Results from Test 2 with the proposed channel design show very similar ship response as compared with the base test conditions. Smaller distances off the channel center line occurred in the 650-ft-wide channel, with a maximum of 35 ft (Figure A2b). Slightly smaller rudder activity was used by the autopilot in the wider channel. The turning basin and anchorage area obviously provide much wider clearances than the 400-ft-wide base channel condition.

Professional Pilot

40. The first test in the pilot series (Test 3) was an initial trial run using a steersman under pilot orders. All other tests were with the individual pilot acting as steersman and in control of the ship. Results of Test 3 are shown in Appendix A, but will not be discussed further because of the different methods of ship control noted above.

41. Results of the second test in the pilot series (Test 4) showed some preference for the right side of the channel with maximum distance off channel center line (Figure A4b) to about 50 ft. Clearance to the right edge of the channel decreased to 20 ft after negotiating the small 7-degree right turn. Rudder activity (Figure A4d) in the straight reaches of the channel averaged about 20 degrees, but the maximum of 35 degrees was used at the beginning of the test run and again at the small right turn. Ship speed at the beginning of this run was 6 knots, but increased gradually to about 9 knots as a result of the 100-rpm engine setting. This test ended by a premature abort by the computer.

42. Results of Test 5 indicate that the pilot had good control of the ship at the Arlington Channel, but strayed about 25 ft beyond the right edge of the channel (Figure A5c) near the docked ship at the coal terminal. A much slower engine setting than the previous test resulted in a slower ship speed of about 4 knots. Very large rudder angles (Figure A5d) with several full rudder reverses (full right to full left rudder, or vice versa) were used by the pilot.

43. During Test 6 the test results showed that the pilot began to feel comfortable with the simulator. The strong preference for the right side of the channel is evident, even to the point of grazing the channel edge near the small right turn (see clearance plot, Figure A6c). Ship speeds were down to about 5 knots with engine setting and rudder plots showing the use of kick turns (use of propeller wash from increased rpm to increase flow past rudder) to help in turning the ship. Several rudder settings (Figure A6d) used the maximum available right rudder and much less left rudder activity of about 10 degrees. Results show good control through the Arlington Channel junction. This test was aborted prematurely by the computer.

44. The final base test was Test 8 and showed that the pilot had very good control of the ship. The ship was on the right side of the channel during most of the test, but did not stray out past the channel edge (Figure A8c). Ship speeds were controlled to between 4 and 5 knots and the use of two kick turns is evident from the data (Figure A8d) when the ship was just past Arlington Channel and near the docked ship at the coal terminal. Rudder activity was high with several complete rudder reversals indicating the need for strong correcting maneuvers at Arlington Channel and at the docked ship at the coal terminal.

45. The proposed channel improvements were tested with the pilot in control and these results are presented as Test 7. The wider 650-ft channel provided the pilot much more leeway in controlling the ship and the test results showed that the ship was as close as 25 ft to the right channel edge (Figure A7c). Ship speed was very low, down to about 4 knots. Rudder settings (Figure A7d) were very high with maximum values of 35 degrees predominating during this test. A total of four kick turns were used during this test. It is believed that if there had been time to repeat the design channel test, the pilot would have been able to achieve better ship control in the widened channels without the use of the large rudder angles indicated in the test results.

Pilot WES2

46. The data plots from pilot WES2's base channel test condition are presented as Tests 9-14 in Appendix A. About six previous trial inbound transits had been done prior to Test 9 as training exercises. Results from Tests 9-14 show that WES2 was still learning to pilot the ship, as is evident from the continual improvement in ship control from successive tests.

47. Test 9 results (Figure A9a) indicate a pattern of zigzagging up the channel with several (actual or near) out-of-channel incidents. Control of the ship was lost at Arlington Channel and could not be recovered. Rudder angles (Figure A9d) were generally less than 20 degrees, except at the end of the test when the maximum of 35 degrees was used to try to regain control of the ship. Several kick turns were used, as can be seen from the large number of changes in the engine settings. Ship speeds varied from a high of about 6 to a low of 4 knots.

48. Results shown for Test 10 indicate that pilot WES2 was beginning to anticipate the Arlington Channel and giving the ship several small right kick turns (Figure A10d) to compensate for the left outdraft at the side channel. However, the docked ship was still causing some difficulty, since the sailing ship nearly went out of the channel to the right near the coal terminal. The distance off the channel center line (Figure A10b) was greatly reduced from the previous Test 9. Rudder activity was very similar to the previous test, but fewer kick turns were used in the straight channel segments south of the Arlington Channel. Engine settings and ship speeds were also close to being equal to the previous test.

49. Test 11 results show improved ship control, especially in the straight channel segments. However, the control was lost north of Arlington Channel with the ship being drawn beyond the left edge of the channel (Figure A11c) and then the right edge near the docked ship. This indicates that WES2's piloting strategy was still being perfected near the critical Arlington Channel/docked-ship channel reach. Rudder activity for Tests 10 and 11 appears to be very similar in magnitude and duration for the two tests. Engine rpm settings, however, are quite different, especially as the ship is approaching Arlington Channel. Several kick turns were used for Test 10 with right rudder to keep the ship at or to the right of the channel center line. Test 11 results, on the other hand, do not show that any kick turns were used

prior to Arlington Channel; and consequently, the ship was to the left of the channel center line when approaching the outdraft caused by the Arlington Channel. This shows that the pilot's anticipation of the effects of the Arlington Channel is crucial to good ship control in this channel reach.

50. Tests 12-14 show a trend of continued improvement in ship control performance. A comparison of those three test results shows that it is vitally important that the ship position be to the right of the channel center line upon approaching the Arlington Channel. The excursion out of the channel near the coal terminal for Test 13 shows this quite clearly (Figure A13c). The pattern of rudder and engine settings needed to control the ship through the difficult Arlington Channel/docked-ship region show a very high consistency from test to test. Results from Test 14 can be considered representative of the trials with pilot WES2 (Figures A13d and A14d).

51. Results of ship simulations piloted by WES2 with the proposed channel configuration are presented as Tests 15 and 16 in Appendix A. Results show that piloting the ship in the wider 650-ft channel is much less demanding as compared with the 400-ft-wide base channel test condition. Pilot WES2 apparently took advantage of the larger channel width and allowed larger distances offtrack than for the narrower channel conditions. This did not cause any problems since there was still ample clearance on each side of the channel. Less rudder activity was needed to control the ship, and as shown by the results from Test 16 (Figure A16d), it was possible to negotiate the wider channel with very little use of kick turns. Ship speeds were nearly equal to base test results; it is very likely that ship speeds could have been increased substantially above the typical 5 knots used except when passing the moored ship.

Pilot WES4

52. Results of Tests 17-24 with WES4 in control of the ship and the existing channel conditions are presented as data plots in Appendix A. The learning phase of the tests was quite consistent with results from WES2. Data in the plots from Tests 17-20 when compared with similar plots from Tests 9-11 show a similar zigzag pattern (e.g. Figures A9a and A17a). A number of excursions are well out of the channel limits, even in the straight channel reaches. A dramatically improved pattern of ship control is evident in the

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results from Tests 21-24 (e.g. Figure A21c). The ship is within channel limits and there is evident anticipatory rudder settings south of Arlington Channel. Rudder activity (Figure A21d) is highly consistent from run-to-run and generally not over 20 degrees.

53. The piloting strategy of WES4 which evolved during the test sequences, however, turned out to be different from that of WES2. The ship engine rpm setting was kept fairly constant, with very little use of kick turns. Thus the resulting ship speed was also quite constant at about 5 knots. Rudder settings tended to be somewhat larger than those of pilot WES2 with longer periods of nearly constant rudder.

54. Test 17 indicates that WES4 tried to keep engine rpm nearly constant, but was unable to gain control of the zigzagging ship. WES4 next tried to use kick turns during Test 18, but was still unable to gain control of the ship. Test 19 shows the continued use of kick turns without much improvement. It was apparently during Test 20 that WES4 began to use the nearly constant engine rpm setting strategy, with some resulting improvement in ship control. Test 21 results show good control, so that the ship was never more than 100 ft off the channel center line (Figure A21b). Ship speed was constant at about 6 knots and rudder activity showed a much different pattern in the straight channel reaches as compared with Test 12 results with WES2 doing the piloting (e.g. compare Figures A12e and A21e). The rudder activity at the Arlington Channel through the coal terminal, however, showed quite similar patterns between pilots WES2 and WES4. These results suggest that a variety of combinations of ship engine and rudder settings can achieve equally good ship piloting results in a given navigation channel situation.

55. Results for Tests 21-24 indicate very similar patterns of succesful ship control using a nearly constant engine rpm setting. Rudder activity was also very similar during these tests with maximum rudder angles being about 15 to 20 degrees. These results show that pilot WES4 had devised a very good pilot strategy which was easily repeatable.

56. Tests 25-27 show results of the three runs made with pilot WES4 in control of the ship and with the proposed channel condition. Test 25 shows large deviations about the channel center line, but there was still enough clearance to the edge of the widened channel to accommodate these wide swings (Figure A25b). Constant engine rpm setting was used and ship speed was about 6 knots. Rudder angles were generally less than 20 degrees. Much better ship

control was obtained during Test 26 with less than 100-ft distance (Figure A26b) off the channel center line. Test results were similar to the previous Test 25. Test 27 shows continued improvement in ship control as compared with the two previous inbound simulations. The only difference was a small reduction in engine rpm setting and ship speed.

Pilot WES3

57. The five tests in which test pilot WES3 was in control will now be discussed in order to provide the reader a perspective of the simulator familiarization phase of testing. These tests were conducted and are presented sequentially in Appendix A as Tests 28-32. After an initial practice trial which was terminated without collecting any data, Test 28 results indicate that WES3 was having considerable difficulty controlling the ship. The ship went out of the channel limits (Figure A28c) three times and the run was terminated before reaching Arlington Channel. The ship speed varied from 6 knots at the start of the test to 10 knots at the end. The engine setting (Figure A28d) was at full ahead (110 rpm). Rudder settings were generally less than 20 degrees left and right, except near the end of the test when the maximum of 35 degrees was used in an attempt to regain ship control. The high ship speed caused very strong bank-suction forces that led to piloting difficulties during this test.

58. Results from Test 29 show that pilot WES3 realized that a lower ship speed was necessary to keep the ship in control. The engine setting (Figure A29d) was reduced to about 60 rpm and the ship speed was nearly uniform at about 6 knots. Ship control was maintained fairly easily with only moderate (generally less than 20 degrees) rudder activity until the ship reached Arlington Channel. The strong, unbalanced bank forces at Arlington Channel could not be overcome and the ship went well out of the channel (Figure A29c) on the left side. The overreaction by WES3 is evident from the data and the ship then went almost completely out of the right bank near the coal terminal. The test was then terminated.

59. The next run (Test 30) showed that WES3 could maintain ship control through the critical Arlington Channel/docked-ship segment, even without the use of kick turns. However, very large rudder settings (Figure A30d) are needed to keep the ship in control. This test was a successful run without

straying beyond the channel edges. The engine was set at about 75 rpm and the ship speed at about 6 knots.

60. The last two trials with pilot WES3 (Tests 31 and 32) show that the ship was not in good control, even in the straight channel reaches. Test results show a consistent pattern of zigzagging up the ship channel (e.g. Figures A31a and A32a) with many major bank intrusions. Very large rudder angles were used to try to stop the zigzag behavior, but each correction seemed to lead to overcompensation. Time did not allow pilot WES3 to complete the familiarization process, but the six runs that had been completed suggested that several additional trials would have been required in order to develop an optimum combination of engine and rudder settings. Results also indicated that more trial runs than the other pilot subjects tested would probably have been necessary to develop a consistent pattern of ship control.

PART VII: DISCUSSION OF RESULTS

61. Test results show that a variety of pilot strategies can be used to
successfully navigate the upper Mobile Bay navigation channel in the study
area. Adequate ship control was achieved by the autopilot and by three of the
four tested human-pilots. The two WES engineer-pilot test results show evi-
dence of continued learning, even after several initial training trials. The
professional pilot results are difficult to interpret, possibly due to the
short length of time available for testing. The professional pilot data show
a considerably different pattern with more rudder activity as compared with
the other two human-pilots and the autopilot. This is due, in part, to the
expressed desire of the professional pilot to keep to the right-hand side of
the channel. There are some similarities between the autopilot and the two
WES engineer-pilot rudder command sequences. However, the engine rpm settings
differed between the two WES engineer-pilots and indicated different strat-
egies in use of kick turns.

62. A comparison of the base and proposed channel test conditions for
the four ship pilots will be presented and discussed. Figure 14 gives a com-
parison of ship tracks for the existing and proposed channels. These results
were selected from the many plots given in Appendix A as being representative
of the level of improved control that is possible in the proposed channel as
compared with the existing channel. The autopilot test results in Figure 15
indicate very similar rudder activity for the two channel conditions. The
minimum channel clearance in the vicinity of the docked ship and Arlington
Channel is increased from about 90 to 250 ft in the widened 650-ft channel,
and indicates the relative magnitude of the safety margin gained by the wider
channel. The professional pilot test results shown in Figure 16 indicate
greater (or at least more severe) rudder activity for the proposed rather than
the base channel conditions. Port and starboard channel clearances were dif-
ferent. Possible reasons for this are examined in the previous paragraph.
Figure 17 shows the comparison of test results with WES2 piloting the ship and
indicates somewhat less rudder activity for the proposed channel condition.
Channel edge clearances are increased in the wider proposed channel. Compar-
ison of test results with WES4 piloting the ship is shown in Figure 18 and
suggests different rudder activity but improved channel edge clearance in the
wider, proposed channel.
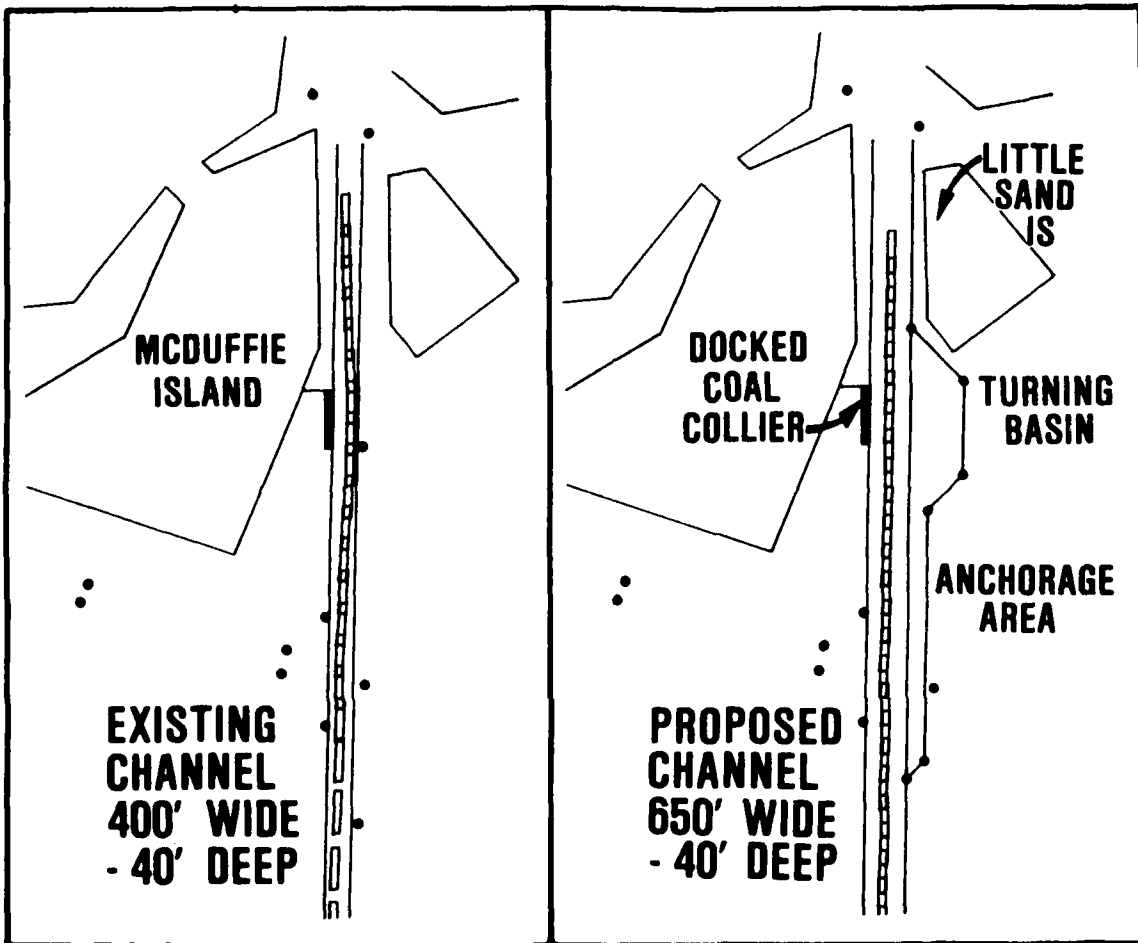
Figure 14. Comparison of ship tracks
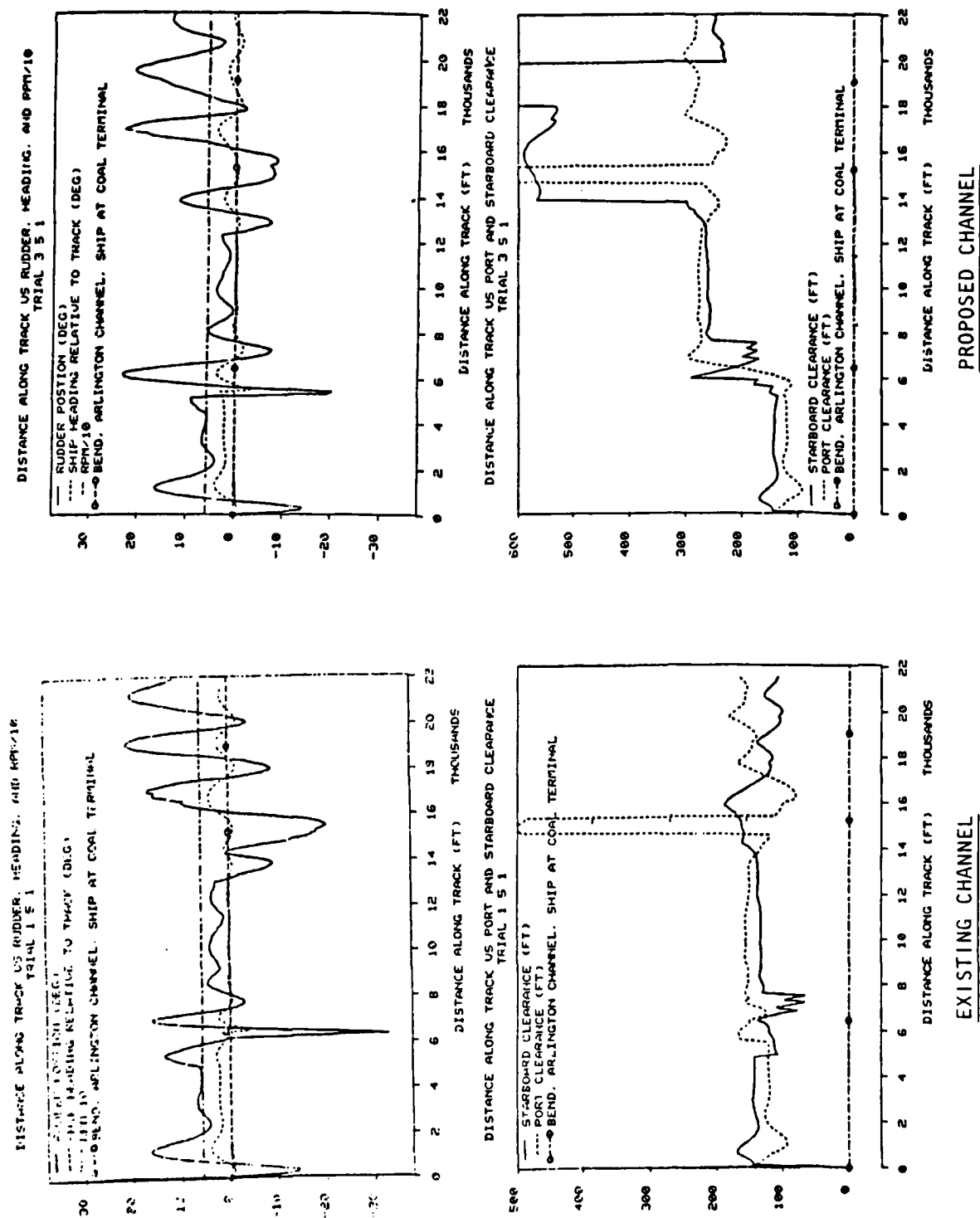
Figure 15. Autopilot tests

PROPOSED CHANNEL

EXISTING CHANNEL

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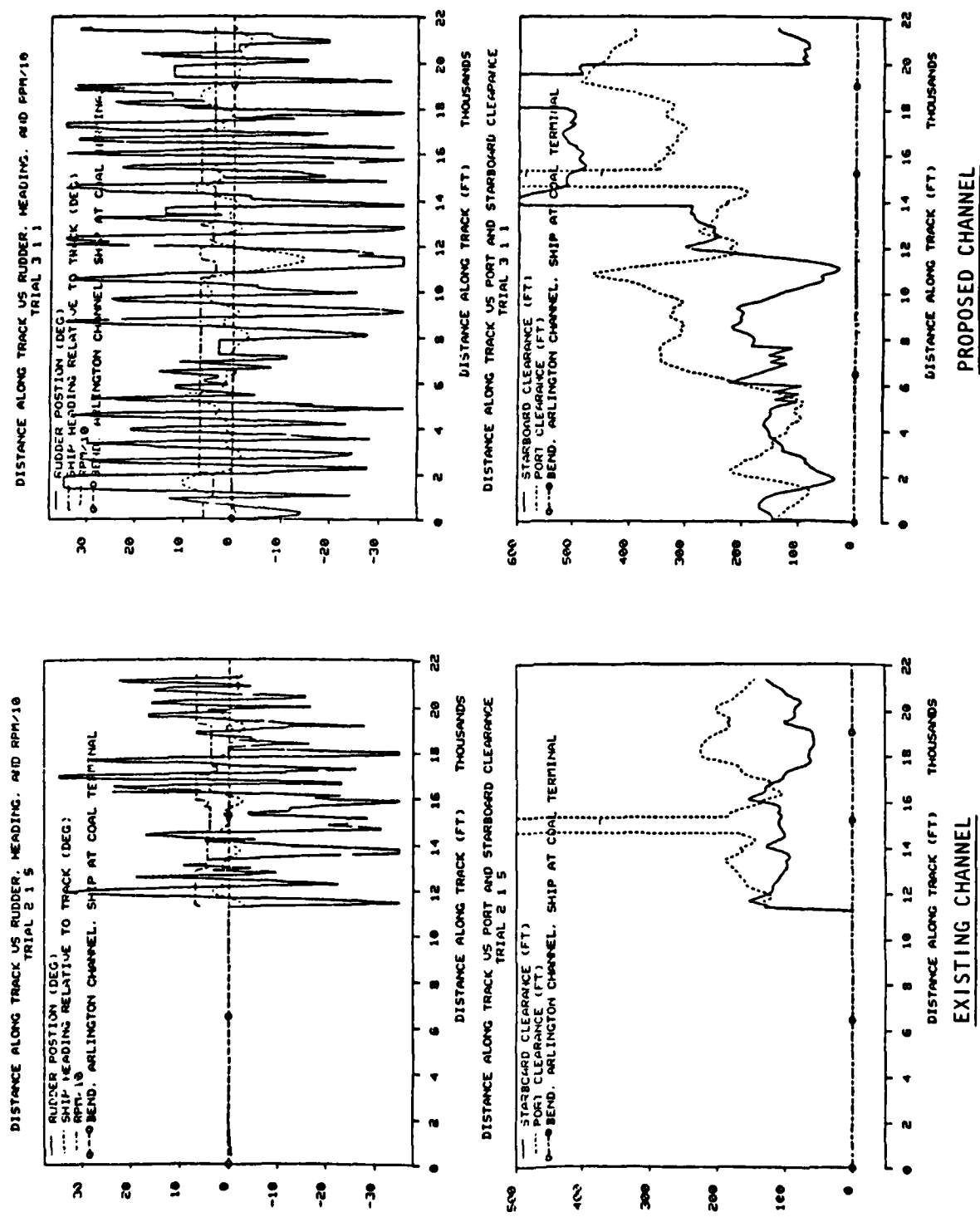
Figure 16. Professional pilot tests

38
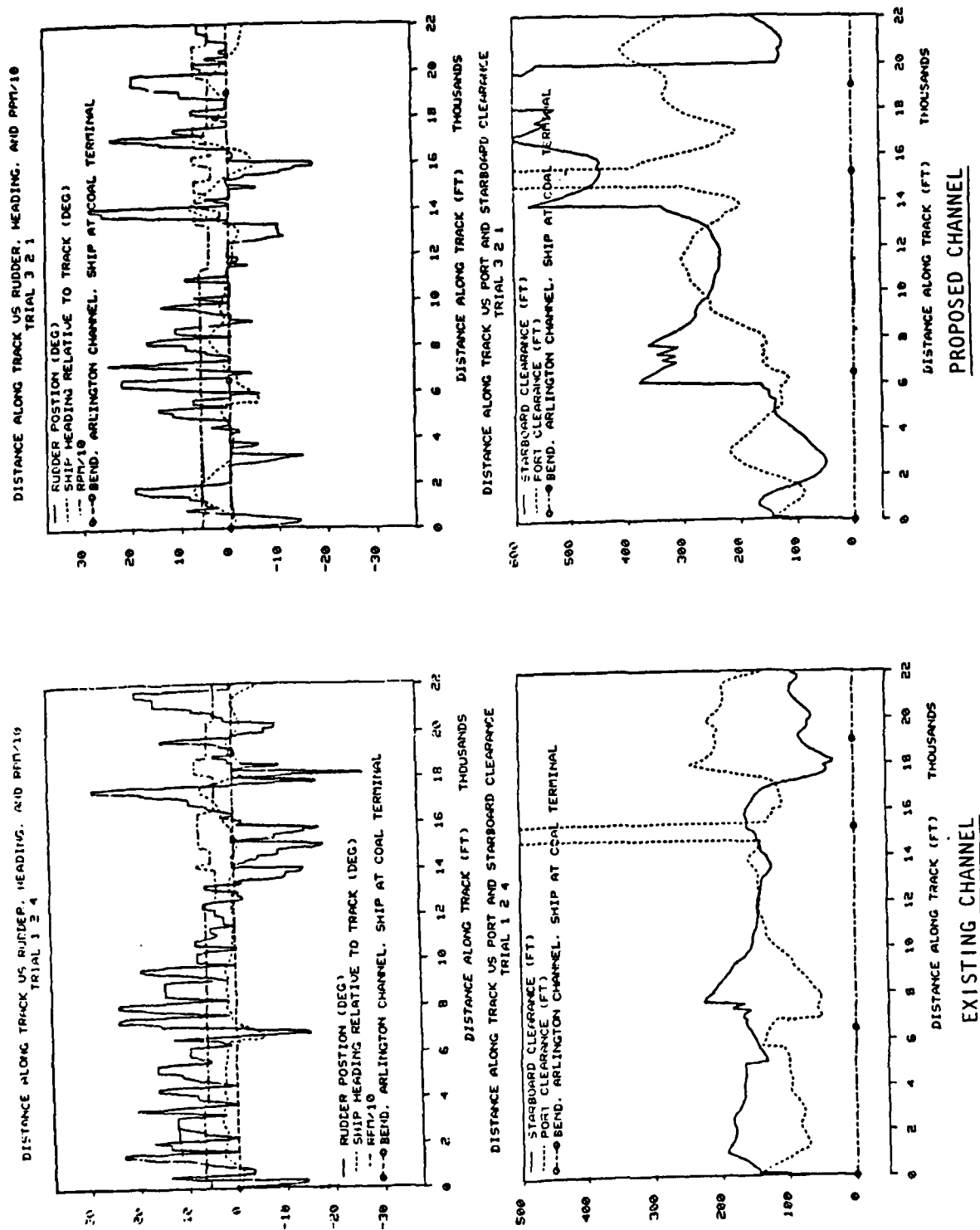
Figure 17. WES2 pilot tests

DISTANCE ALONG TRACK VS RUDDER, HEADING, AND RPM/10
TRIAL 3 4 3

RUDDER POSTION (DEG)
SHIP HEADING RELATIVE TO TRACK (DEG)
RPM/10
BEND, ARLINGTON CHANNEL. SHIP AT COAL TERMINAL

DISTANCE ALONG TRACK (FT)   THOUSANDS

DISTANCE ALONG TRACK VS PORT AND STARBOARD CLEARANCE
TRIAL 3 4 3

STARBOARD CLEARANCE (FT)
PORT CLEARANCE (FT)
BEND, ARLINGTON CHANNEL. SHIP AT COAL TERMINAL

DISTANCE ALONG TRACK (FT)   THOUSANDS

PROPOSED CHANNEL

DISTANCE ALONG TRACK VS RUDDER, HEADING, AND RPM/10
TRIAL 1 4 5

RUDDER POSTION (DEG)
SHIP HEADING RELATIVE TO TRACK (DEG)
RPM/10
BEND, ARLINGTON CHANNEL. SHIP AT COAL TERMINAL

DISTANCE ALONG TRACK (FT)   THOUSANDS

DISTANCE ALONG TRACK VS PORT AND STARBOARD CLEARANCE
TRIAL 1 4 5

STARBOARD CLEARANCE (FT)
PORT CLEARANCE (FT)
BEND, ARLINGTON CHANNEL. SHIP AT COAL TERMINAL

DISTANCE ALONG TRACK (FT)   THOUSANDS

EXISTING CHANNEL

Figure 18. WES4 pilot tests

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PART VIII: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

63. Results of simulation tests with the active Mobile Bay pilot proved
the validity of the simulator visual scene and the method of channel schema-
tization. The pilot's comments during these runs indicated satisfactory bank-
suction simulation at the Arlington Channel and the docked ship at the
McDuffie Island Coal Terminal. Crosscurrent effects near Little Sand Island
corresponded very well with those encountered during inbound ship transits.

64. Very careful pilot control is required to maneuver the ship in the
400-ft-wide channel in the study area. It is necessary to anticipate the ship
response at the Arlington (side) Channel and the docked ship at the McDuffie
Island Coal Terminal in order to avoid grounding or collision. Speed should
also be kept below 5 knots.

65. A reasonable level of proficiency and repeatability was achieved by
two of the WES engineer-pilots after about six training trial runs on the
simulator. Test results from the engineer-pilots were consistent with the
professional pilot runs, although the piloting strategies all were dissimilar.

66. Results of the simulations with the 650-ft-widened channel, the
anchorage area, and the turning basin show that the proposed channel modifi-
cations will provide a greatly increased safety margin in the upper bay study
area. The bank-suction forces on the ship were much smaller at the Arlington
(side) Channel and the docked ship. The proposed project will provide greatly
improved navigation conditions in the upper bay.

Recommendations

67. The transition from the 400-ft-wide midbay channel to the 650-ft-
wide upper bay channel should be located so as to be coincident with the 7-
degree right turn. The start of the transition from the 650-ft-wide channel
to the anchorage area should be located so as to coincide with the Arlington
Channel transition on the west side of the main channel. These two slight
modifications to the proposed improvement plan will minimize the number of
bank-suction force changes on the ship and should help in ship control.

68. During the professional pilot's tests, he suggested that the

turning basin northerly and southerly transitions be modified to 60 degrees instead of 45 degrees to provide longer transitions. A more gradual, tapered transition into the anchorage area was also recommended to improve navigation and reduce shoaling problems. The Mobile District has adopted these suggestions, and they have been included in the channel deepening tests of outbound transits from the McDuffie Island dock at the coal terminal that followed this study. The turning basin and anchorage area configuration developed from the test results, pilot recommendations, and other design considerations, are shown in Figure 19.

69. A more detailed study would be required to further optimize the width of the channel between the existing 400-ft and the proposed 650-ft channel. The geometric design of the anchorage area and the turning basin could also be optimized in order to minimize dredging consistent with navigation requirements.
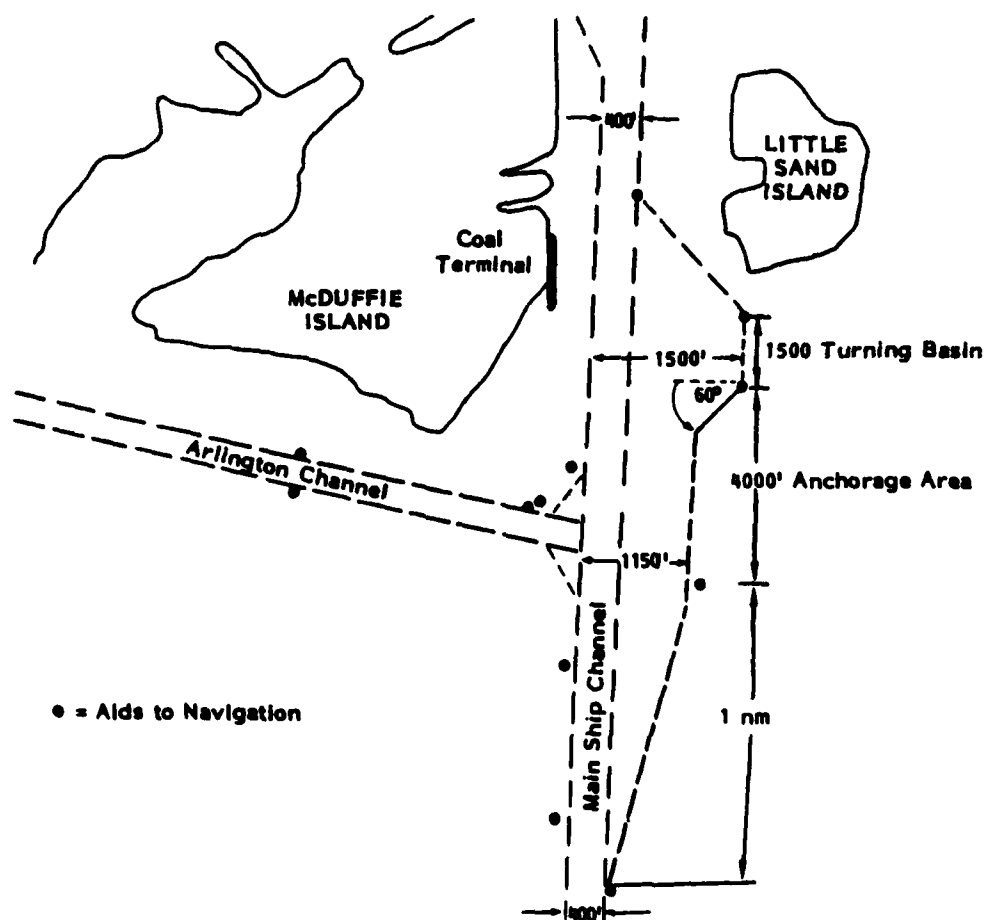
Figure 19. Proposed turning basin and anchorage

Table 1

Navigation Channel Data

Ship Simulator Study

Channel Segment	Beginning Y (Eastings)	Beginning X (Westings)	Bearing	Heading deg-min-sec	Heading degrees	Length to Next PI or Reach	Nominal Width, ft	Notes
Upper Reach #1	338173.07	162344.19	N 05°16'33" W	354°43'27"	354.724	56696.00	400	PI #1 at Mid Bay Reach
Upper Reach #1A	332959.80	218800.00	N 05°16'33" W	354°43'27"	354.724	6454.96	400	South Scenario Bndry
Upper Reach #2	332366.26	225227.61	N 02°04'41" E	002°04'41"	2.078	17925.38	400	PI #2 near Buoy #74
Pinto Reach #1	333016.27	243141.20	N 26°36'09" W	333°23'51"	333.398	3160.00	700	PI @ Pinto Island
Pinto Reach #2	331613.15	245927.61	N 12°26'18" W	347°33'42"	347.562	1428.20	775	
Mobile River	331309.83 331564.75	247323.23 251474.69	N 03°51'38" E	003°51'38"	3.861	4159.28	600	End Channel Data

Table 2
Inbound Transit into Mobile Harbor
20 June 1982

Time CDT	Channel Marker	Engine Setting	Rudder Angle degrees	Pilot Order	Notes
10:11	72	Dead slow	9 Left		Start scenario
10:11-1/2			0		
10:12-1/2			6 Left		
10:14		Slow	0		
10:15			5 Right		Start turn
10:17			10 Right		
10:17-1/4	74		20 Right		
10:18				Midship	
10:19				Steady	
10:20			5-10 Right		
10:22			10 Right		
10:23	76		10 Right		
10:25		Dead slow	10 Right		
10:30		Slow	10 Right		
10:31	78				Arlington Channel
10:32			15 Right		
10:36	82	Dead slow	8 Right		
10:36-1/2			18 Right		Docked ship
10:37			0		
10:37-1/2			9 Right		
10:38			20 Right		
10:40-1/2			0-5 Left		
10:42			5 Left		
10:43			10 Right		
10:44			0		
10:45			10 Right		
10:45-1/2		Slow	10 Left		Start turn
10:45-3/4	84		20 Left		
10:46-1/4		Dead slow		Midship	
10:48				Steady	

Table 3

Channel Schematization

	Proposed Channel							Existing Channel							
				Overbank Depth		Channel Side Slope Angle					Overbank Depth		Channel Side Slope Angle		
Section No.	Bottom Width	Section Azimuth	Port	St'bd	Port	St'bd	Section No.	Bottom Width	Section Azimuth	Port	St'bd	Port	St'bd	Remarks
1	400	84.724	6	12	79	79	1	400	84.724	6	12	79	79	Start scenario
2	400	84.724	6	10	79	79	2	400	84.724	6	10	79	79	Start widening
3	400	84.724	6	10	79	79	3	400	86.323	5	9	79	79	Channel turn
4	650	84.724	6	10	79	79	4	400	92.078	5	8	79	79	
5	650	86.323	5	9	79	79	5	400	92.078	4	8	79	79	
6	650	92.078	5	8	79	79	6	400	92.078	4	7	79	79	
7	650	92.078	4	8	79	79	7	400	92.078	4	7	79	79	Start anchorage area
8	650	92.078	4	7	79	79	8	400	92.078	8	6	79	79	Arlington Channel
9	650	92.078	4	7	79	79	9	775	92.078	16	6	79	79	Arlington Channel
10	950	92.078	6	7	79	79	10	1,150	92.078	22	6	79	79	Arlington Channel
11	950	92.078	8	6	79	79	11	775	92.078	16	6	79	79	Arlington Channel
12	1,325	92.078	16	6	79	79	12	400	92.078	8	6	79	79	Arlington Channel
13	1,700	92.078	22	6	79	79	13	400	92.078	4	4	79	79	Start turning basin
14	1,325	92.078	16	6	79	79	14	400	92.078	2	6	0	79	Docked ship
15	950	92.078	8	6	79	79	15	400	92.078	0	6	0	79	Docked ship
16	950	92.078	4	4	79	79	16	400	92.078	0	6	75	79	Docked ship
17	1,225	92.078	4	4	79	79	17	400	92.078	0	6	60	79	End turning basin
18	1,500	92.078	4	4	79	79	18	400	92.078	0	12	60	75	
19	1,500	92.078	2	6	0	79	19	400	92.078	0	12	60	75	
20	1,500	92.078	0	6	0	79								
21	1,500	92.078	0	6	75	79								
22	1,075	92.078	0	6	75	79								
23	650	92.078	0	6	60	79								
24	650	92.078	0	12	60	75								
25	650	92.078	0	12	60	75								

(Continued)

Table 3 (Concluded)

Proposed Channel

Section No.	Bottom Width	Course Azimuth	Overbank Depth Port	Overbank Depth St'bd	Channel Side Slope Angle Port	Channel Side Slope Angle St'bd
26	650	92.078	0	12	85	85
27	720	92.078	24	12	85	85
28	770	92.078	24	12	85	85
29	820	63.398	24	0	60	70
30	700	63.398	27	0	85	60

Existing Channel

Section No.	Bottom Width	Course Azimuth	Overbank Depth Port	Overbank Depth St'bd	Channel Side Slope Angle Port	Channel Side Slope Angle St'bd	Remarks
20	400	92.078	0	12	85	85	Choctaw Channel
21	470	92.078	24	12	85	85	End widening
22	585	92.078	24	12	85	85	
23	820	63.398	24	0	60	70	
24	700	63.398	27	0	85	60	
25	700	63.398	20	0	60	60	
26	775	77.562	0	25	45	85	
27	775	77.562	0	25	45	85	
28	600	93.861	0	25	45	45	
29	600	93.861	0	25	45	85	End scenario

Table 4

Ship Simulation Trials

Test No.	Pilot	Trial Code			Channel Condition		Type of Run		Outcome
					Existing	Proposed	Complete	Partial	
1	Auto	1	5	1	X		X		OK
2	Auto	3	5	1		X	X		OK
3	Pilot	1	1	1	X		X		Aground
4	Pilot	1	1	2	X		X		Aborted
5	Pilot	2	1	3	X			X	Banked
6	Pilot	1	1	4	X		X		Aborted
7	Pilot	3	1	1		X	X		OK
8	Pilot	2	1	5	X			X	OK
9	WES2	1	2	1	X		X		Aground
10	WES2	1	2	2	x		x		OK
11	WES2	1	2	3	X		X		Banked
12	WES2	1	2	4	X		X		OK
13	WES2	2	2	5	X			X	Banked
14	WES2	2	2	6	X			X	OK
15	WES2	3	2	1		X	X		OK
16	WES2	3	2	2		X	X		OK
17	WES4	1	4	1	X		X		Grounded
18	WES4	1	4	2	X		X		Grounded
19	WES4	1	4	3	X		X		Grounded
20	WES4	1	4	4	X		X		Banked
21	WES4	1	4	5	X		X		OK
22	WES4	1	4	6	X		X		OK
23	WES4	2	4	7	X			X	OK
24	WES4	2	4	8	X			X	OK
25	WES4	3	4	1		X	X		OK
26	WES4	3	4	2		X	X		OK
27	WES4	3	4	3		X	X		OK
28	WES3	1	3	1	X		X		Aground
29	WES3	1	3	2	X		X		Aground
30	WES3	2	3	3	X			X	OK
31	WES3	1	3	4	X		X		Grounded
32	WES3	1	3	5	X		X		Grounded

Note: OK indicates a successful inbound test run.

Aground means ship went well out of channel and test stopped.

Aborted refers to unplanned computer halt of run.

Banked means ship went slightly out of channel.

Grounded indicates ship hit bank, but test not halted.

Meaning and use of trial code:

1st column - case; 1 = present channel, 2 = partial run, present channel, 3 = proposed channel

2nd column - pilot code

3rd column - repetition of case for each pilot

APPENDIX A: RESULTS OF SHIP SIMULATIONS
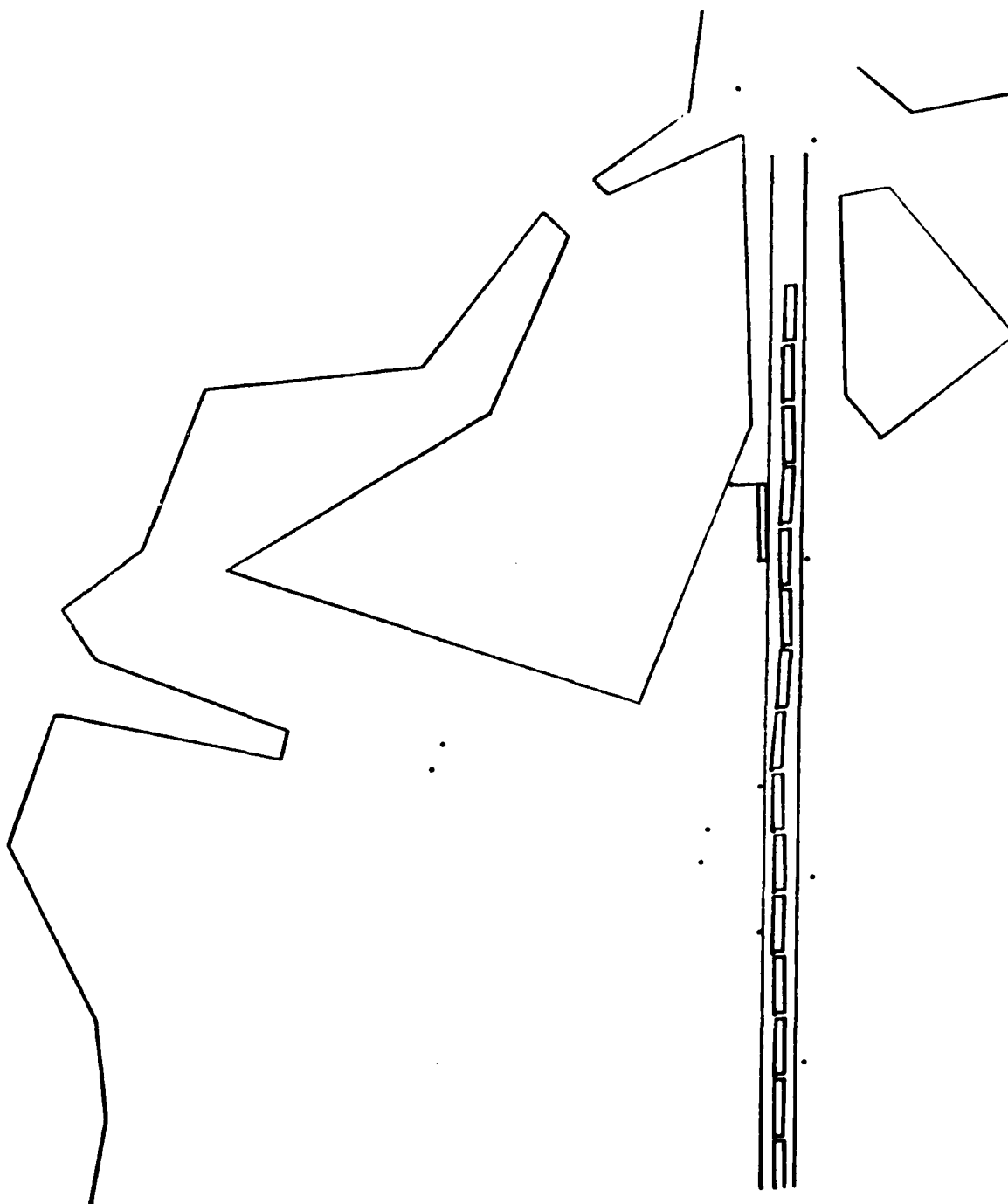
Figure A1a. Ship track for Test 1 (trial 1 5 1)

A2
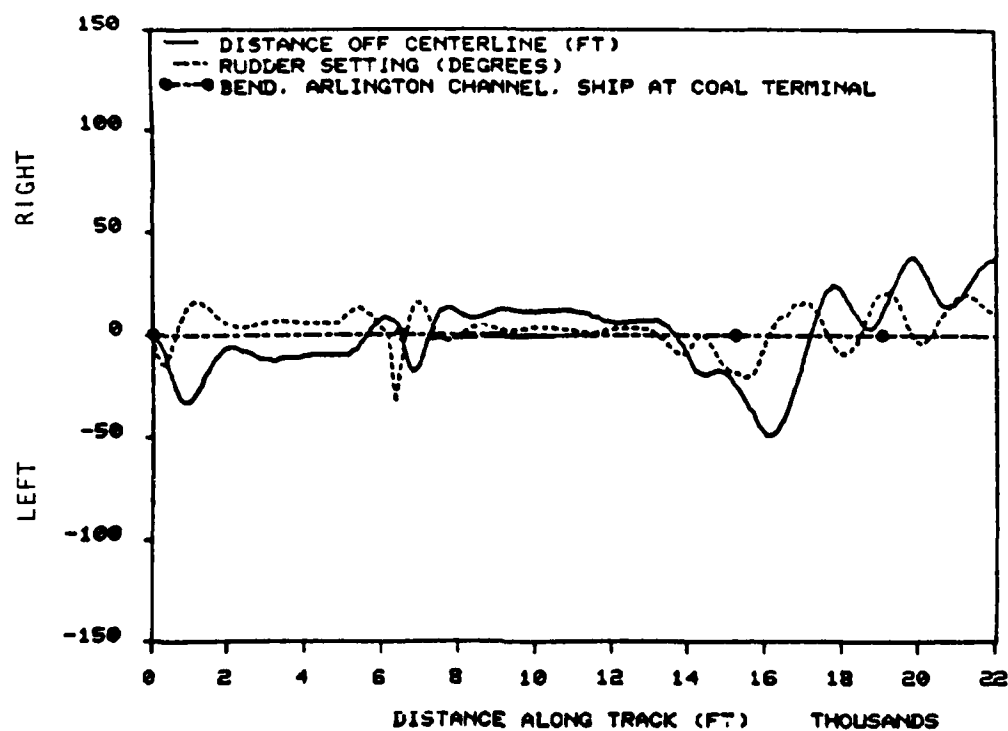
Figure A1b. Distance along track versus rudder setting
and distance off track, Test 1 (trial 1 5 1)
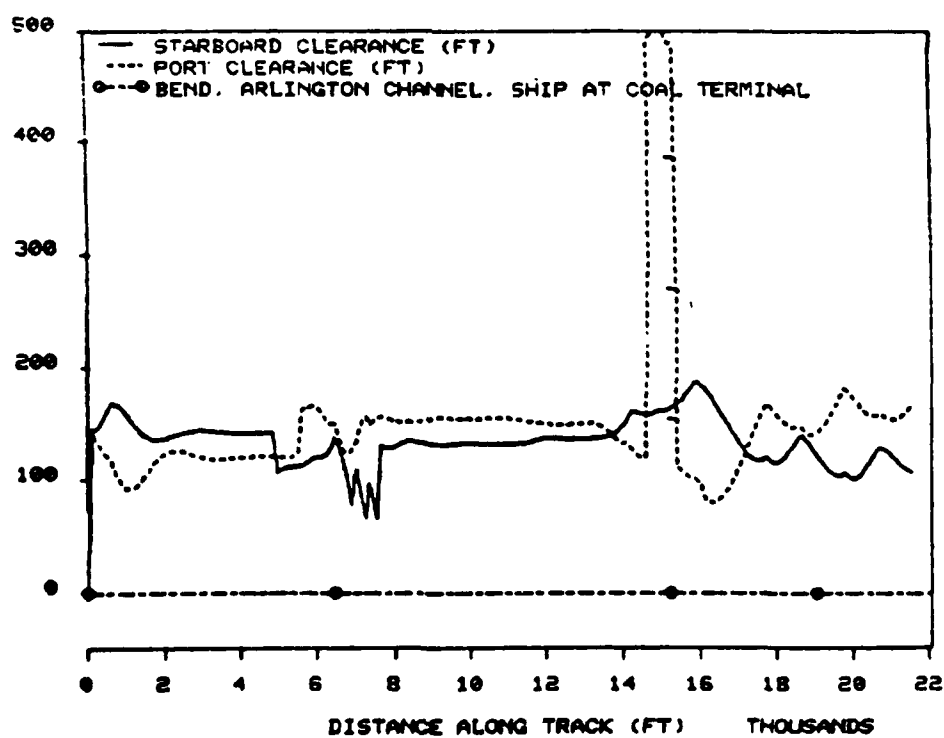
Figure A1c. Distance along track versus port and
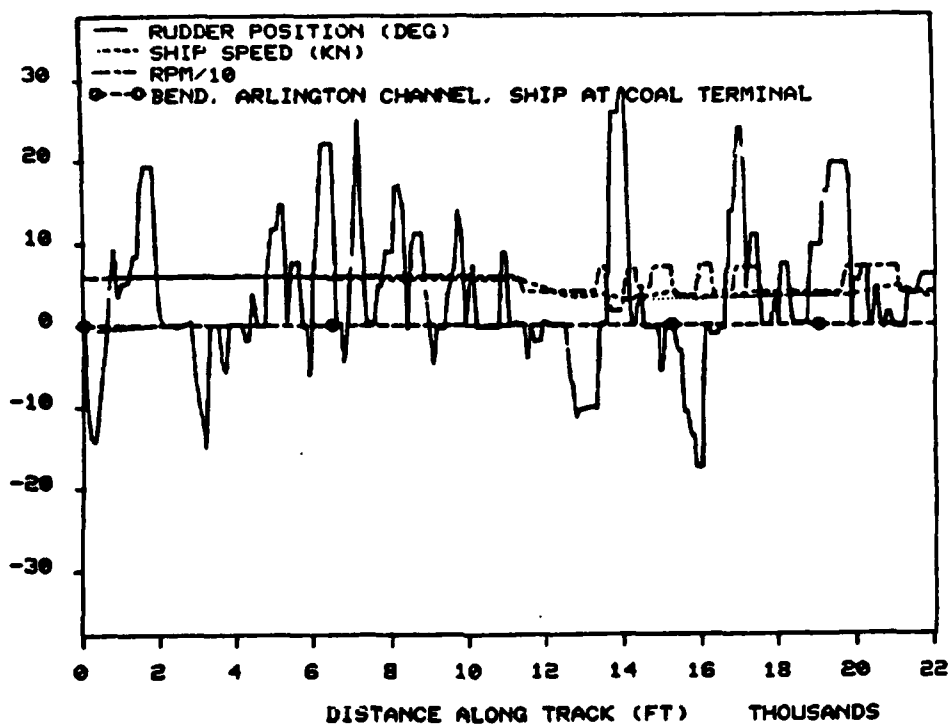starboard clearance, Test 1 (trial 1 5 1)

A3
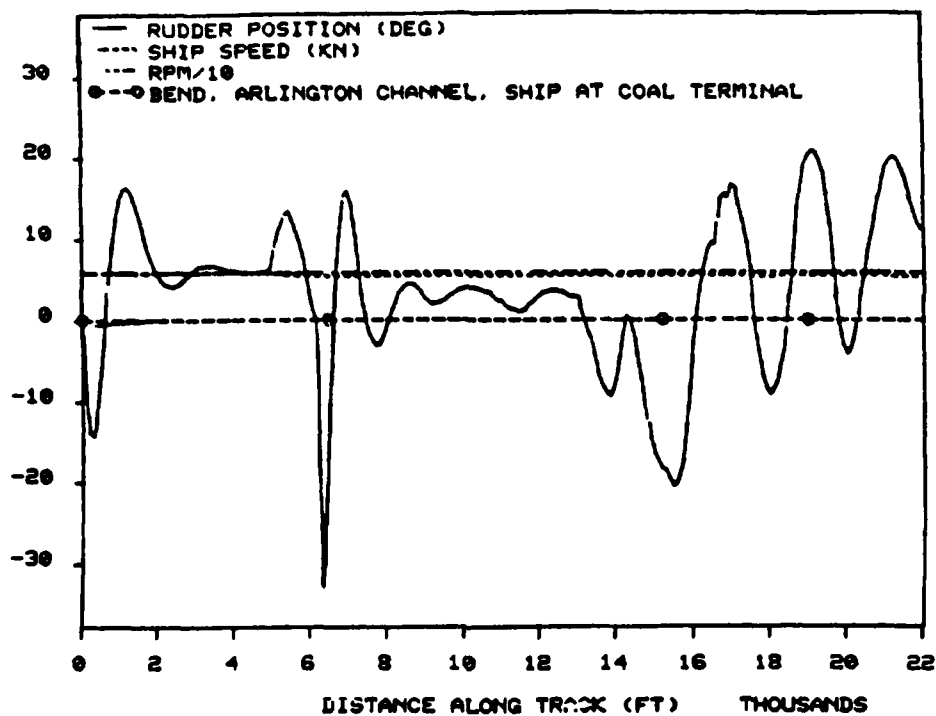
Figure A1d. Distance along track versus rudder, speed,
and rpm/10, Test 1 (trial 1 5 1)
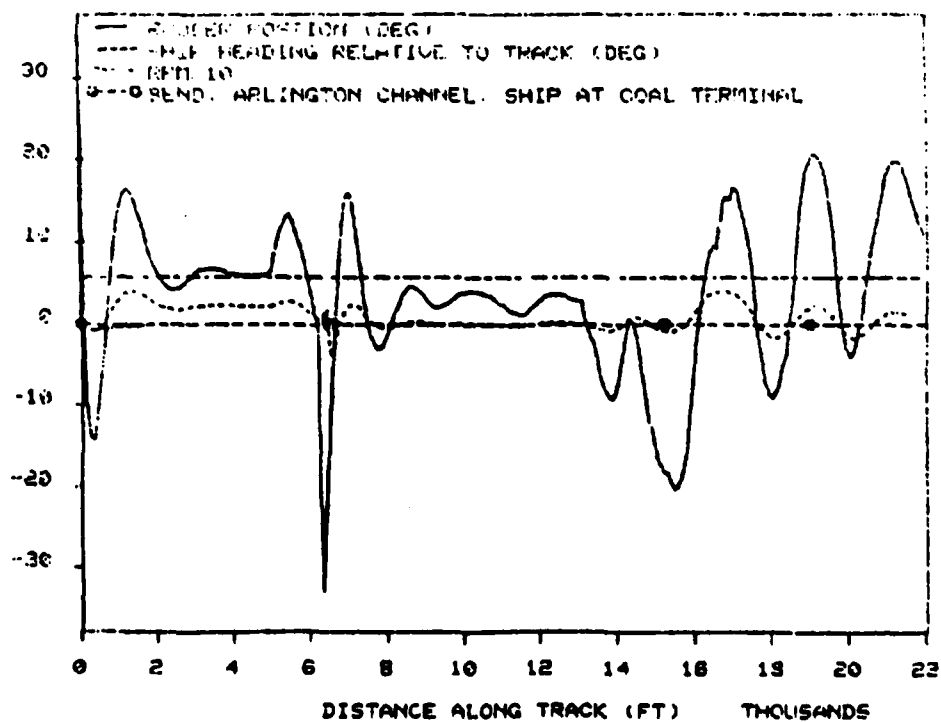
Figure A1e. Distance along track versus rudder, heading,
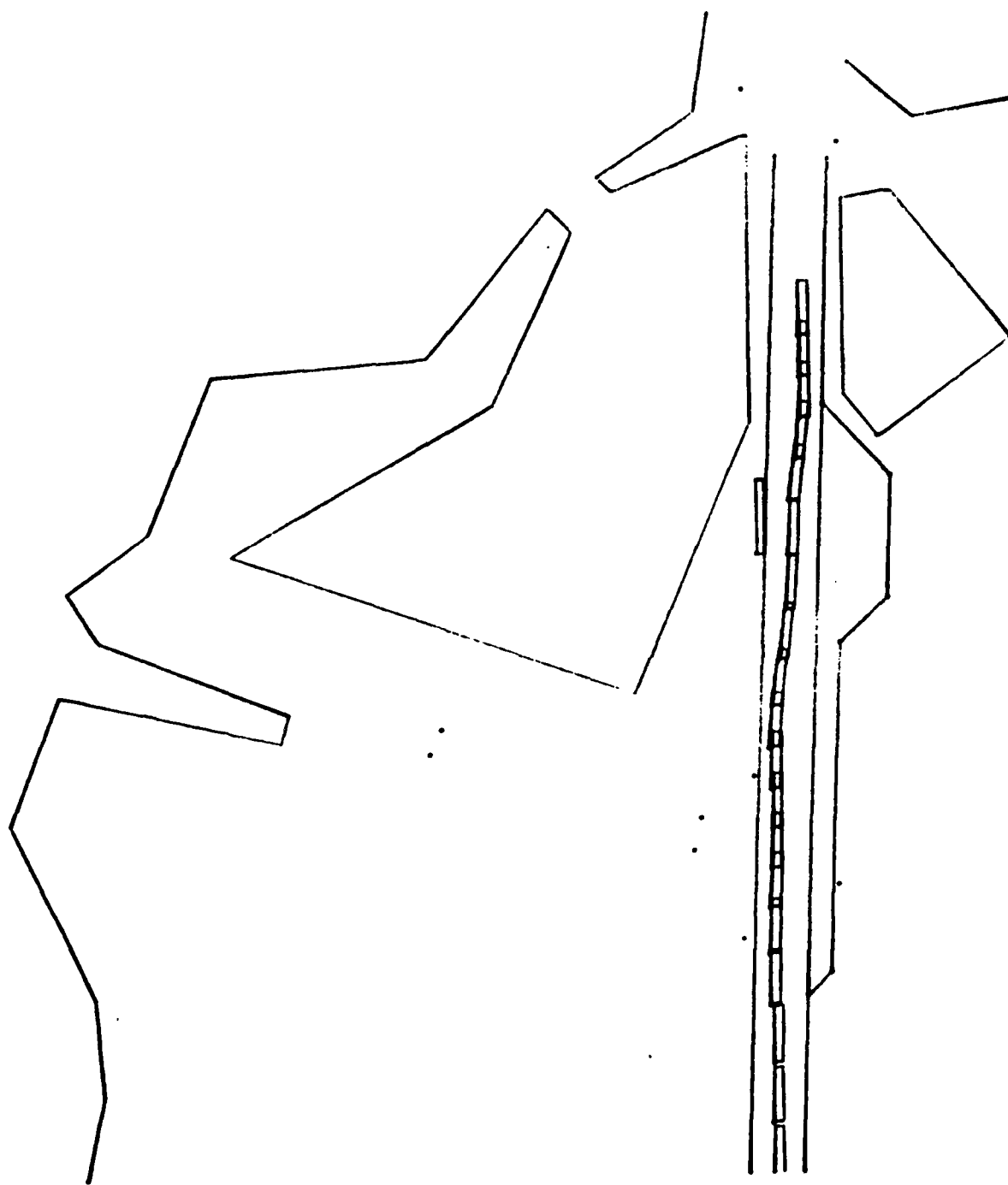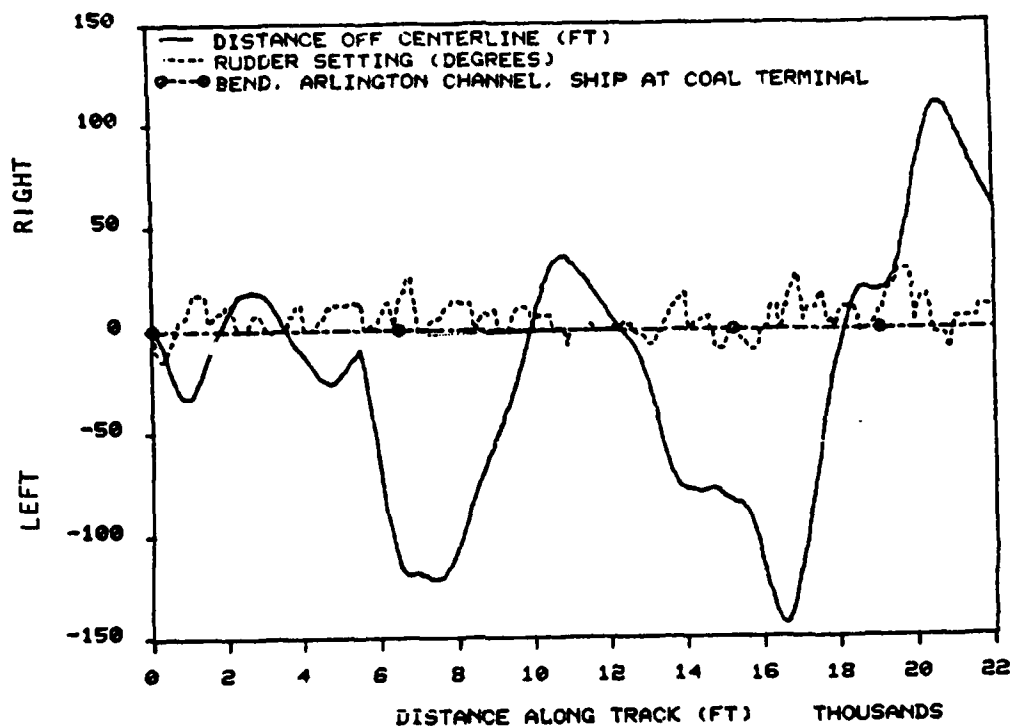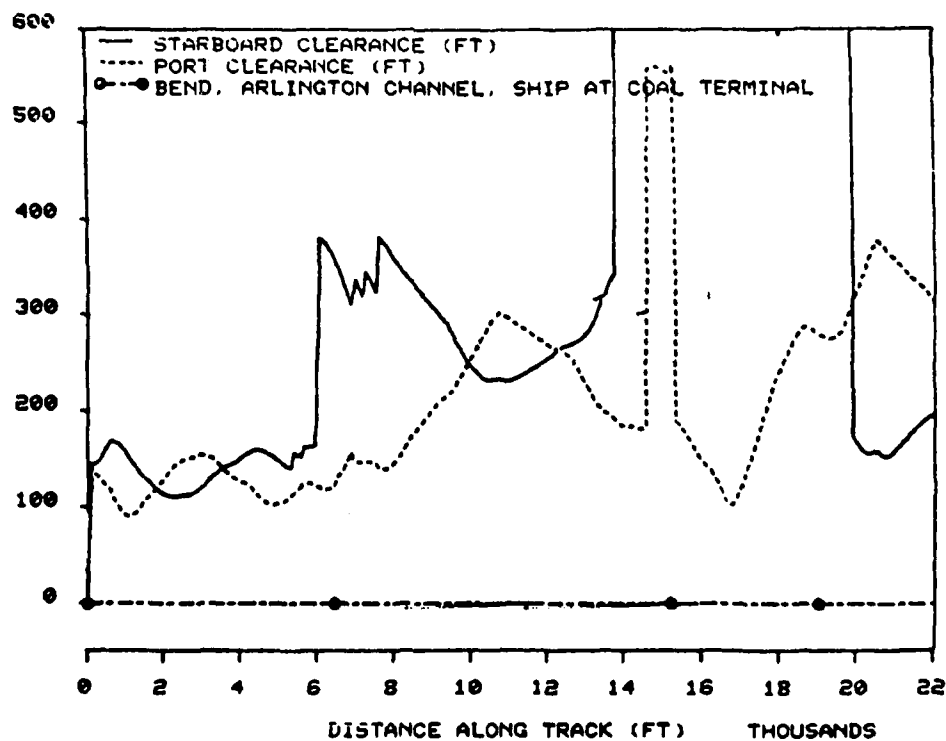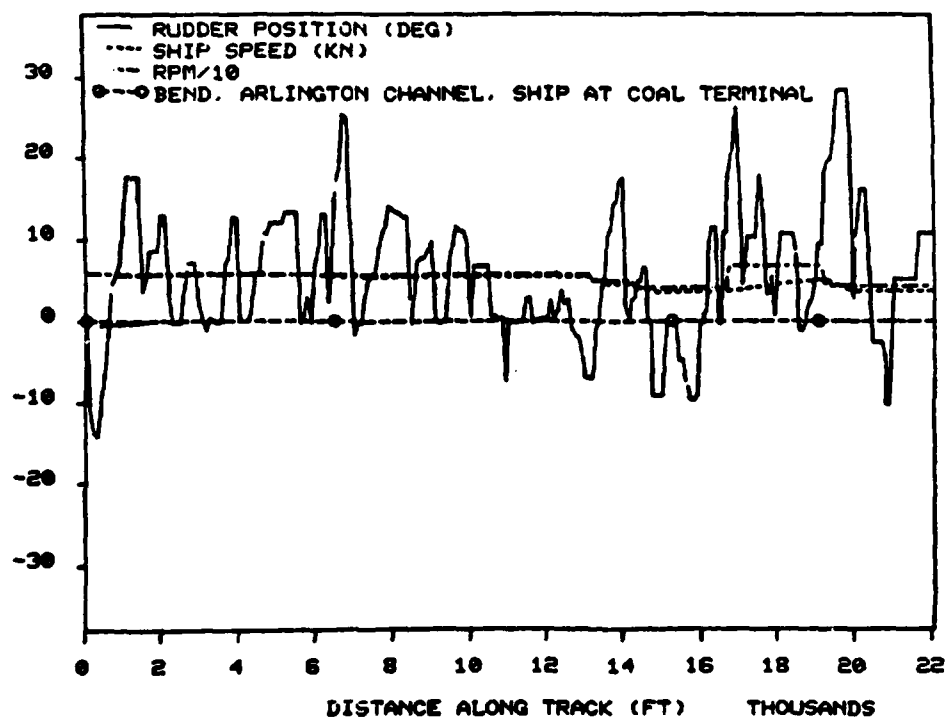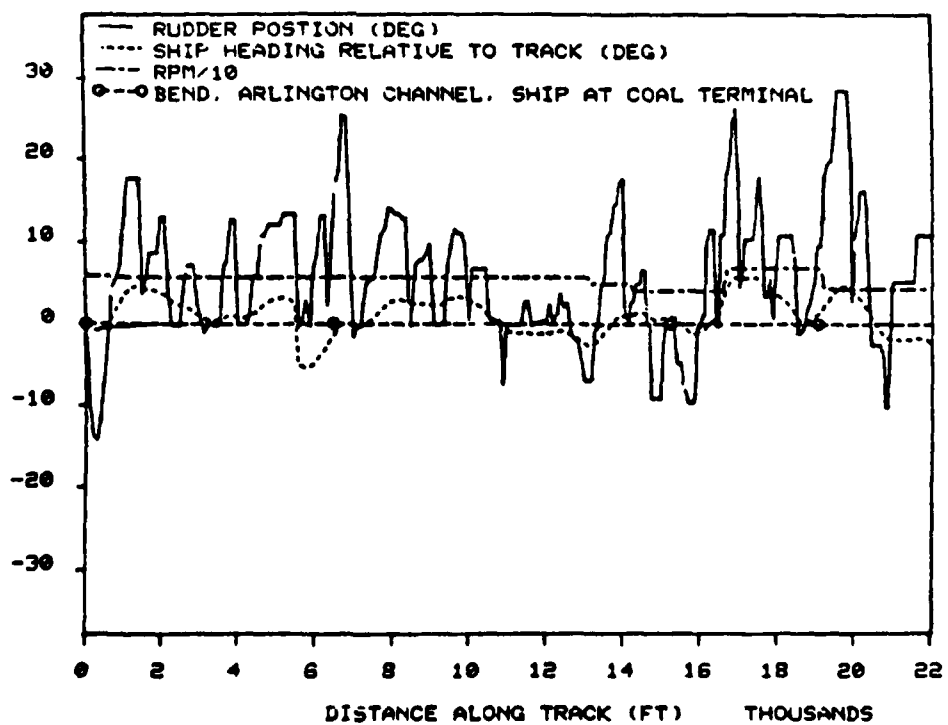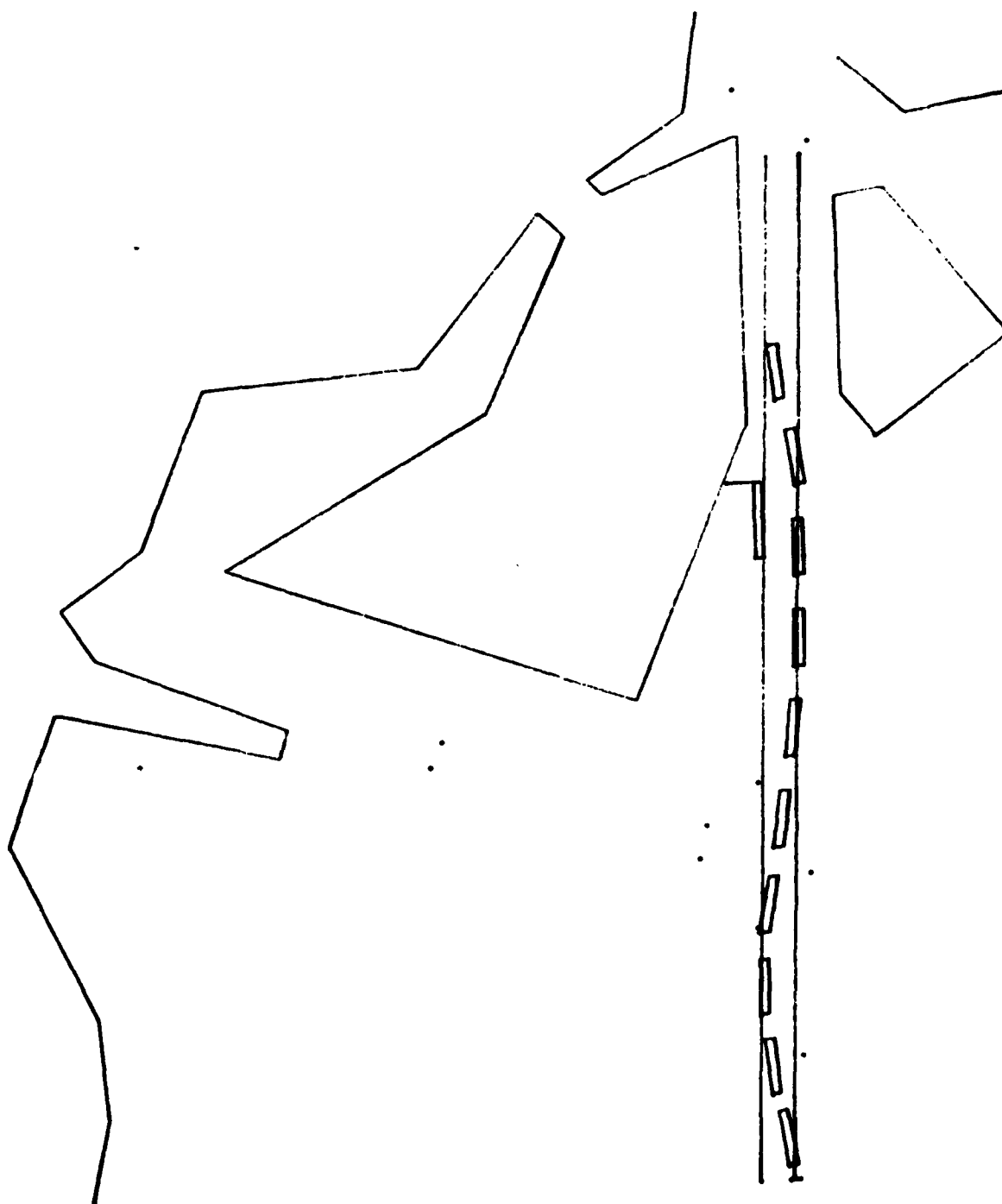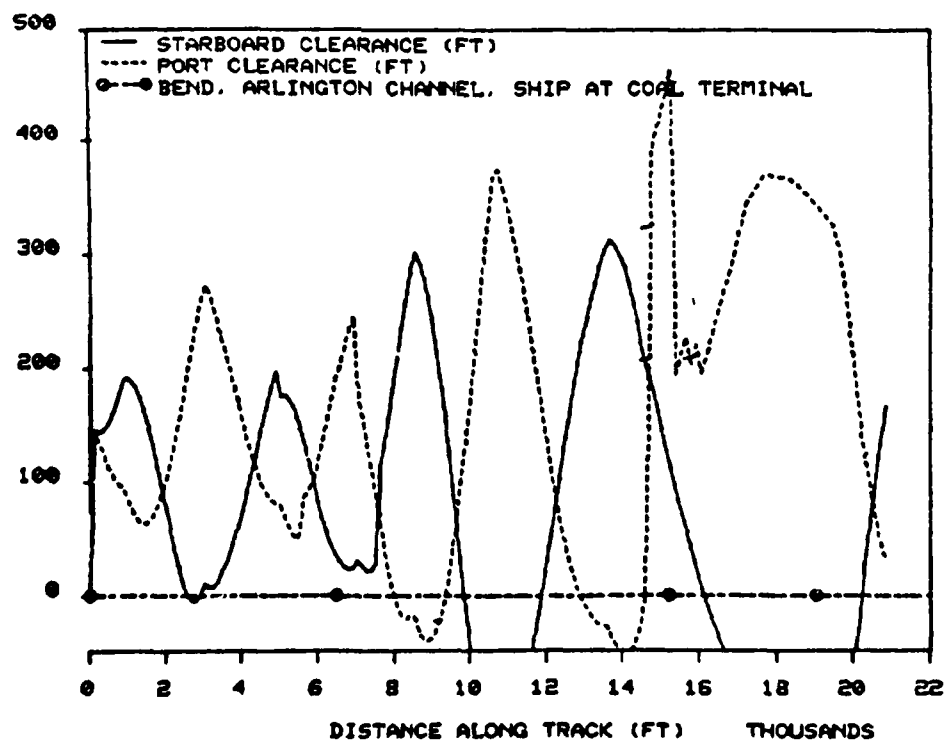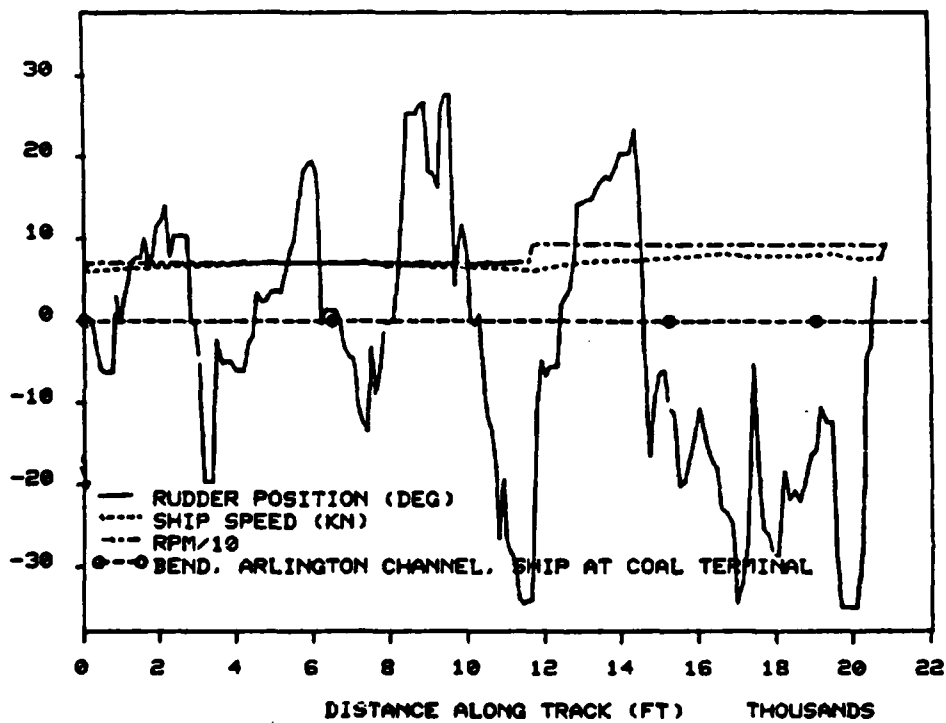and rpm/10, Test 1 (trial 1 5 1)

A4
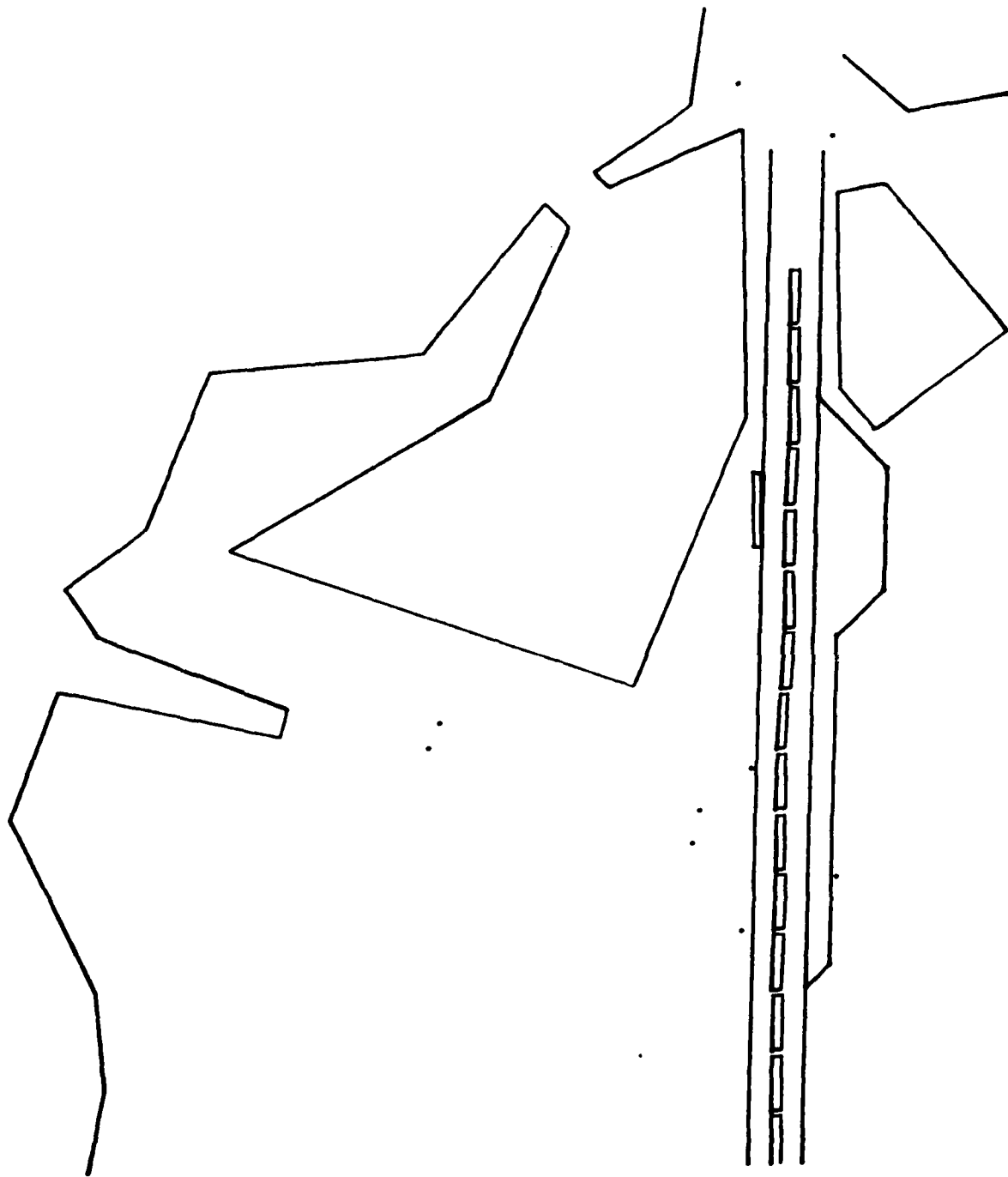
Figure A2a.   Ship track for Test 2 (trial 3 5 1)

A5
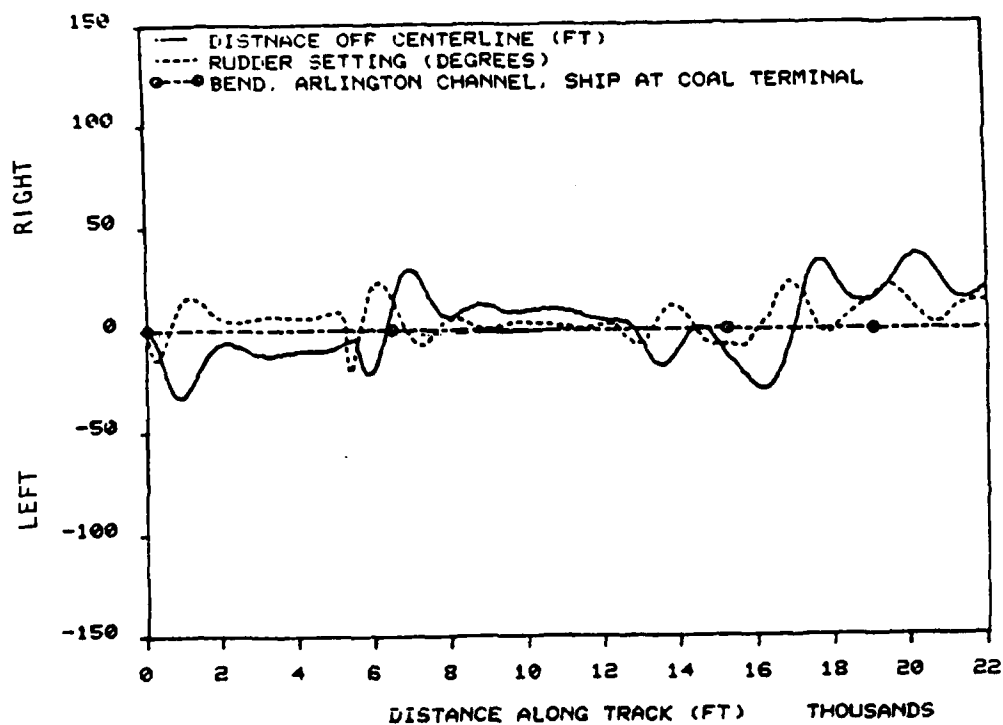
Figure A2b. Distance along track versus rudder setting and distance off track, Test 2 (trial 3 5 1)
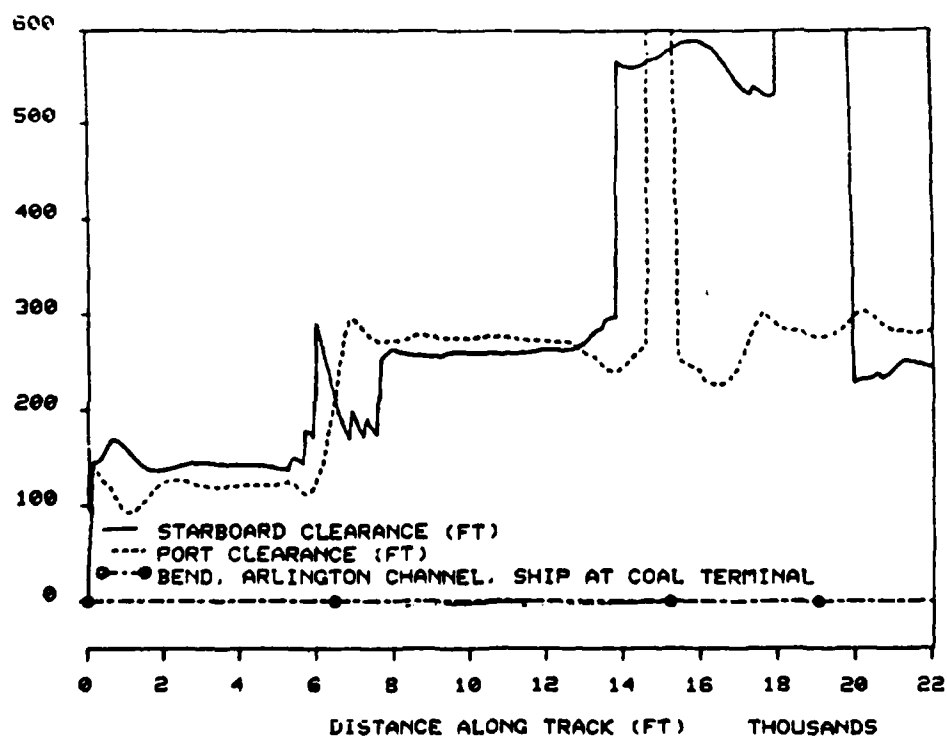
Figure A2c. Distance along track versus port and starboard clearance, Test 2 (trial 3 5 1)

A6
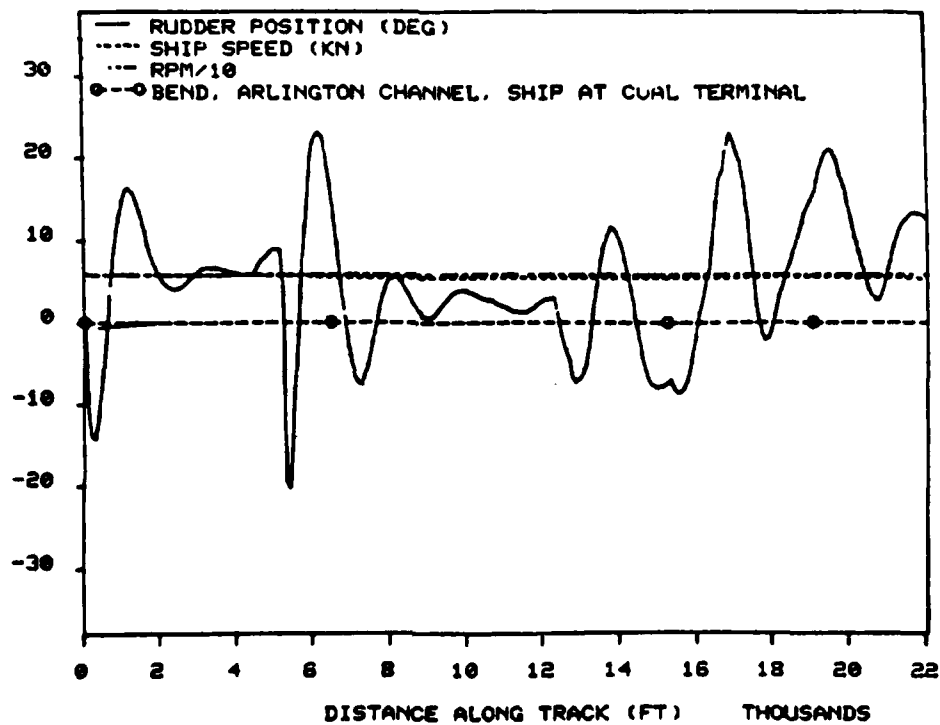
Figure A2d. Distance along track versus rudder, speed,
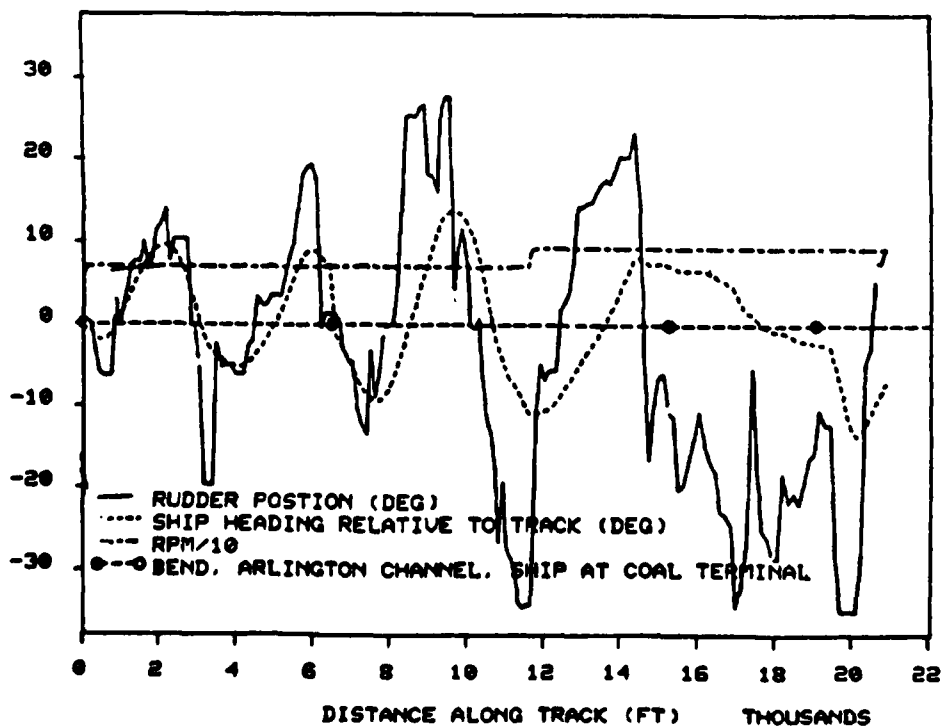and rpm/10, Test 2 (trial 3 5 1)
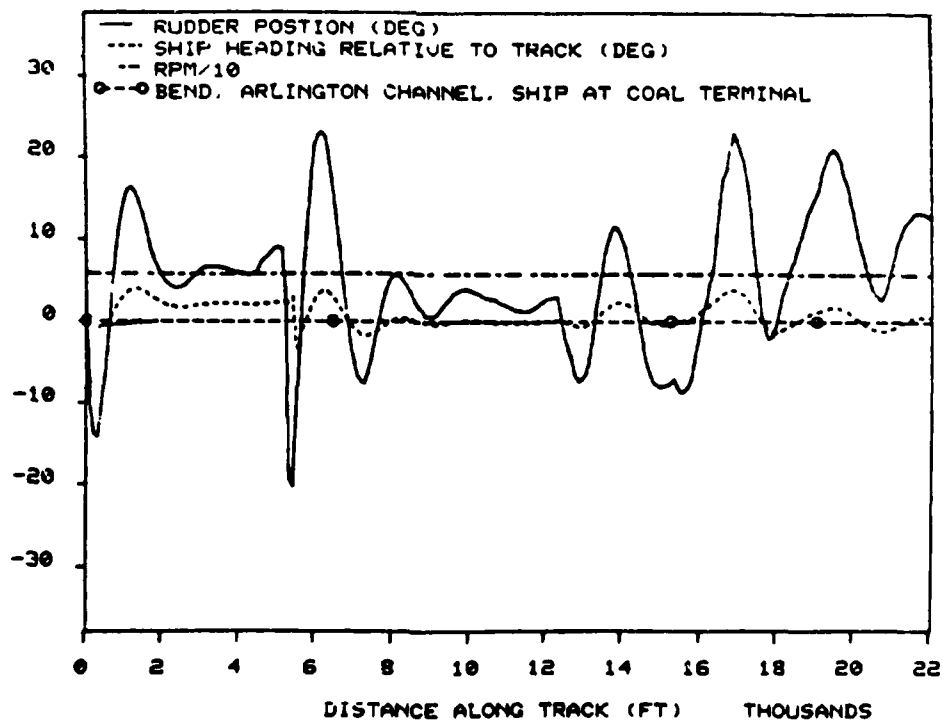
Figure A2e. Distance along track versus rudder, heading,
and rpm/10, Test 2 (trial 3 5 1)

A7
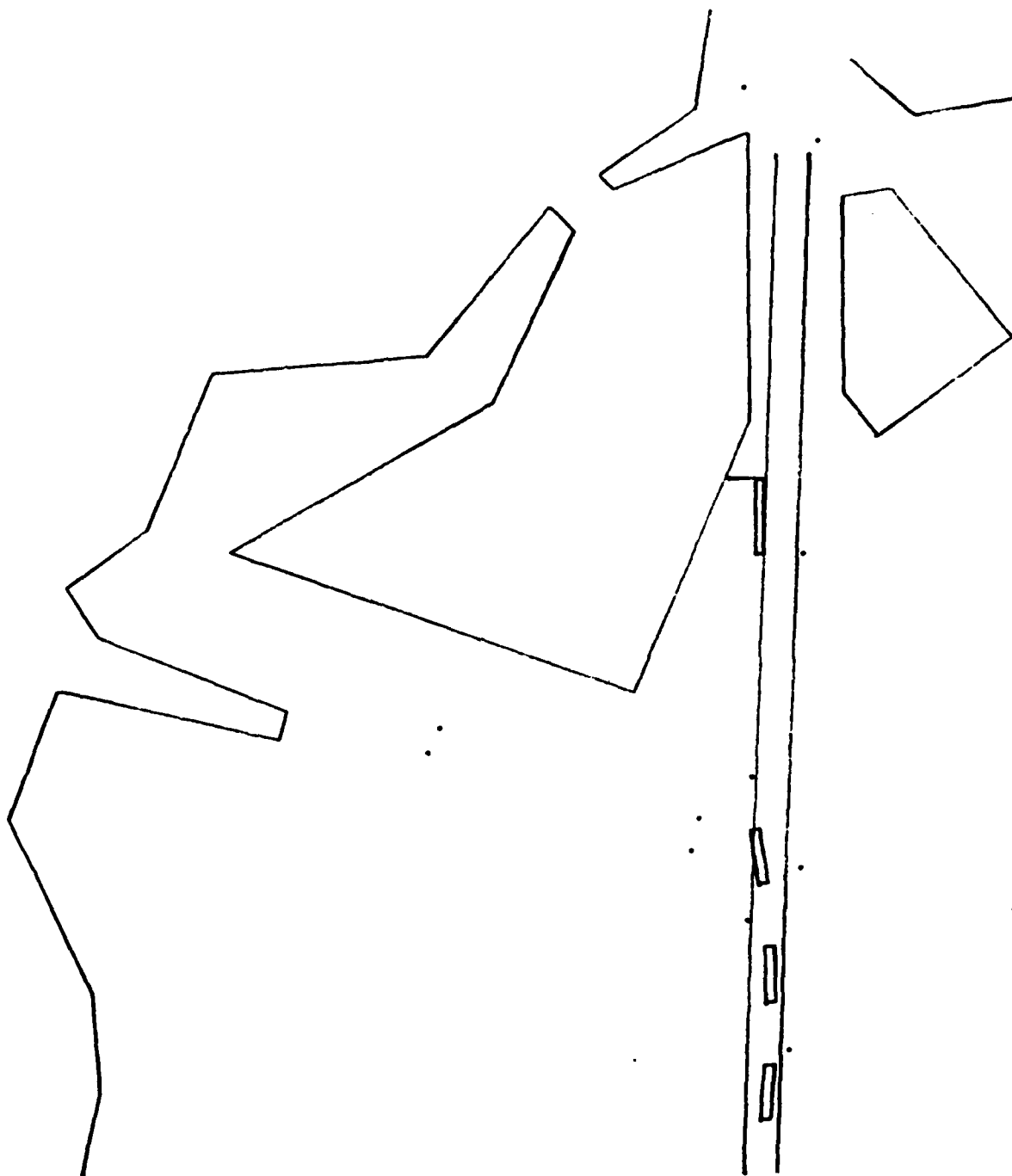
Figure A3a. Ship track for Test 3 (trial 1 1 1)

A8
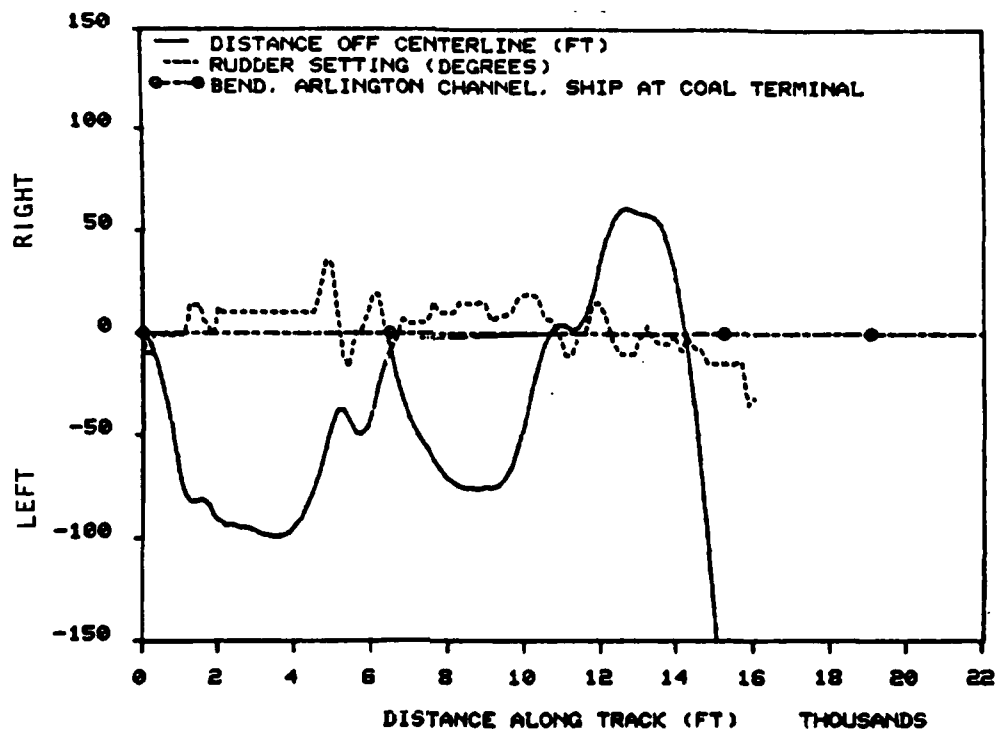
Figure A3b. Distance along track versus rudder setting
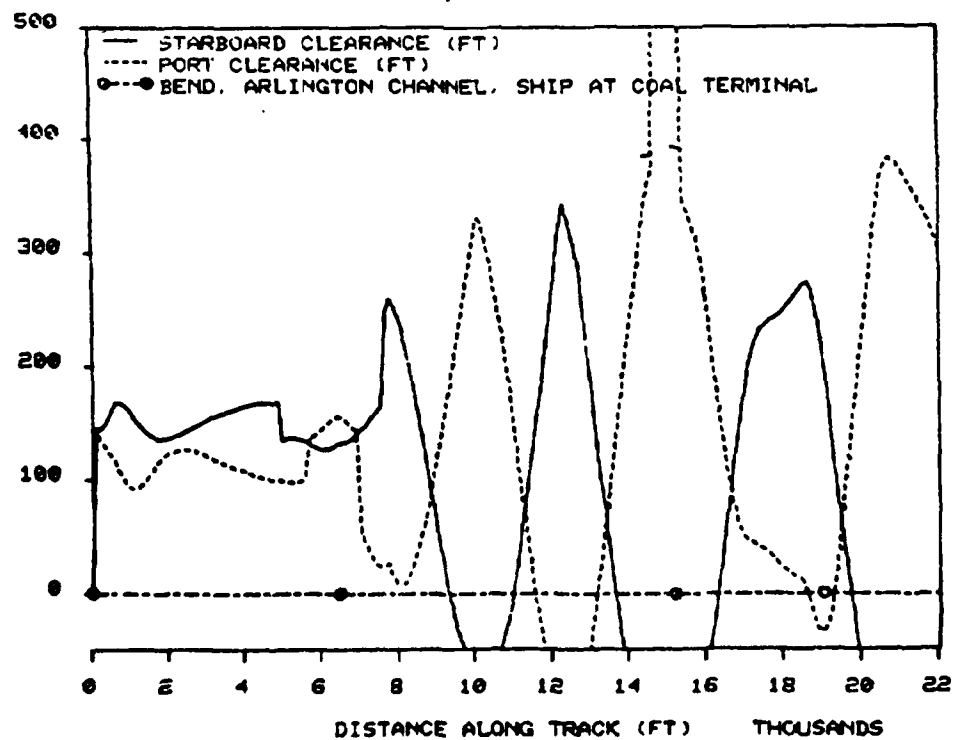and distance off track, Test 3 (trial 1 1 1)
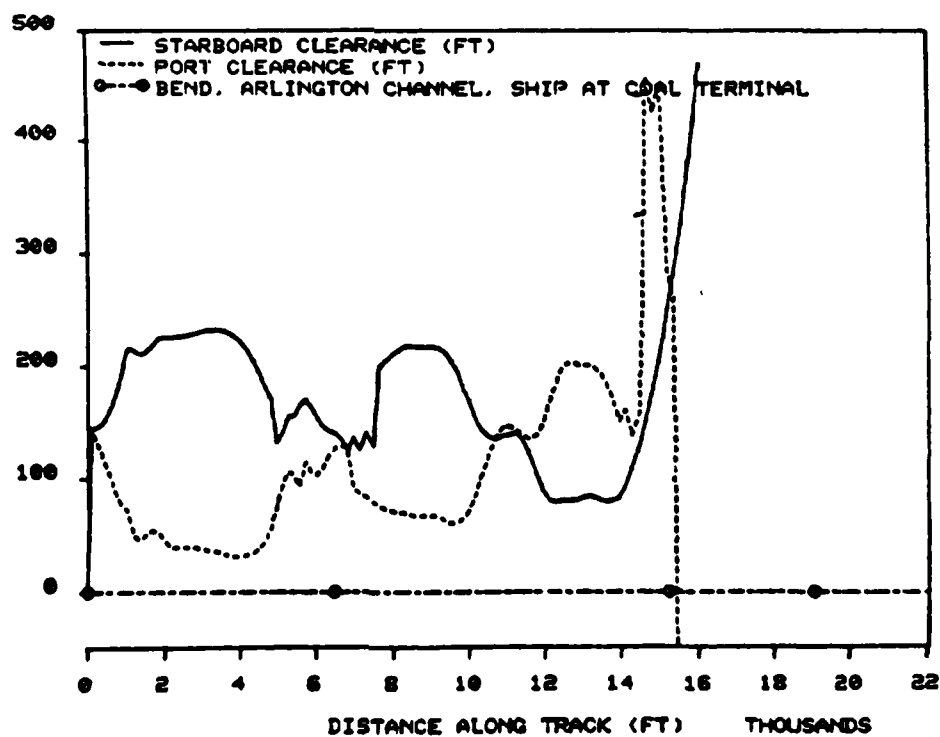
Figure A3c. Distance along track versus port and
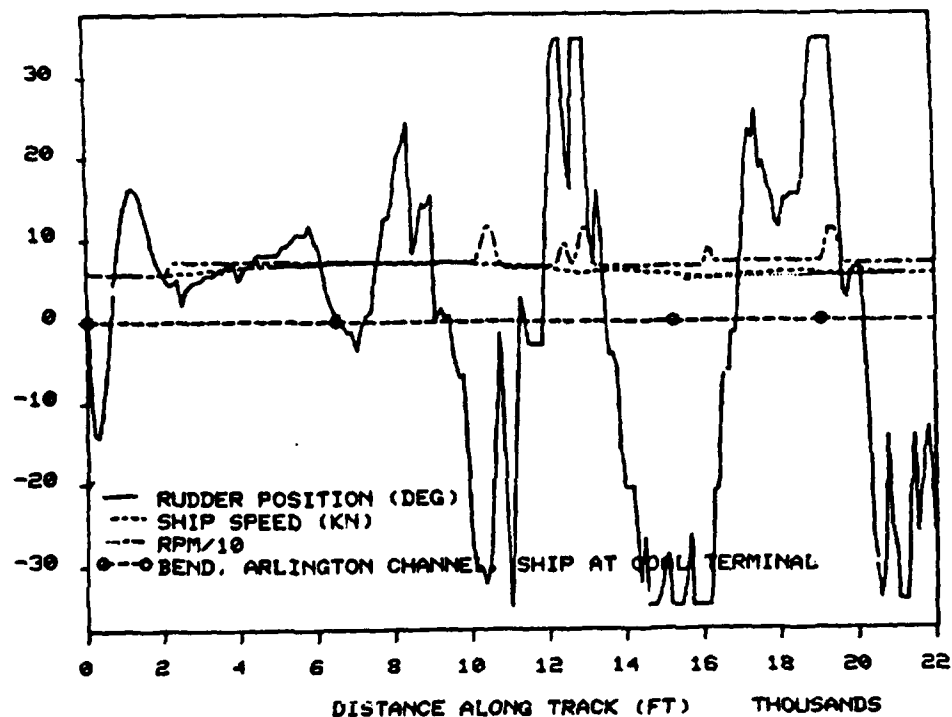starboard clearance, Test 3 (trial 1 1 1)

A9
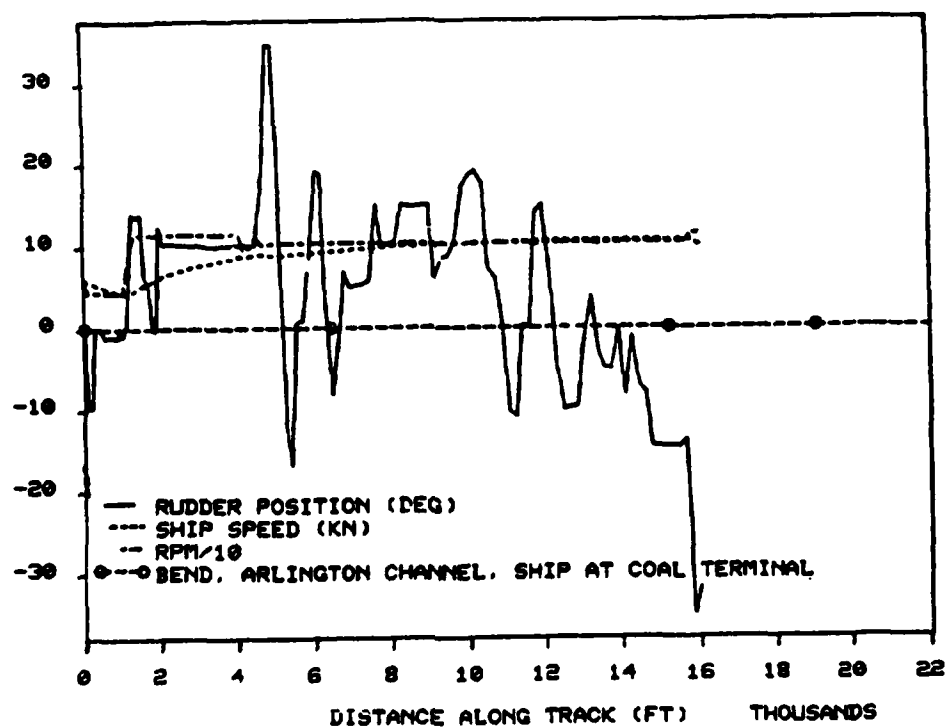
Figure A3d. Distance along track versus rudder, speed, and rpm/10, Test 3 (trial 1 1 1)
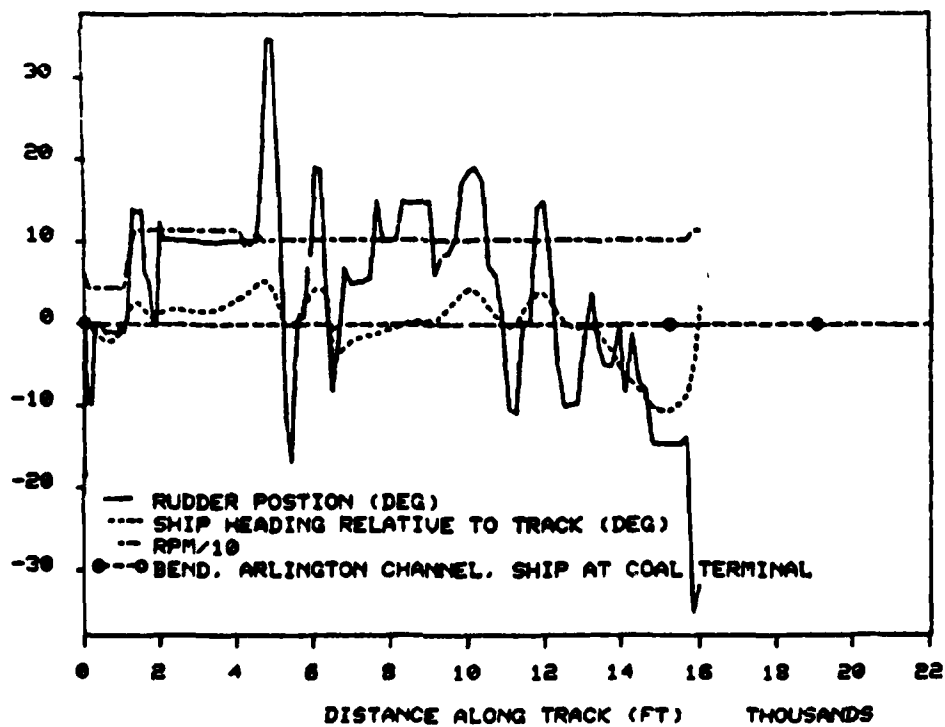
Figure A3e. Distance along track versus rudder, heading, and rpm/10, Test 3 (trial 1 1 1)

A10
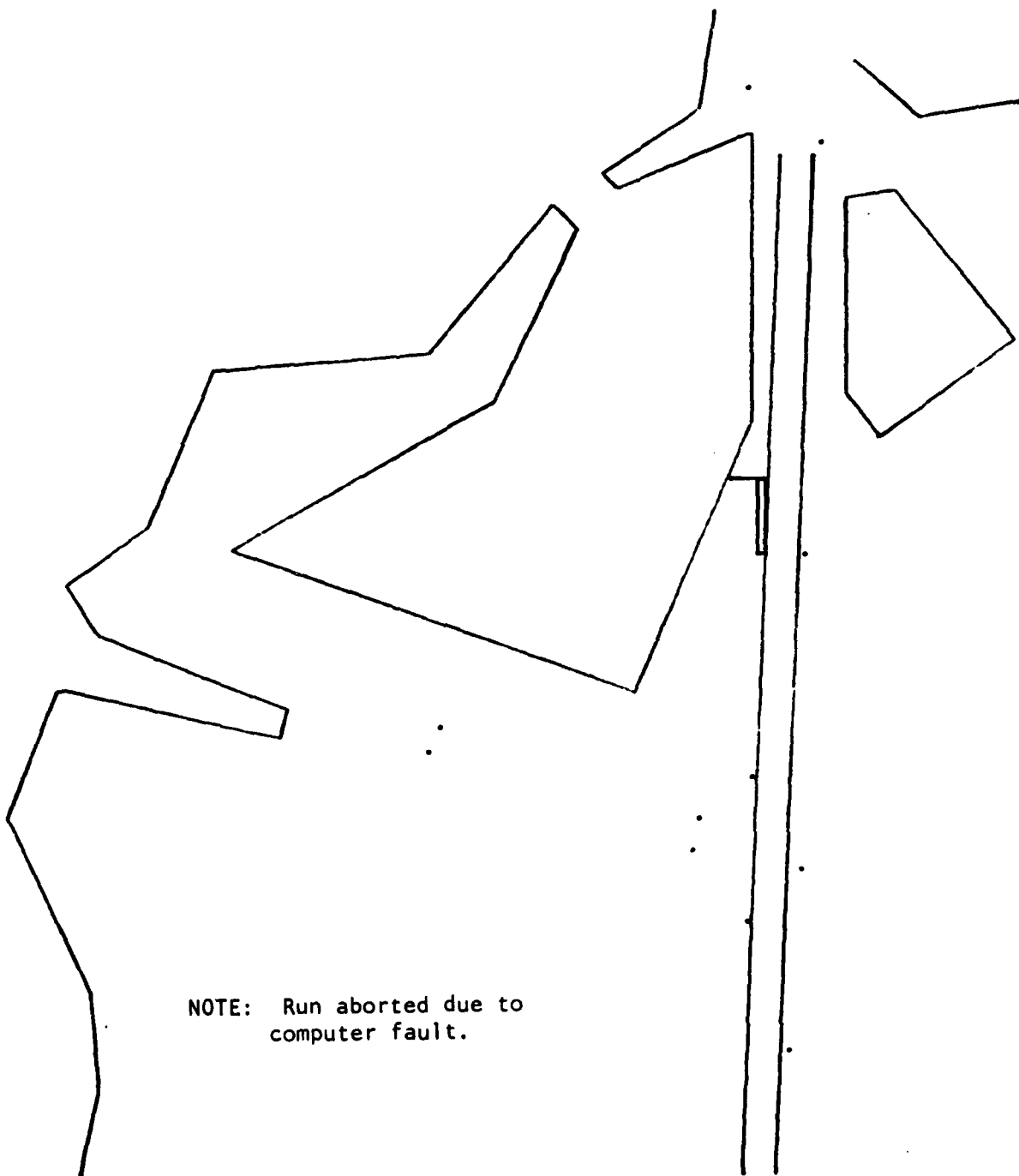
NOTE: Run aborted due to
       computer fault.

Figure A4a. Ship track for Test 4 (trial 1 1 2)

A11
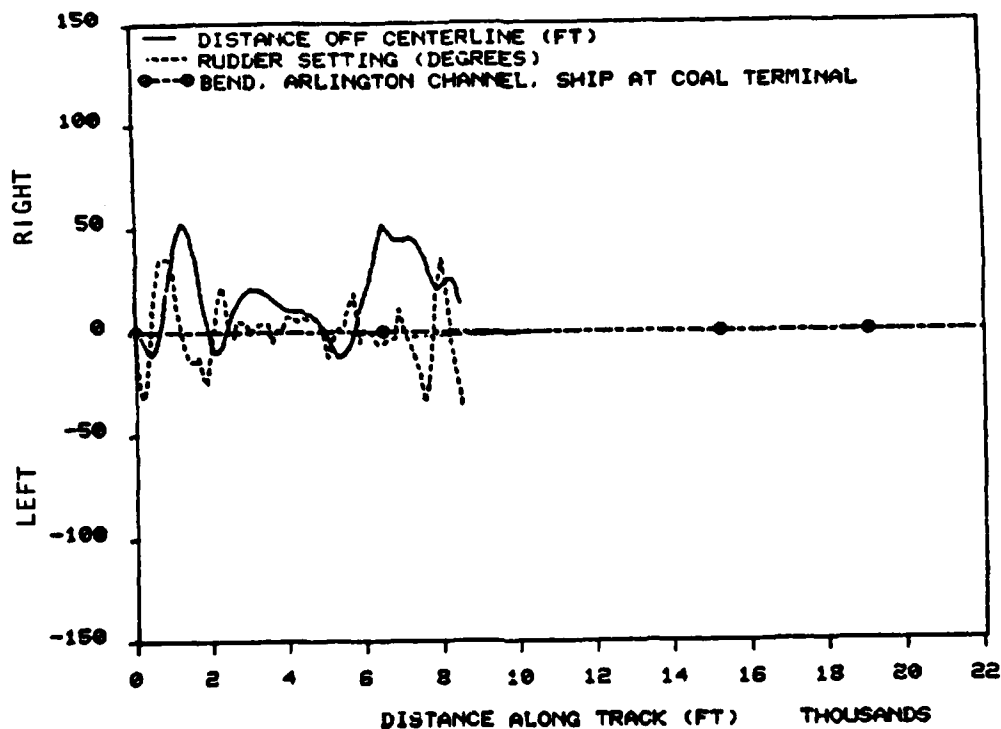
Figure A4b. Distance along track versus rudder setting
and distance off track, Test 4 (trial 1 1 2)
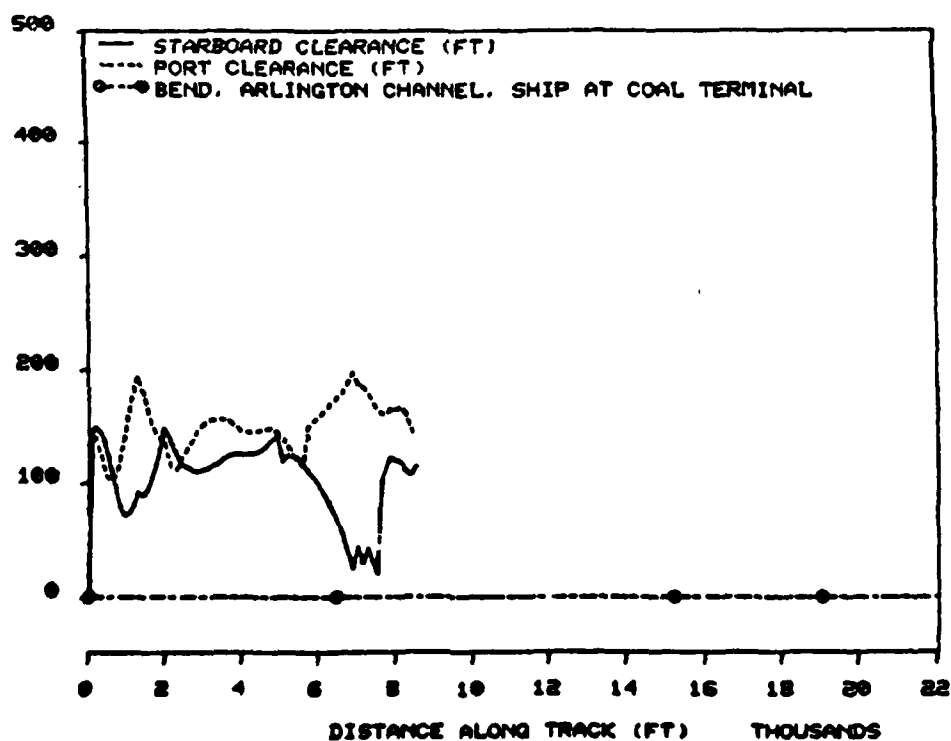
Figure A4c. Distance along track versus port and
starboard clearance, Test 4 (trial 1 1 2)

A12
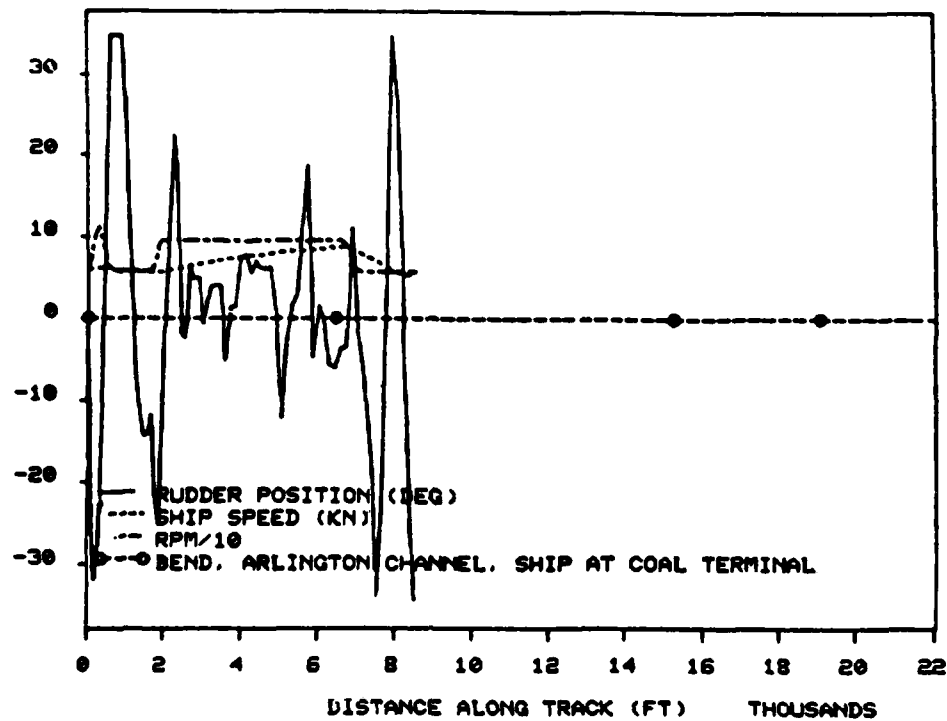
Figure A4d. Distance along track versus rudder, speed,
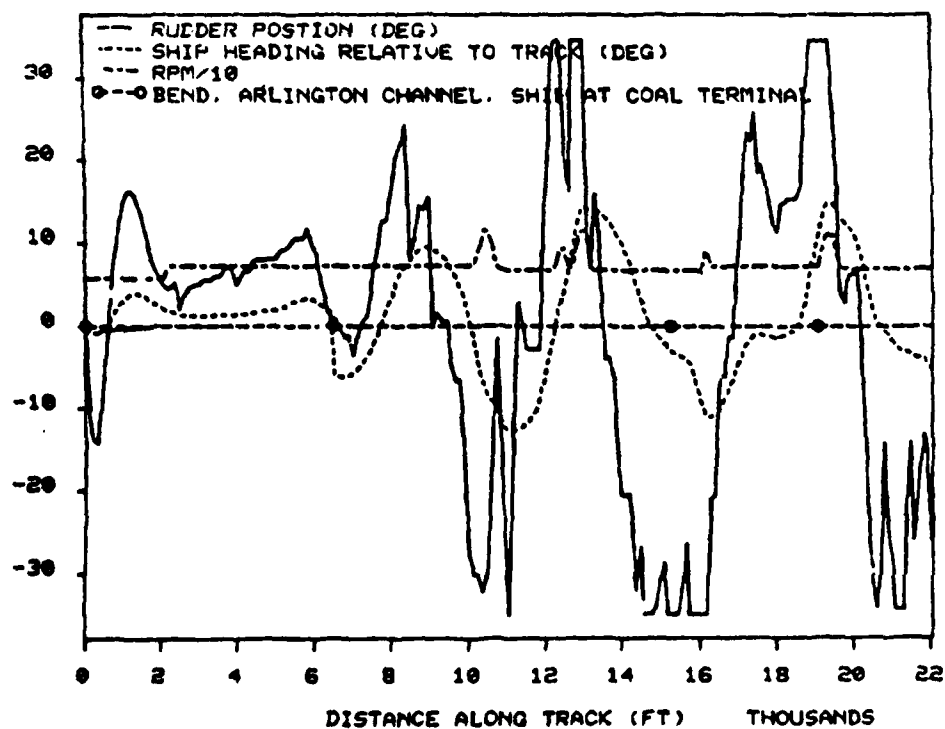and rpm/10, Test 4 (trial 1 1 2)
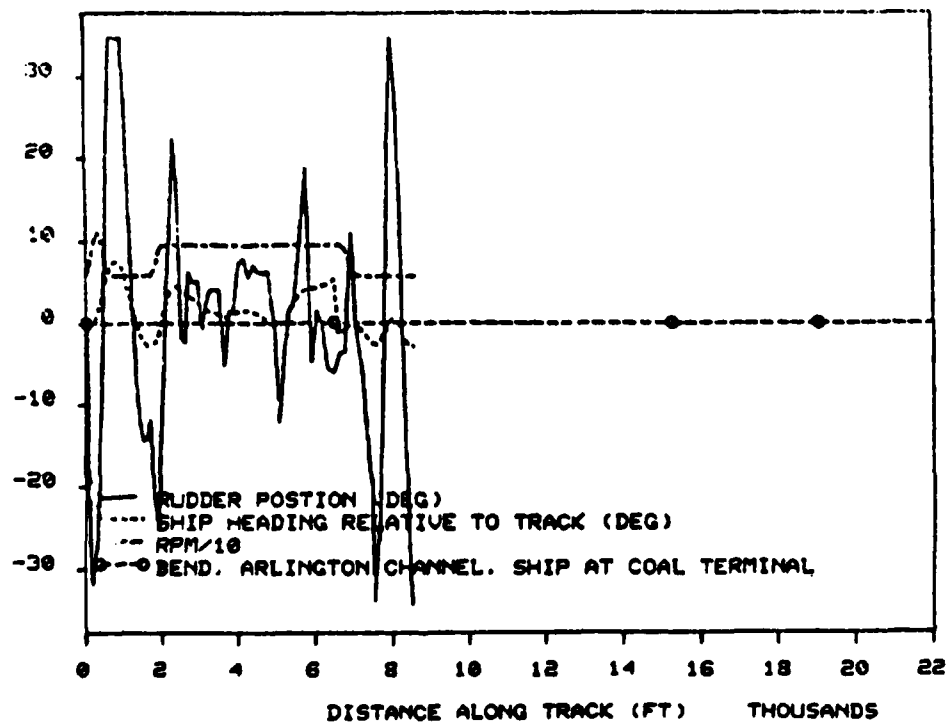
Figure A4e. Distance along track versus rudder, heading,
and rpm/10, Test 4 (trial 1 1 2)
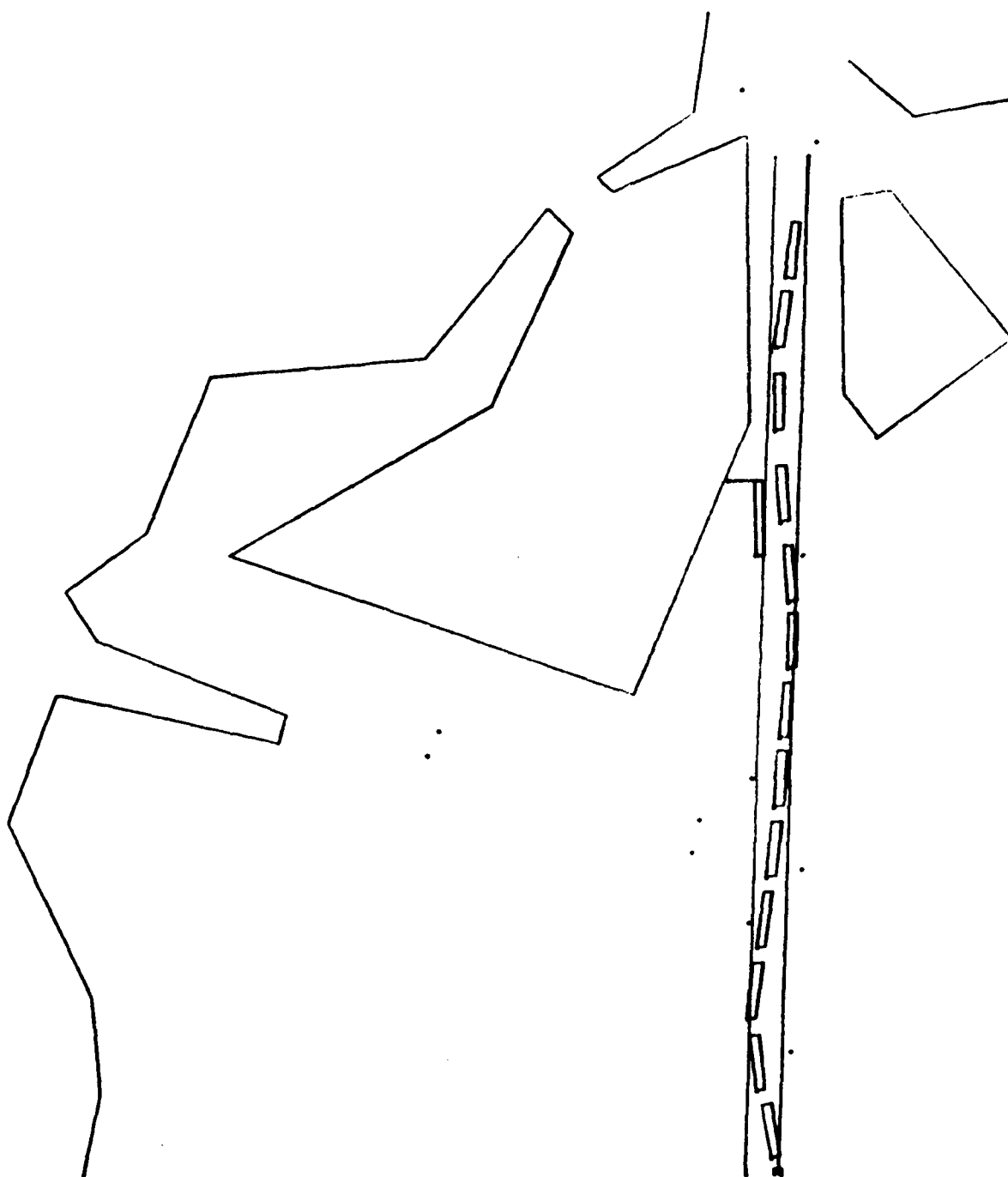
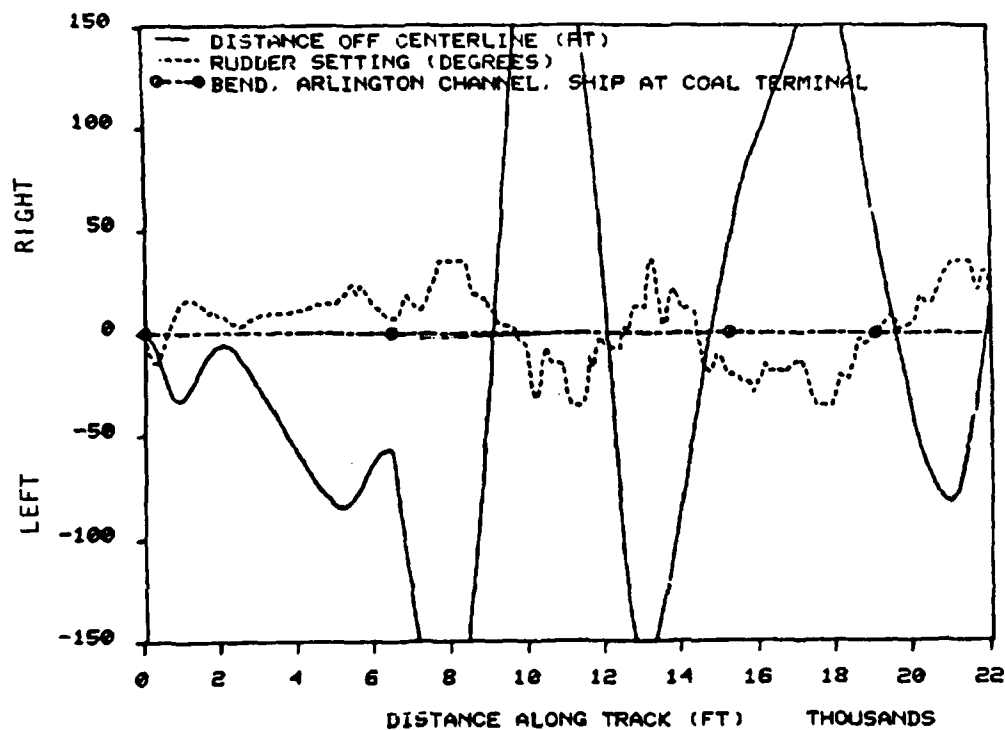A13
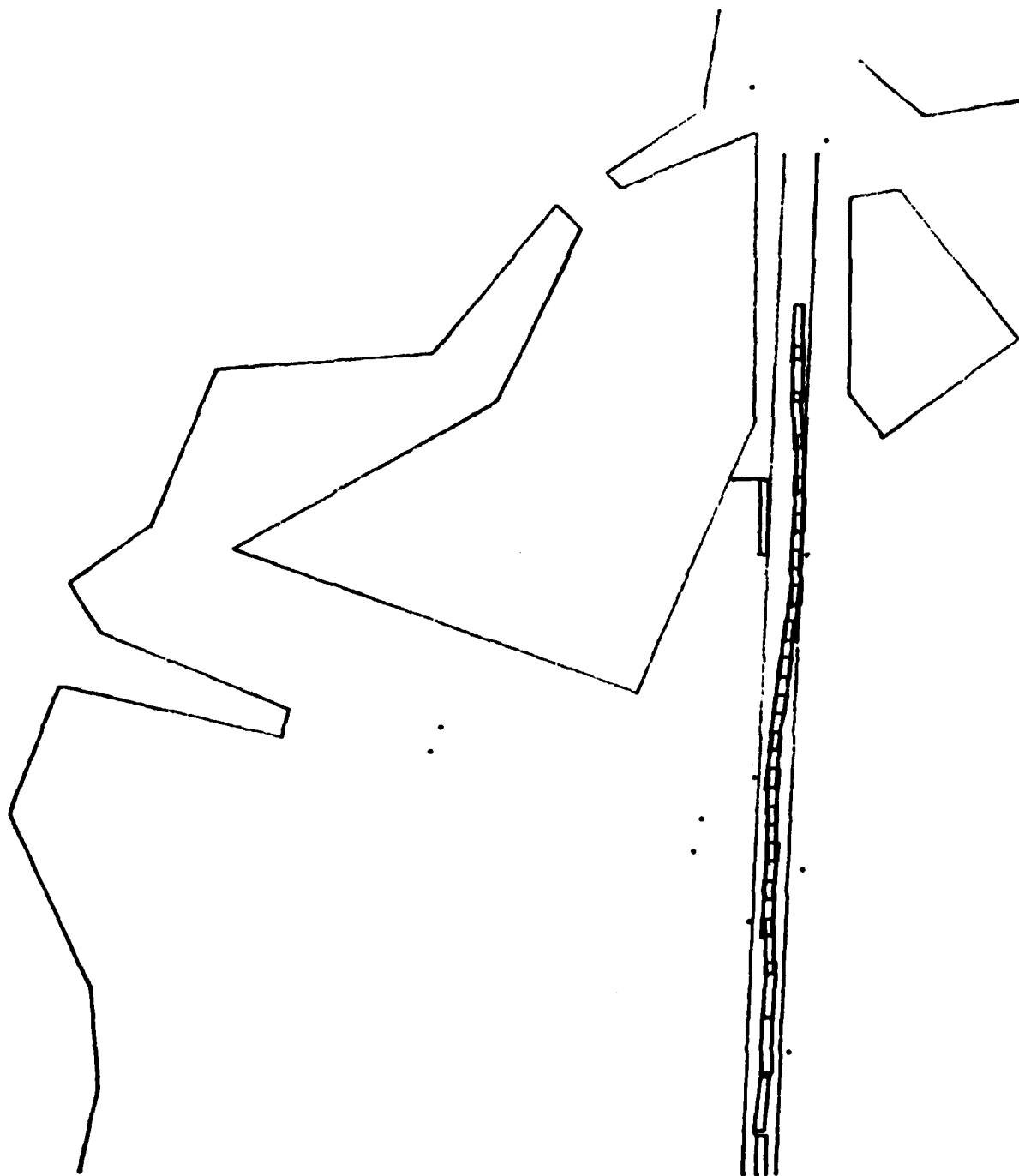
Figure A5a. Ship track for Test 5 (trial 2 1 3)

A14
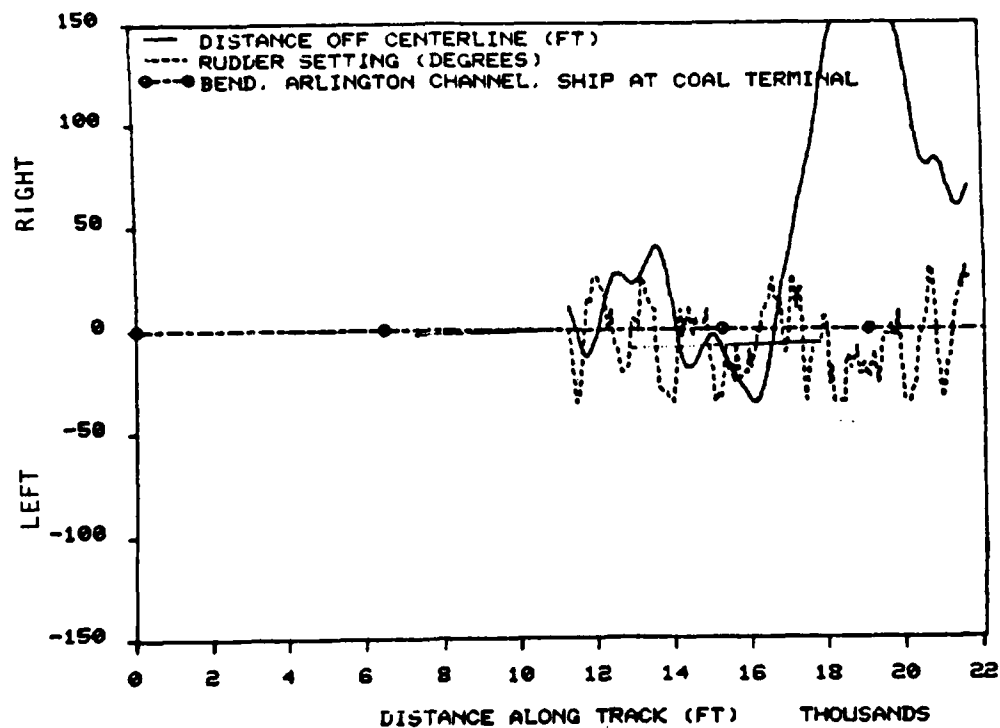
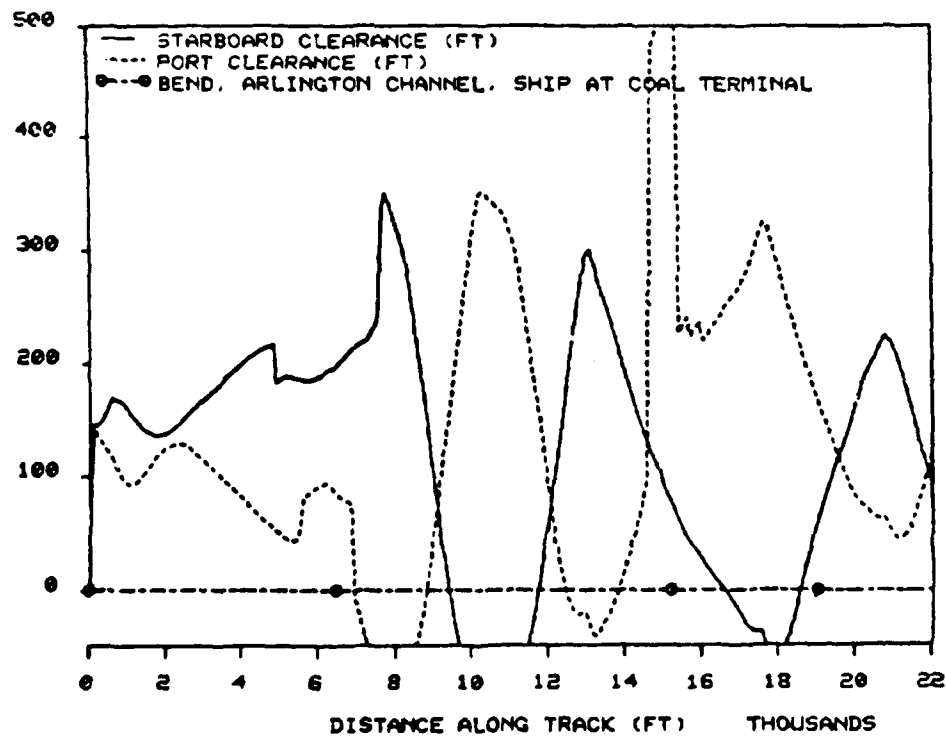Figure A5b. Distance along track versus rudder setting and distance off track, Test 5 (trial 2 1 3)
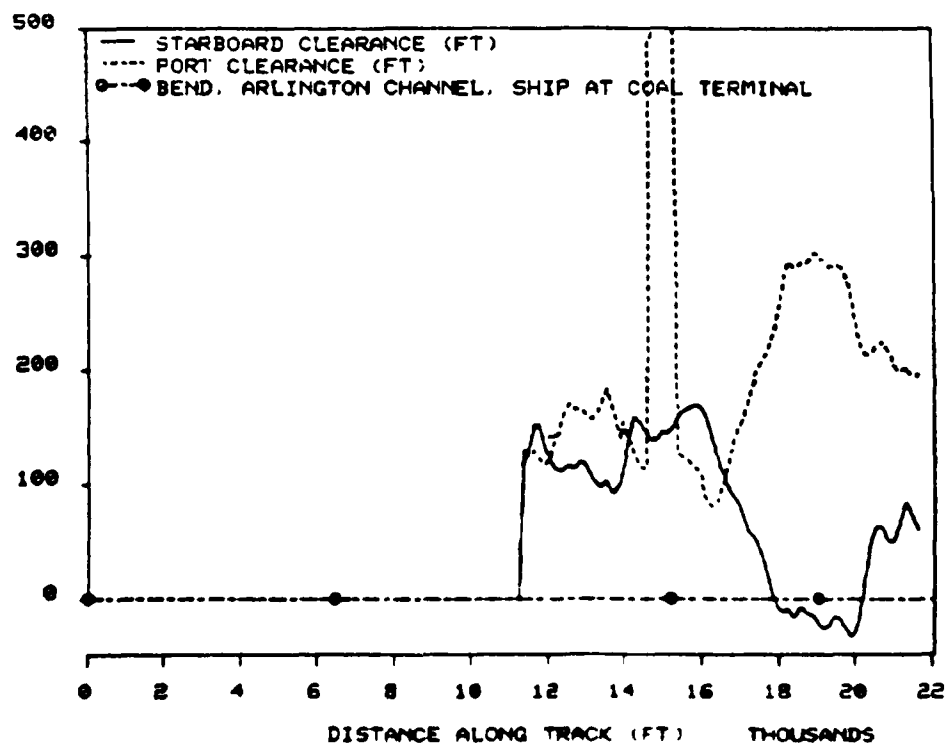
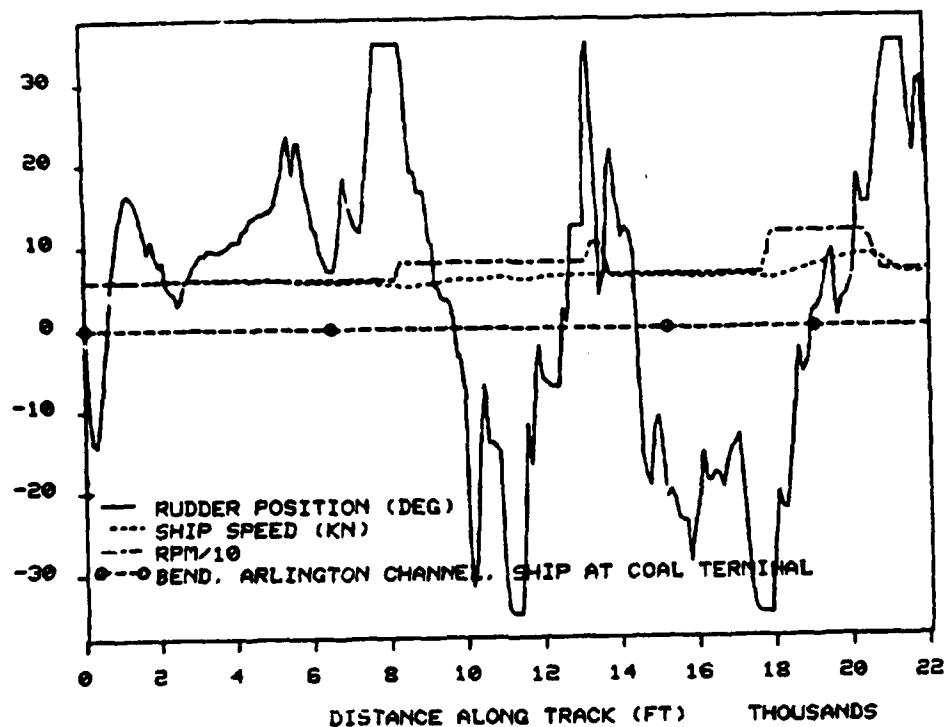Figure A5c. Distance along track versus port and starboard clearance, Test 5 (trial 2 1 3)
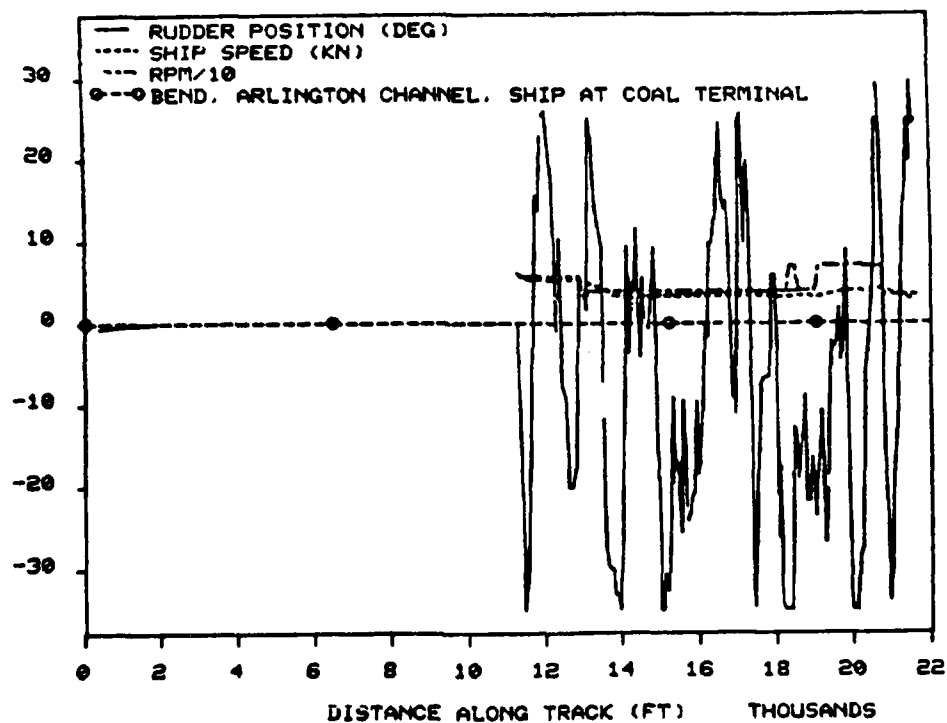
Figure A5d. Distance along track versus rudder, speed, and rpm/10, Test 5 (trial 2 1 3)
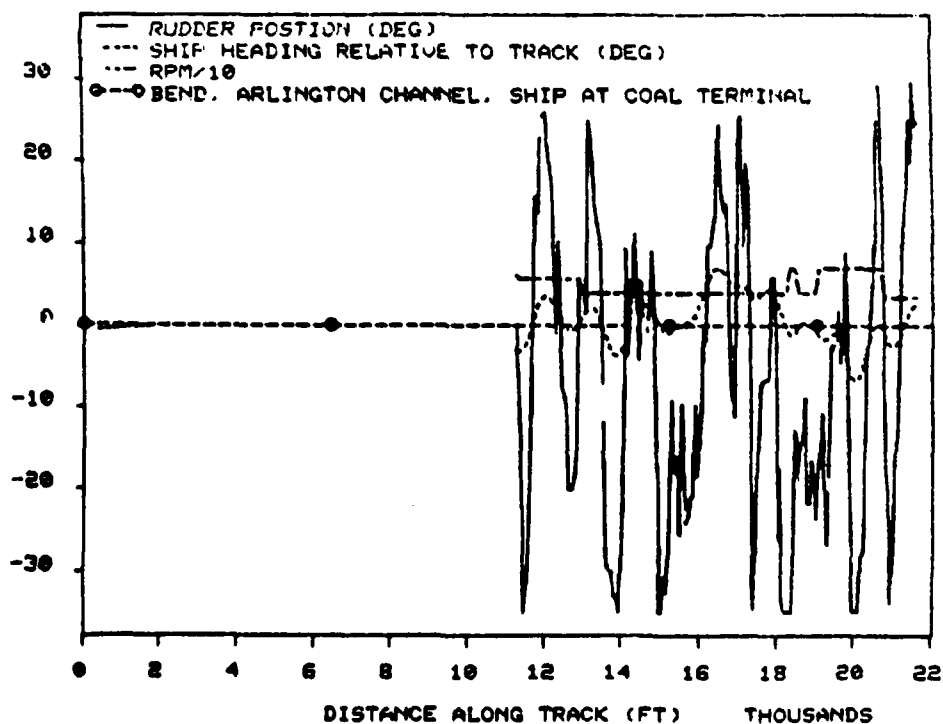
Figure A5e. Distance along track versus rudder, heading, and rpm/10, Test 5 (trial 2 1 3)

A16
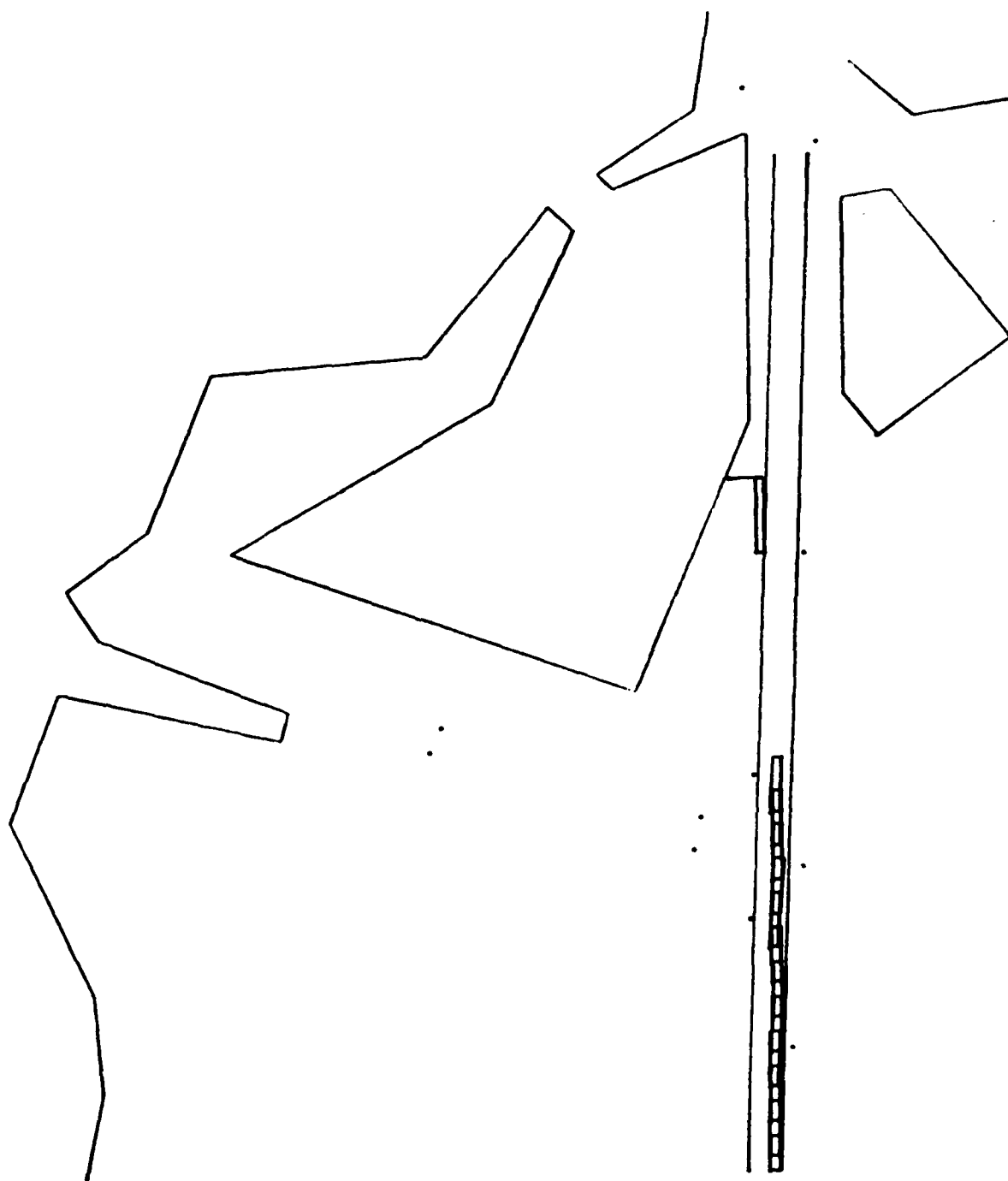
Figure A6a. Ship track for Test 6 (trial 1 1 4)

A17
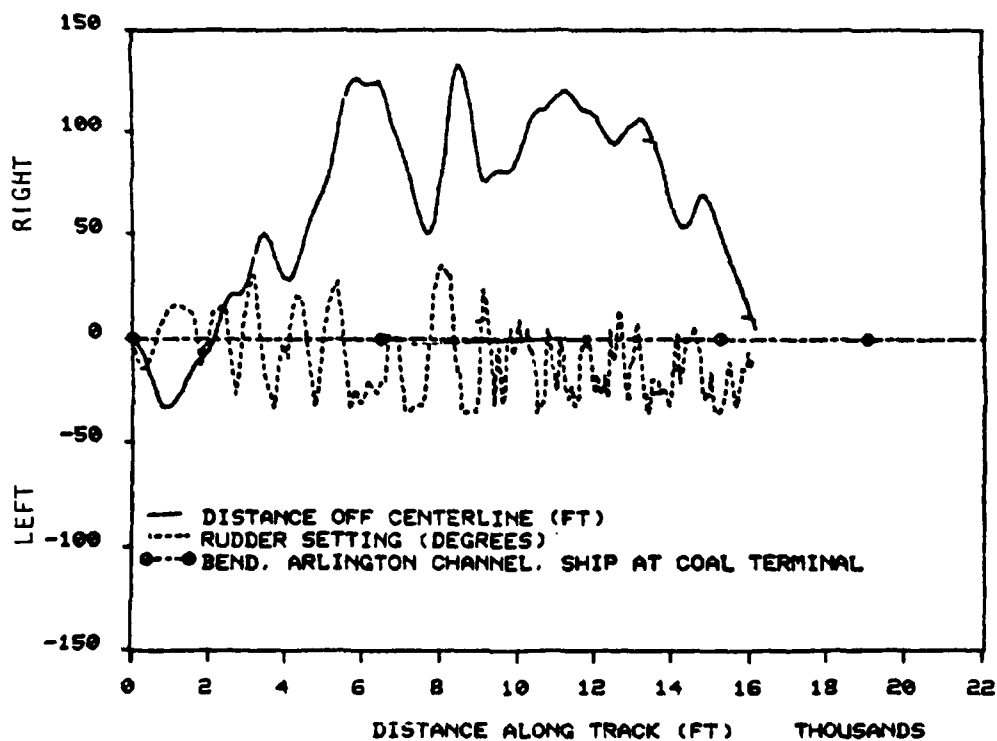
Figure A6b. Distance along track versus rudder setting
and distance off track, Test 6 (trial 1 1 4)
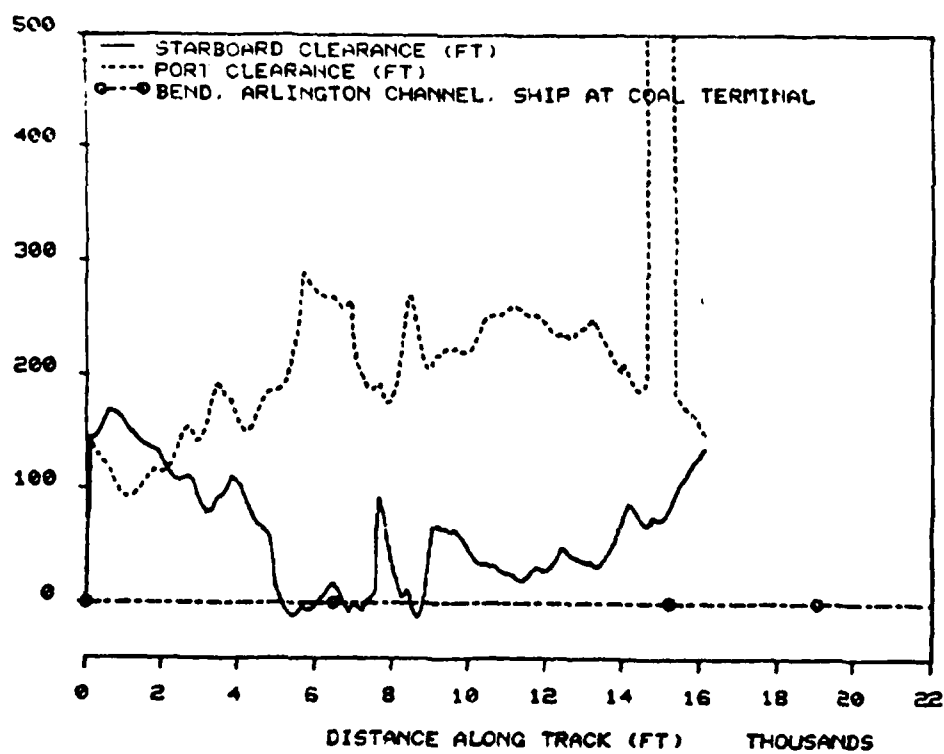
Figure A6c. Distance along track versus port and
starboard clearance, Test 6 (trial 1 1 4)

A18
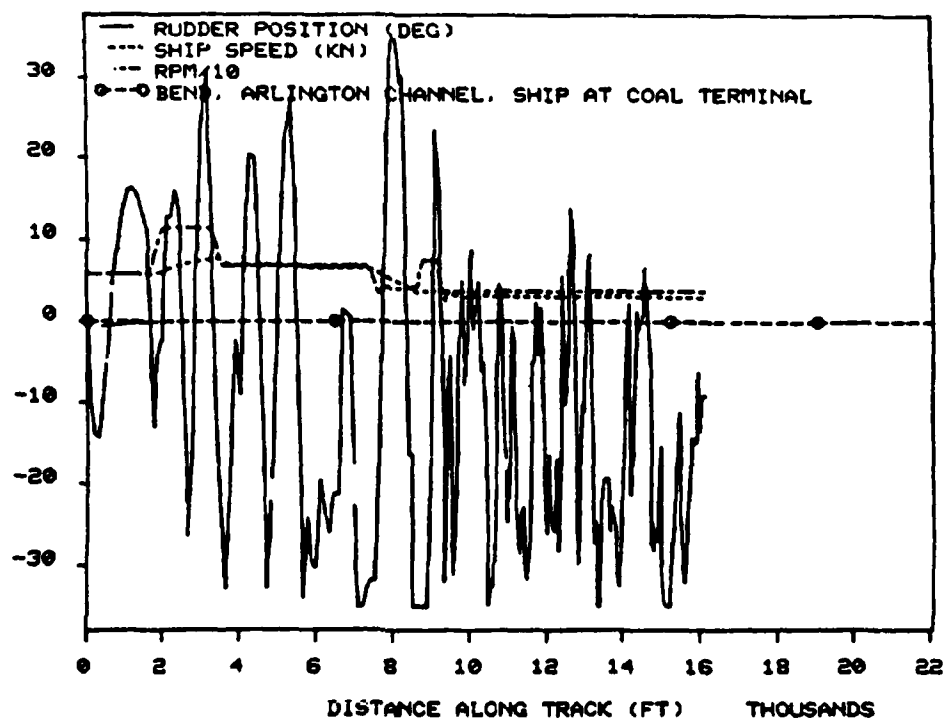
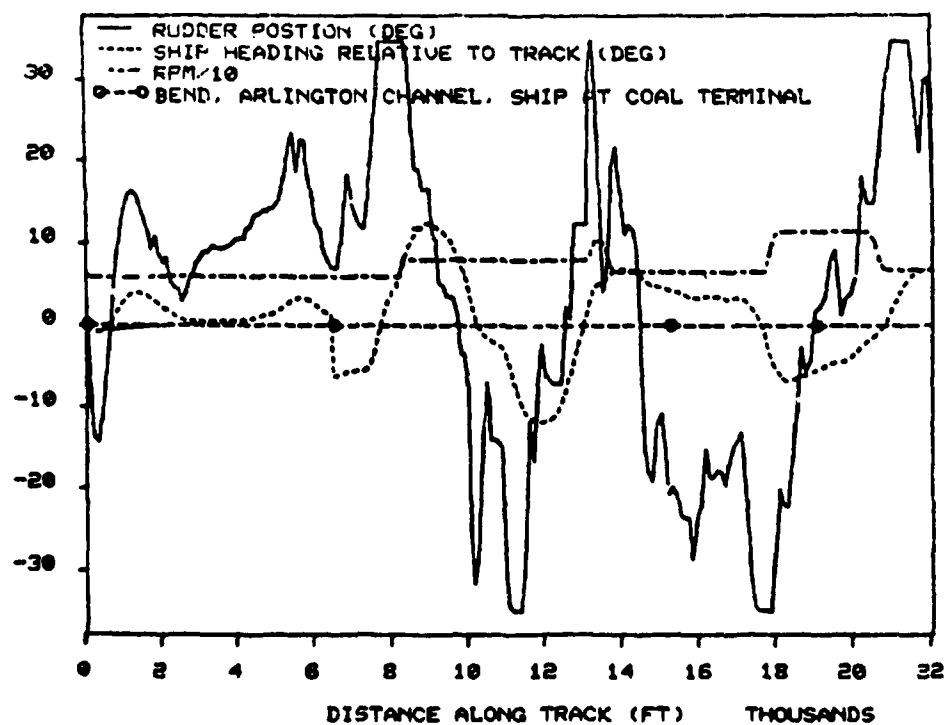Figure A6d. Distance along track versus rudder, speed, and rpm/10, Test 6 (trial 1 1 4)
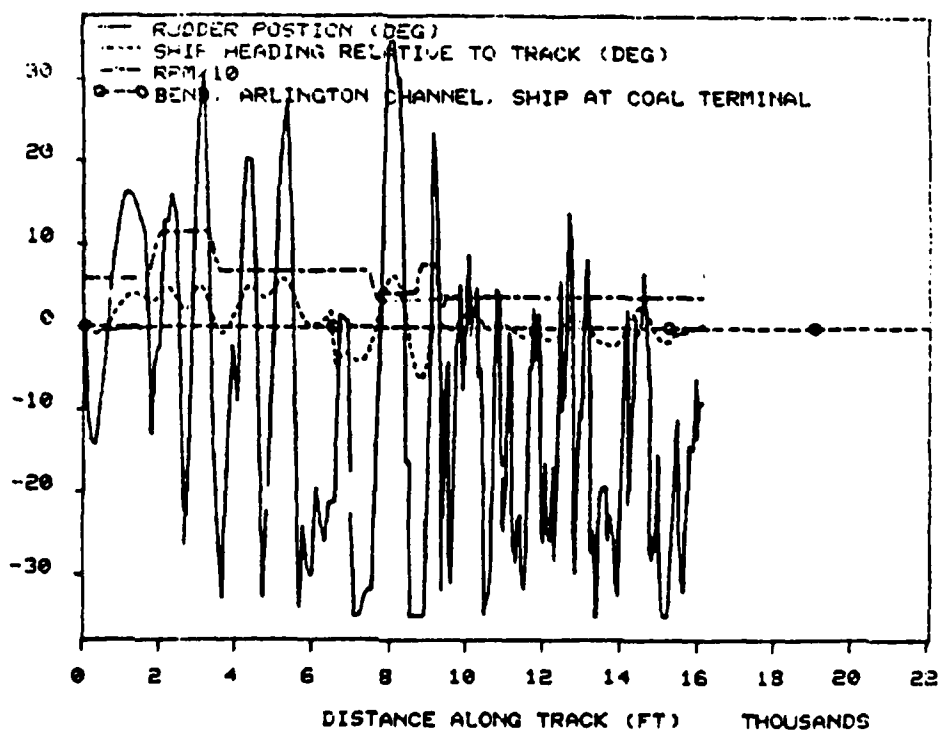
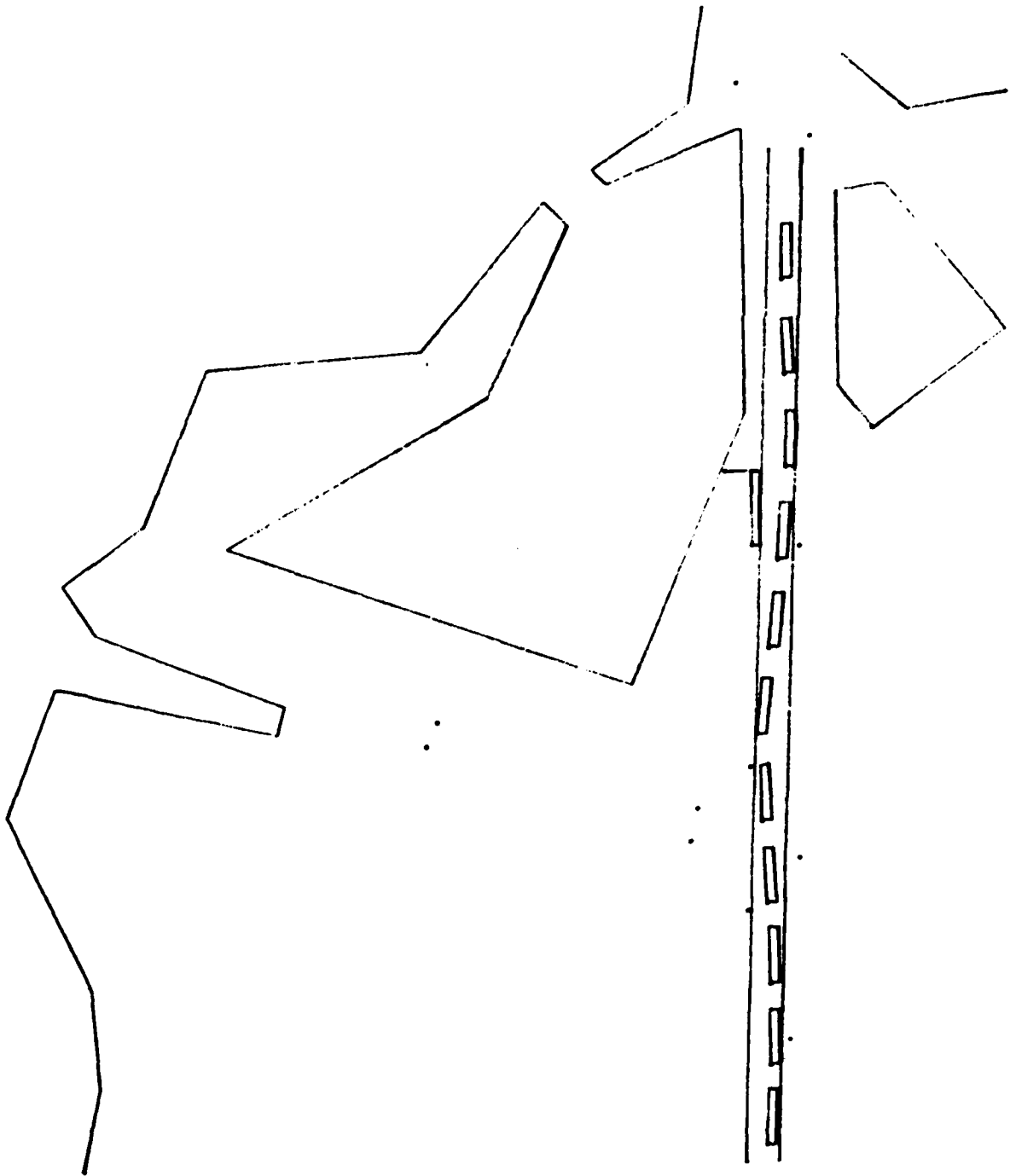Figure A6e. Distance along track versus rudder, heading, and rpm/10, Test 6 (trial 1 1 4)

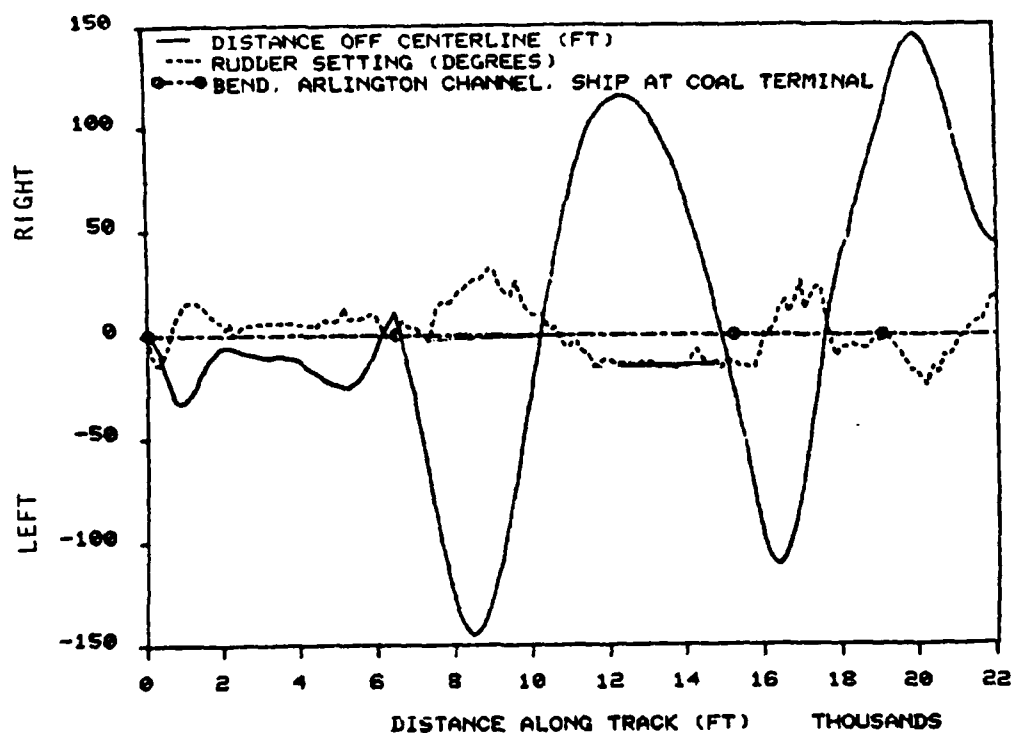A19
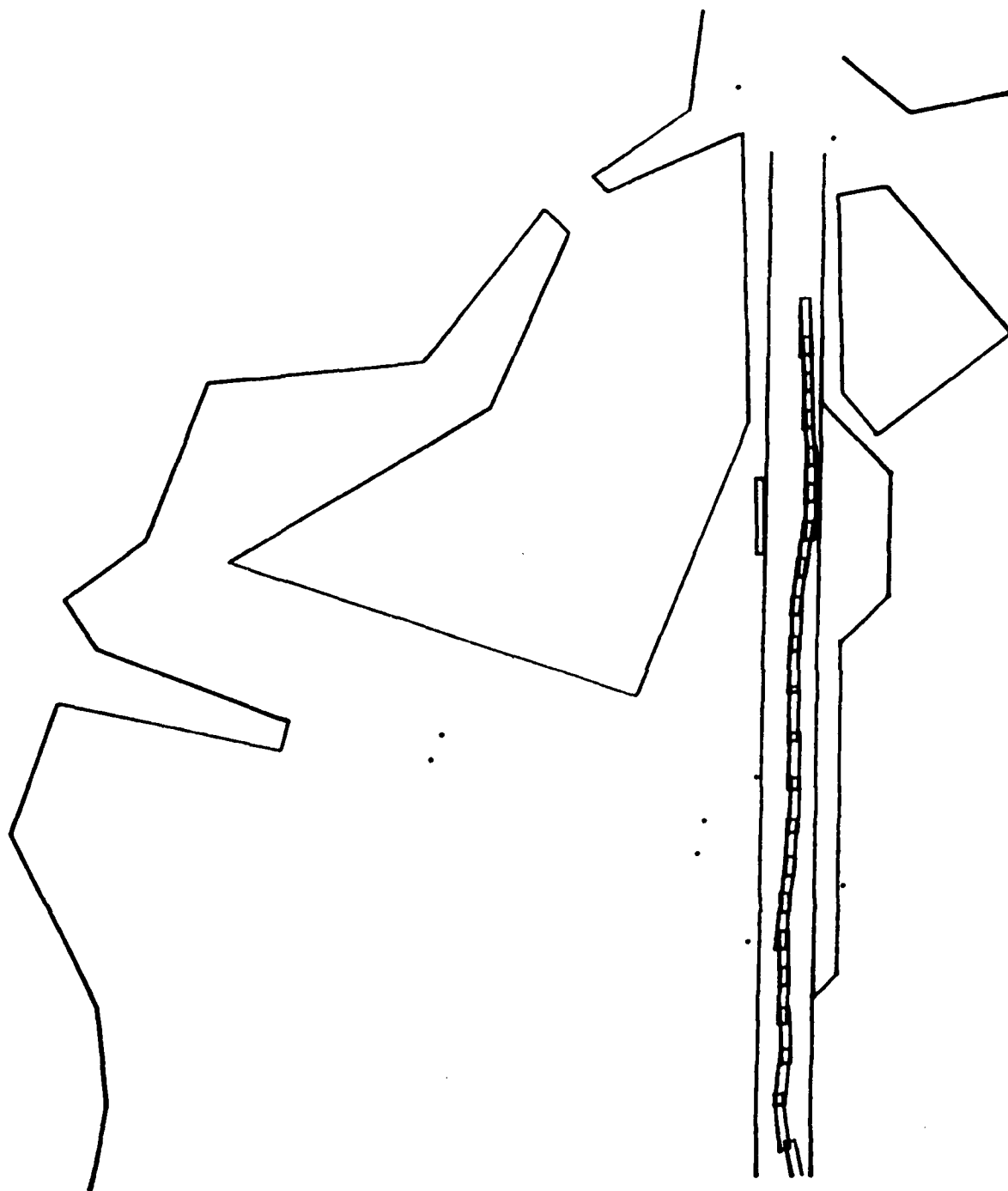
Figure A7a. Ship track for Test 7 (trial 3 1 1)

A20
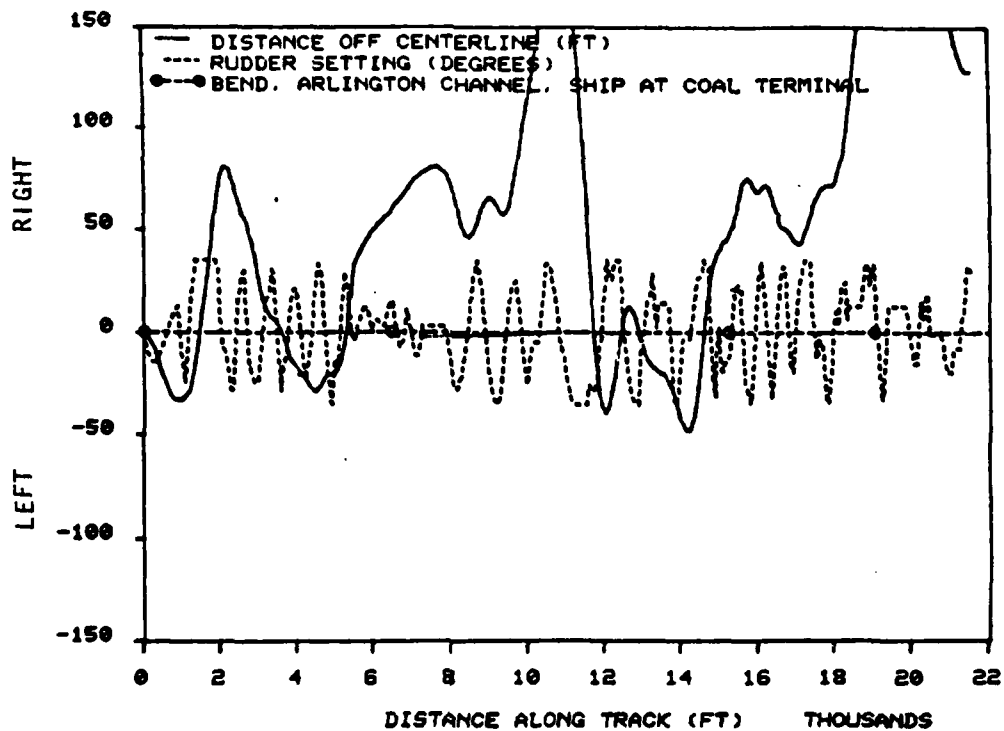
Figure A7b. Distance along track versus rudder setting
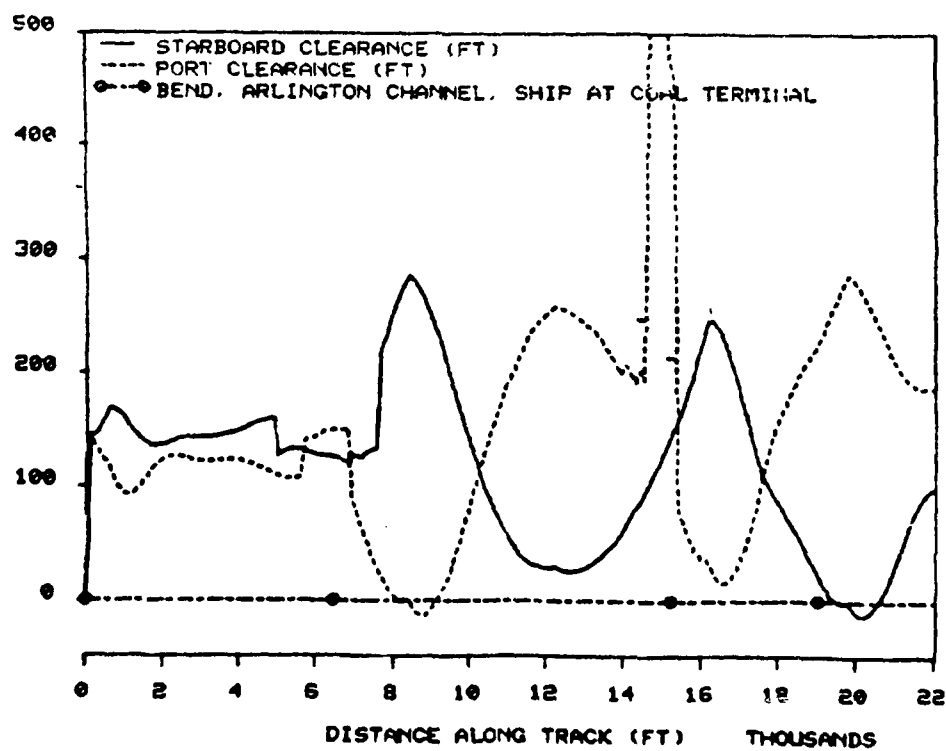and distance off track, Test 7 (trial 3 1 1)
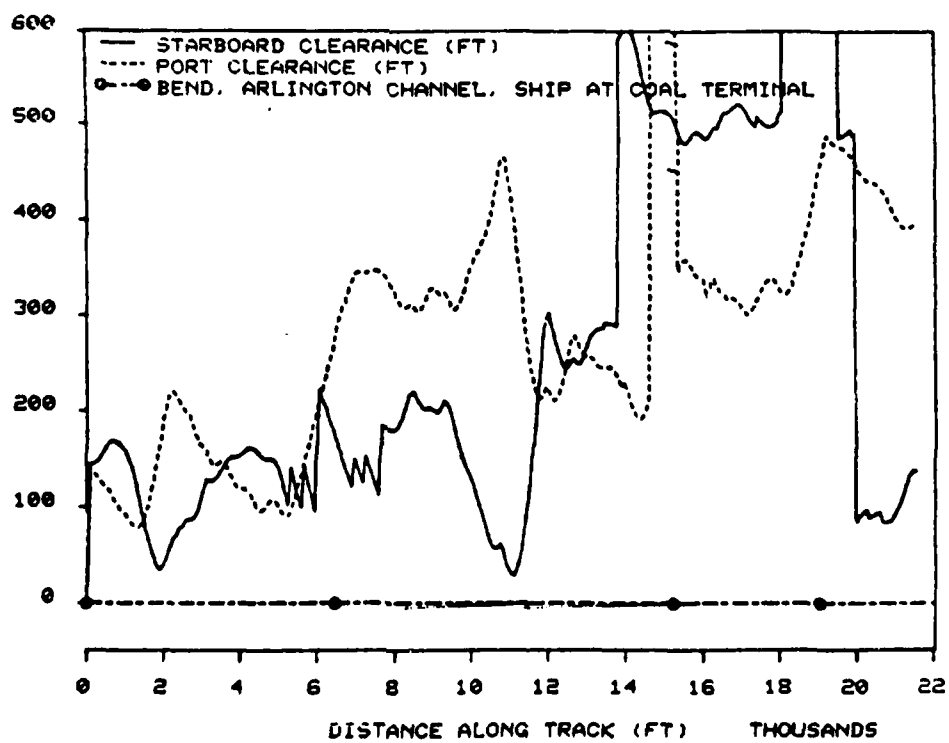
Figure A7c. Distance along track versus port and
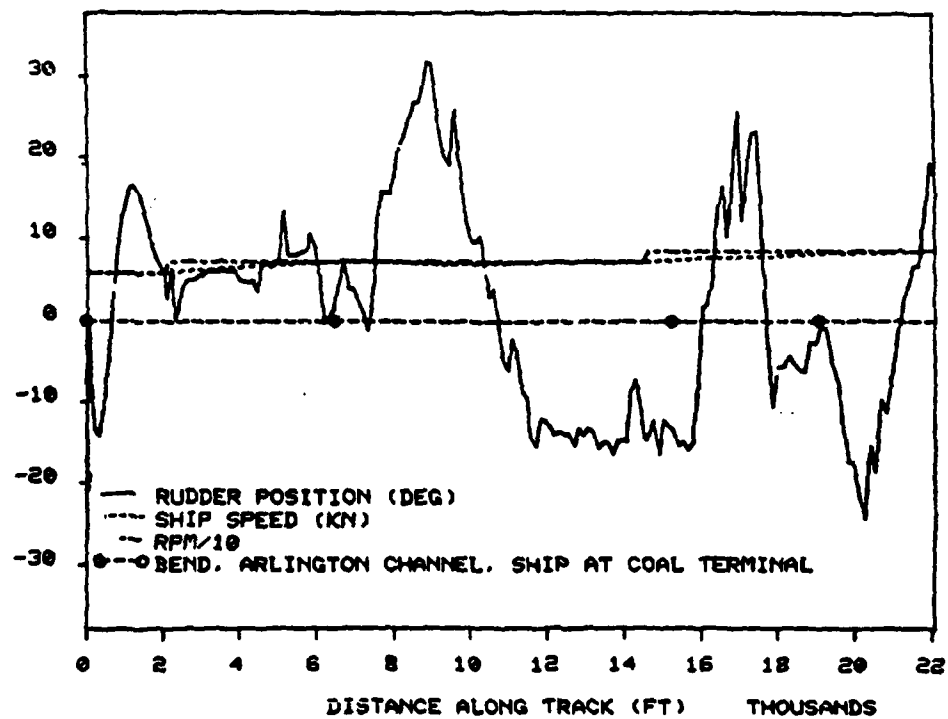starboard clearance, Test 7 (trial 3 1 1)
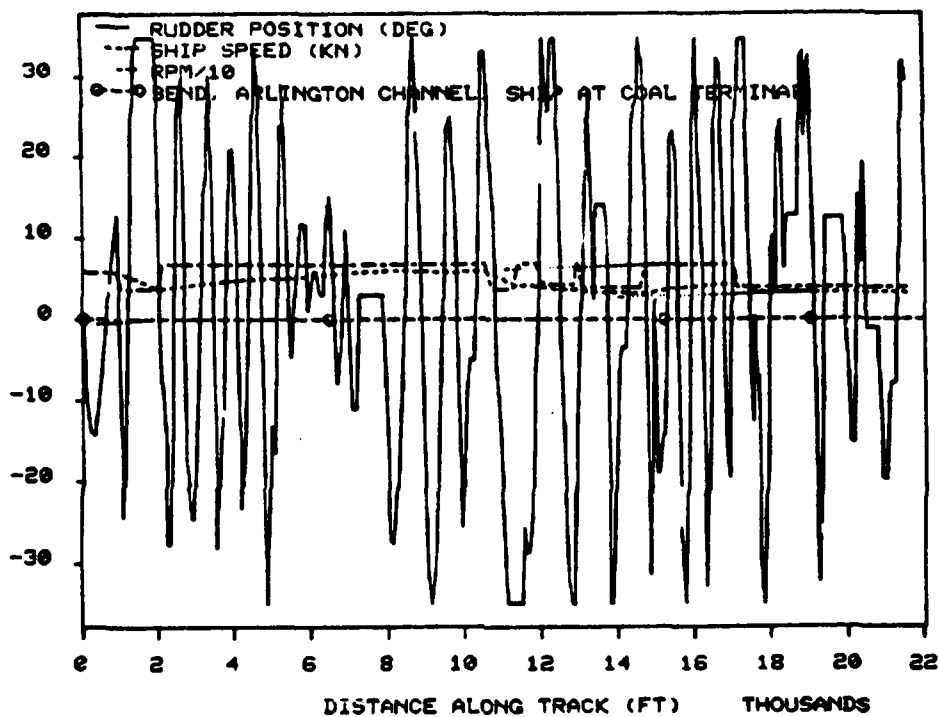
Figure A7d. Distance along track versus rudder, speed,
and rpm/10, Test 7 (trial 3 1 1)
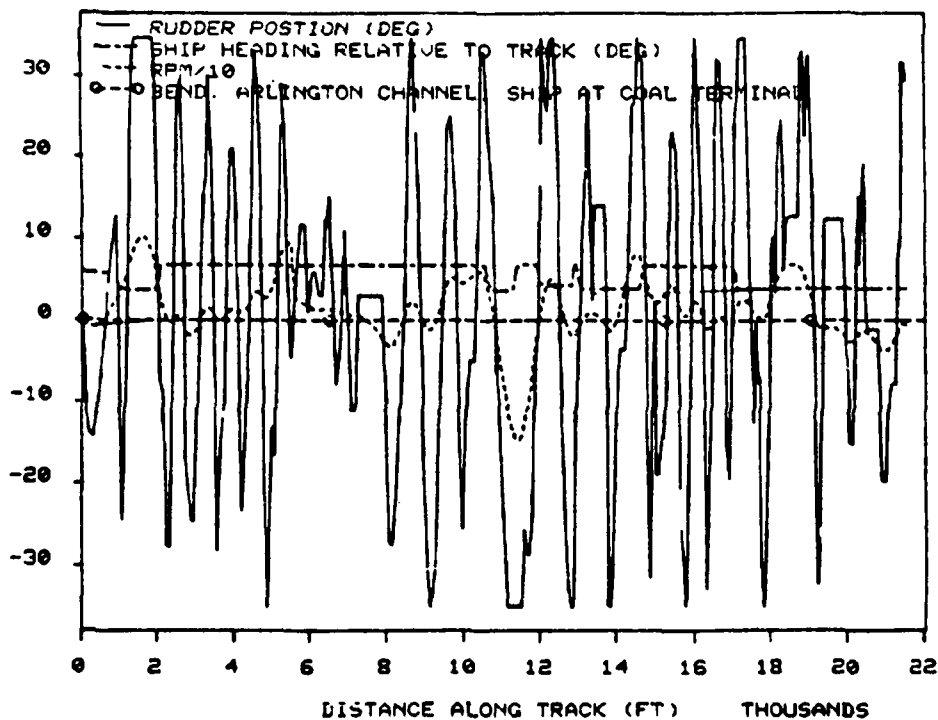
Figure A7e. Distance along track versus rudder, heading,
and rpm/10, Test 7 (trial 3 1 1)

A22
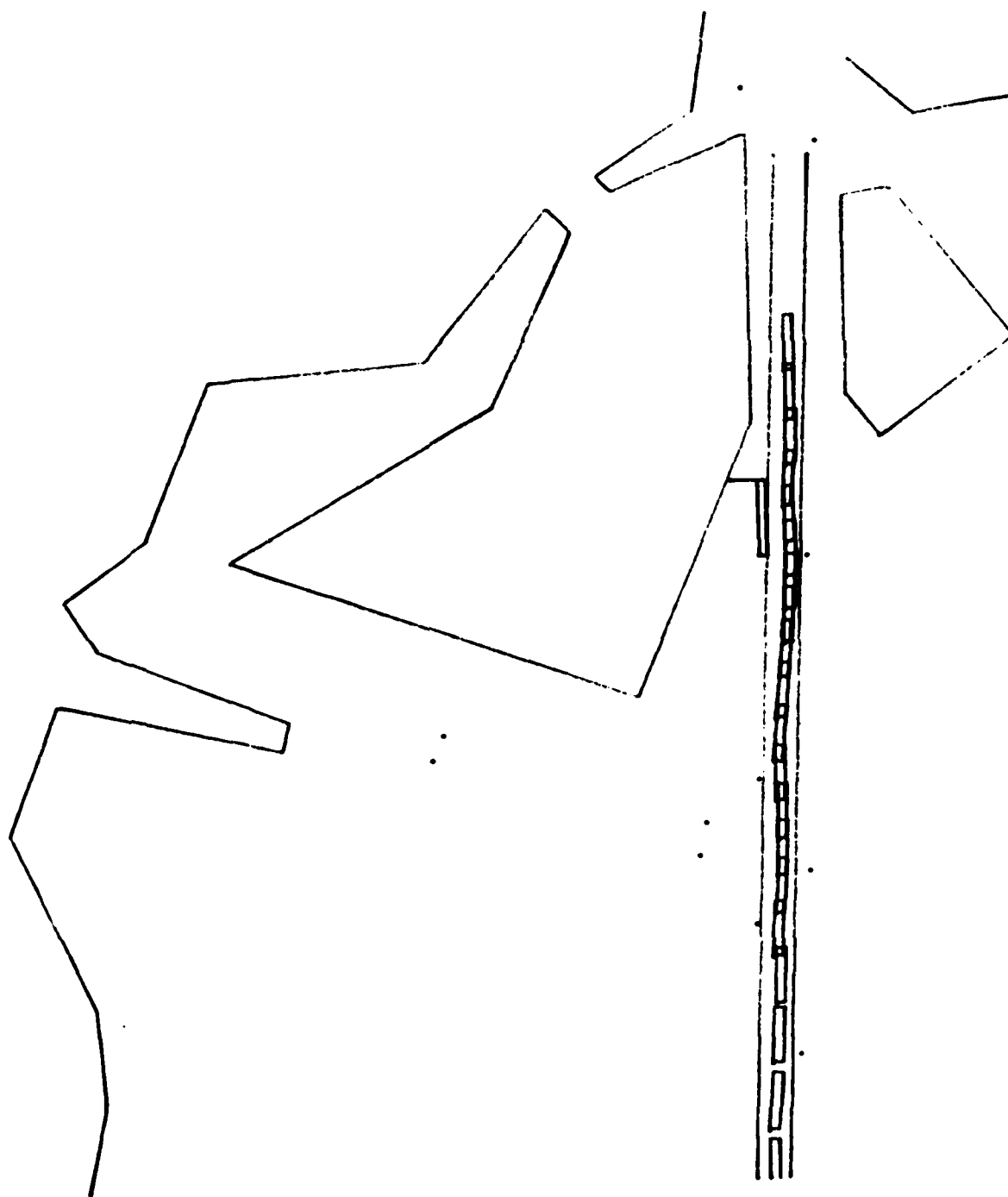
Figure A8a. Ship track for Test 8 (trial 2 1 5)

A23
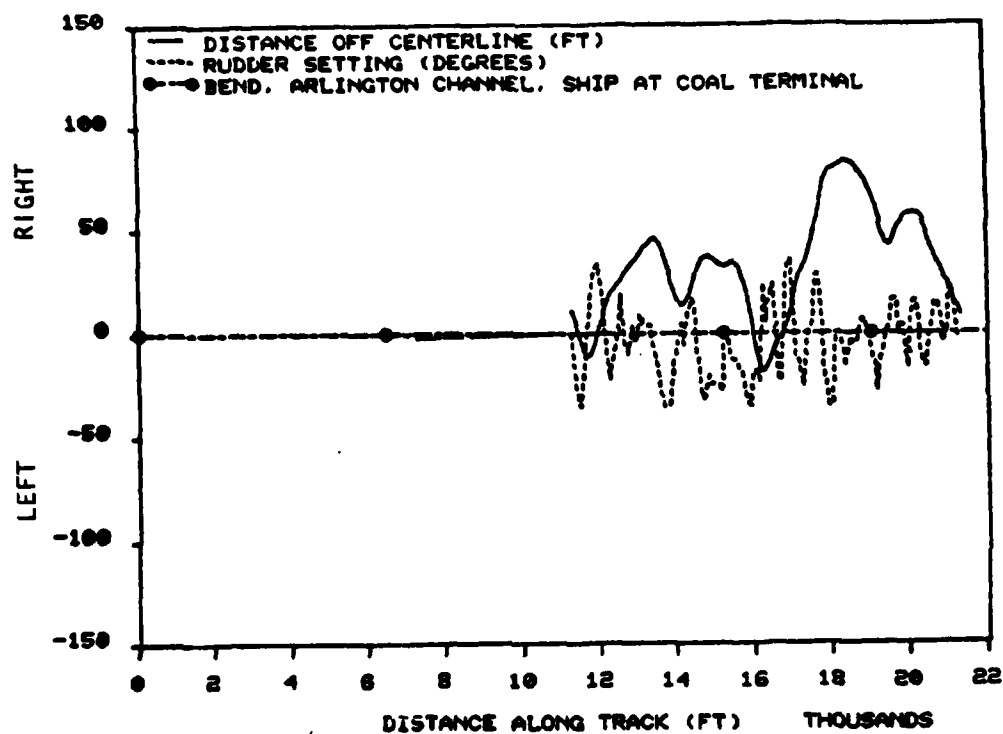
Figure A8b. Distance along track versus rudder setting and distance off track, Test 8 (trial 2 1 5)
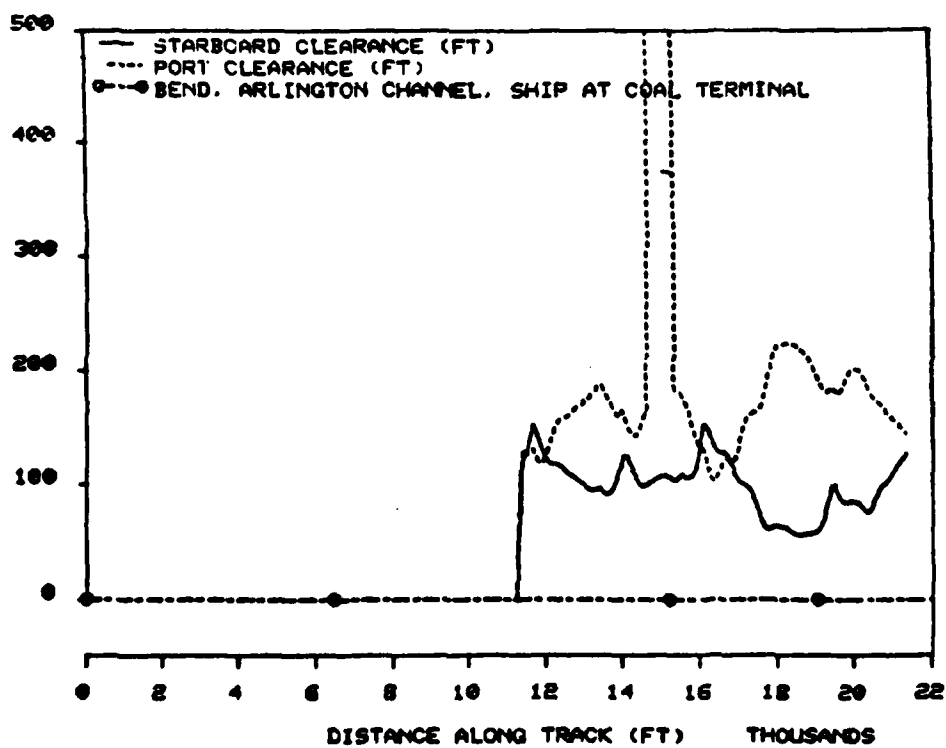
Figure A8c. Distance along track versus port and starboard clearance, Test 8 (trial 2 1 5)

A24
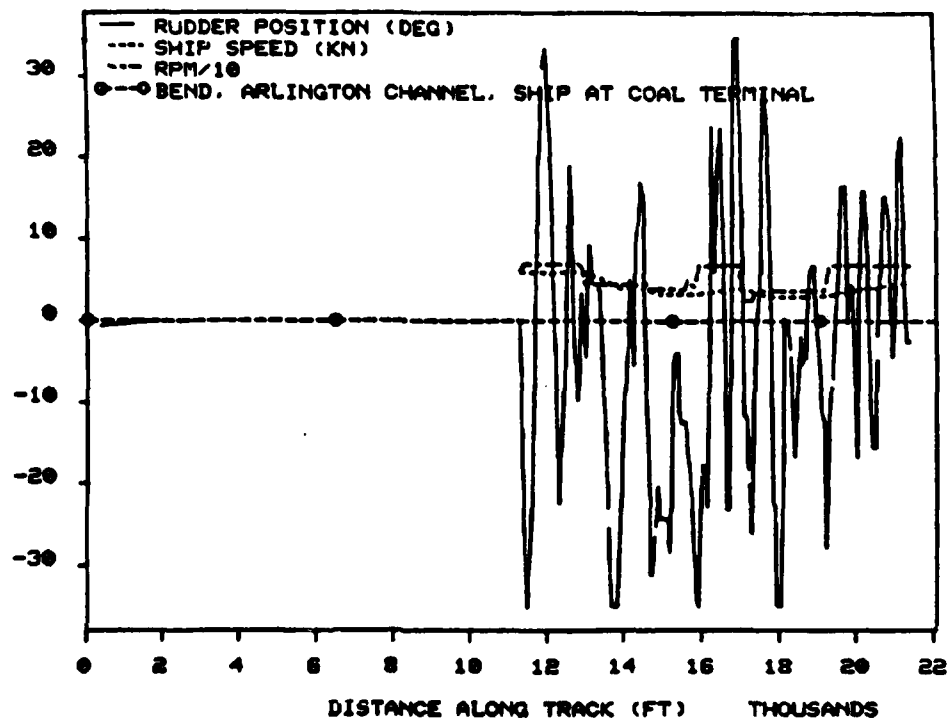
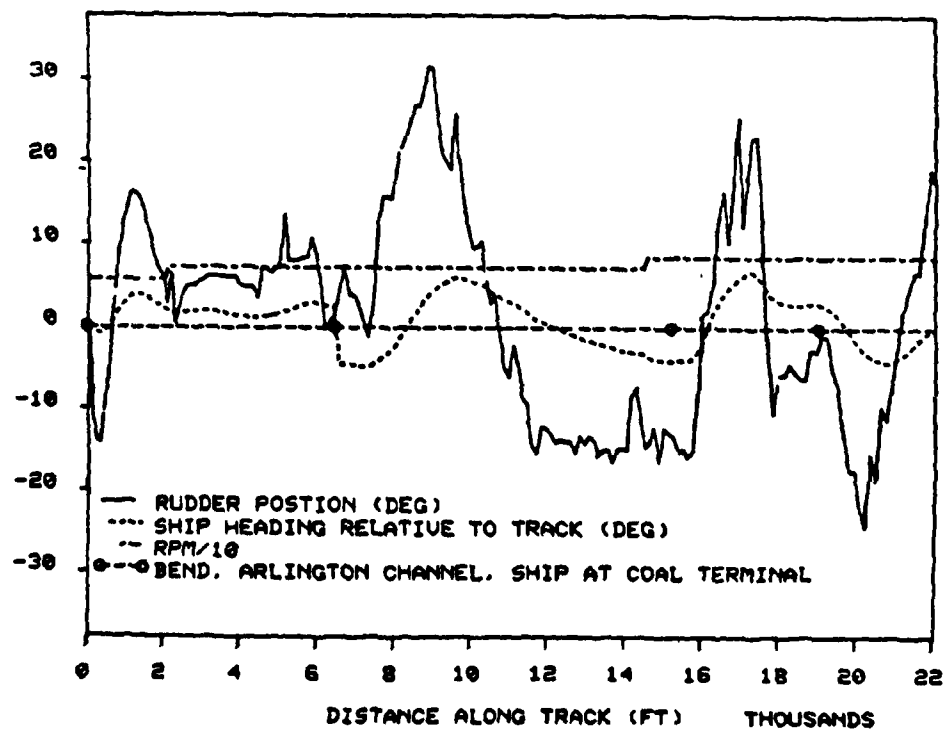Figure A8d. Distance along track versus rudder, speed, and rpm/10, Test 8 (trial 2 1 5)
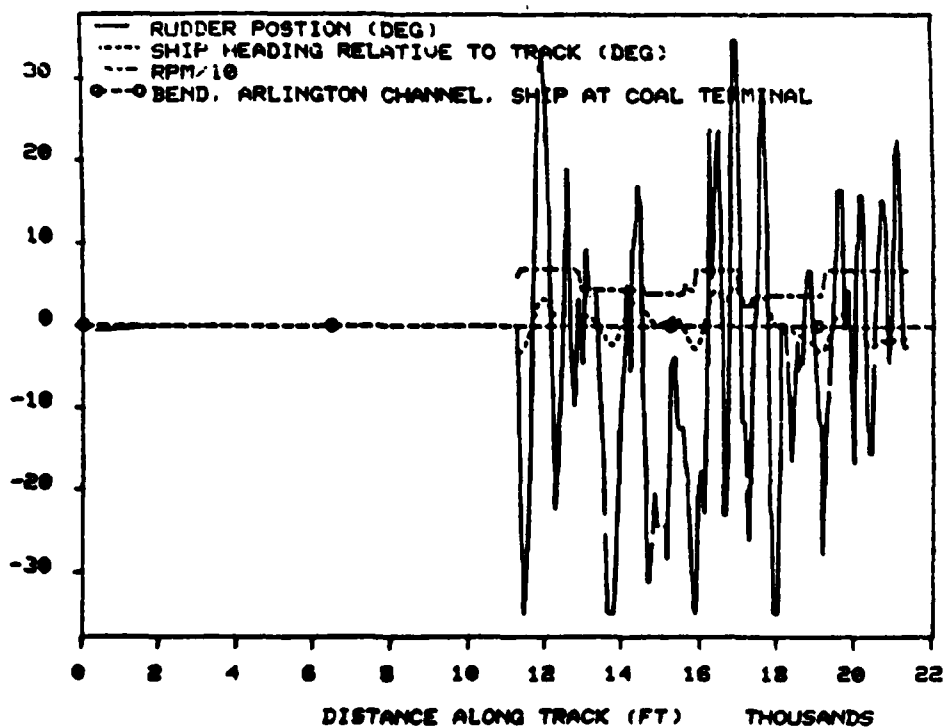
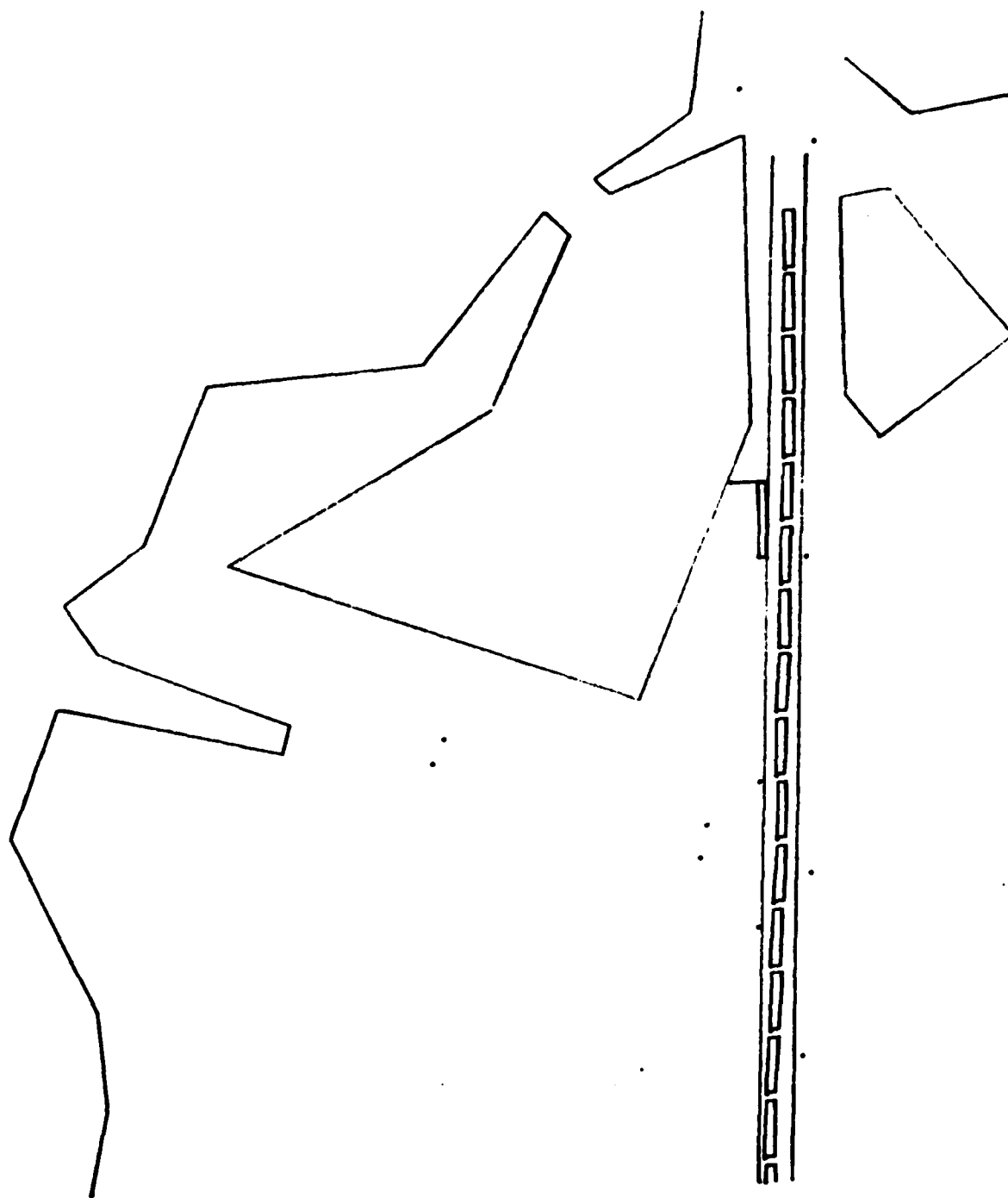Figure A8e. Distance along track versus rudder, heading, and rpm/10, Test 8 (trial 2 1 5)
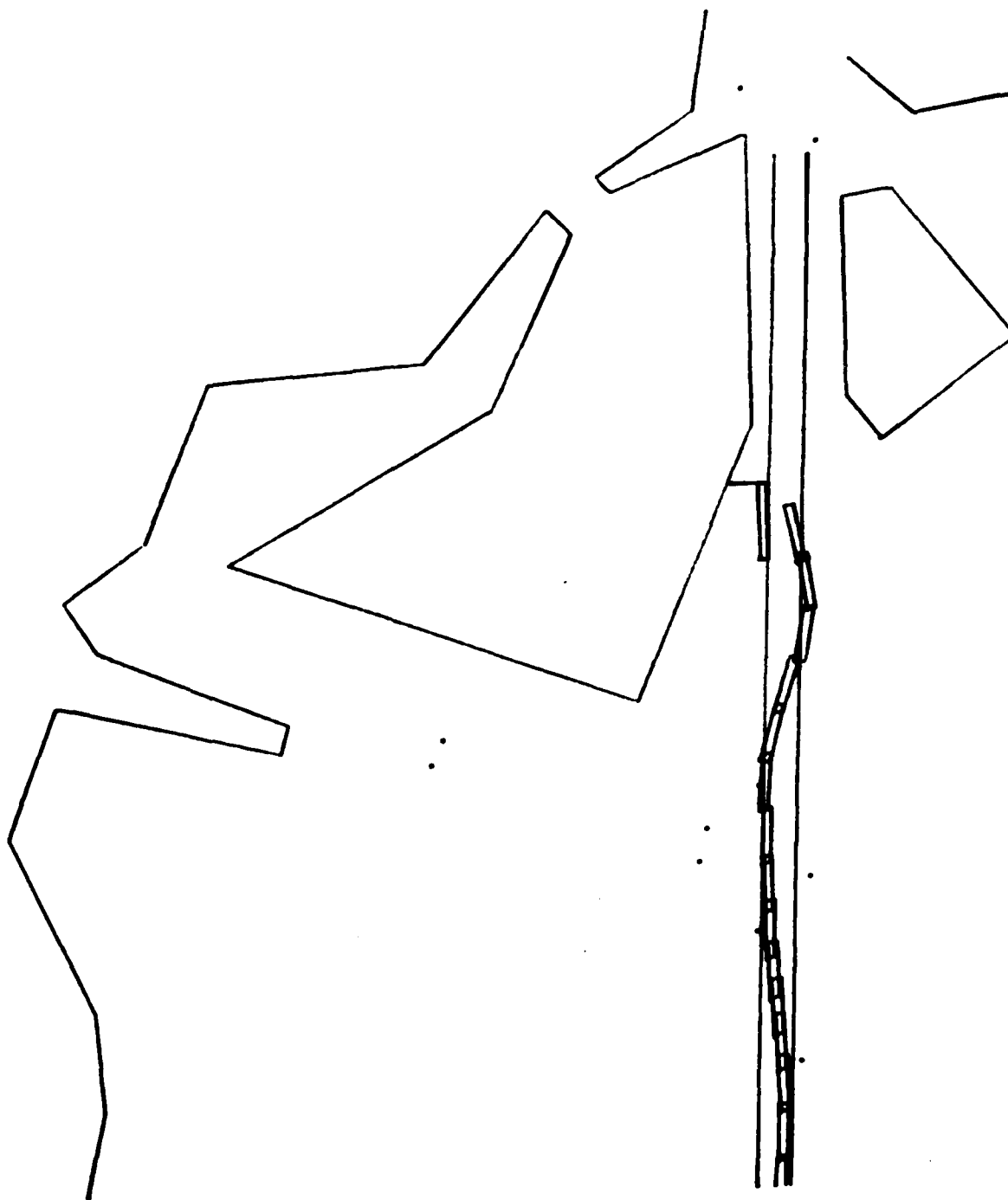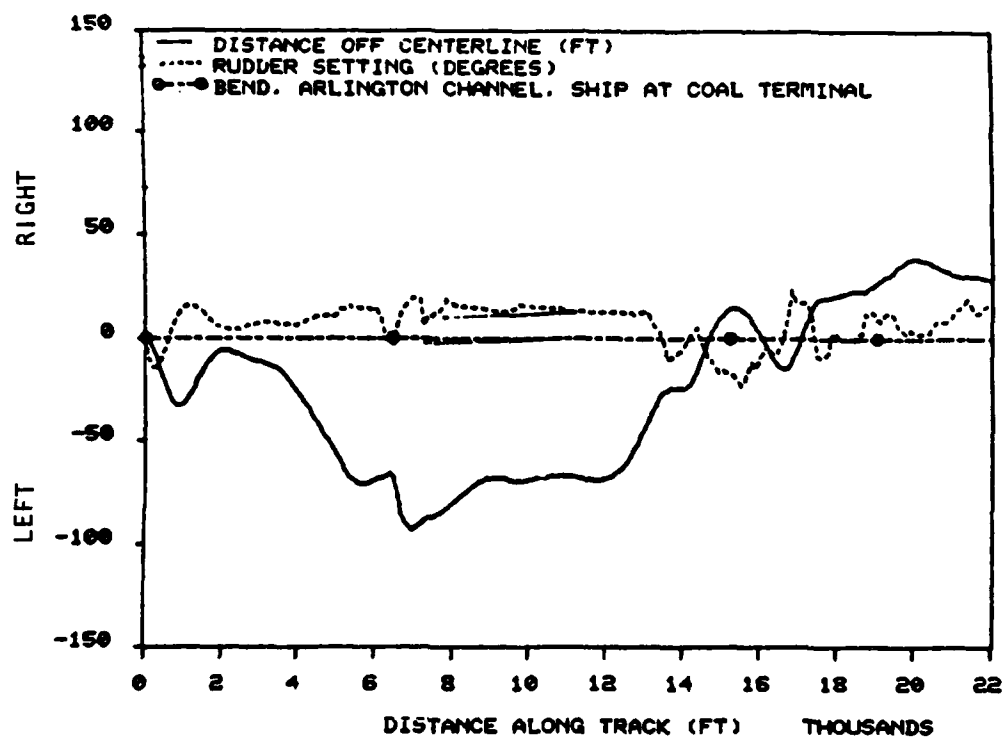
Figure A9a. Ship track for Test 9 (trial 1 2 1)

A26
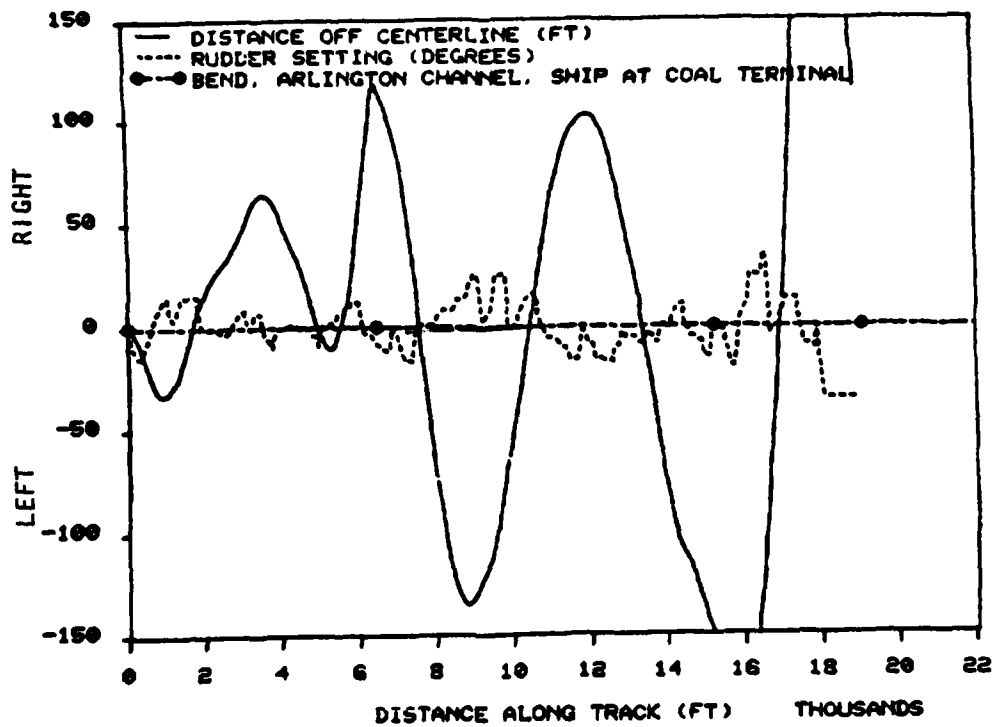
Figure A9b. Distance along track versus rudder setting and distance off track, Test 9 (trial 1 2 1)
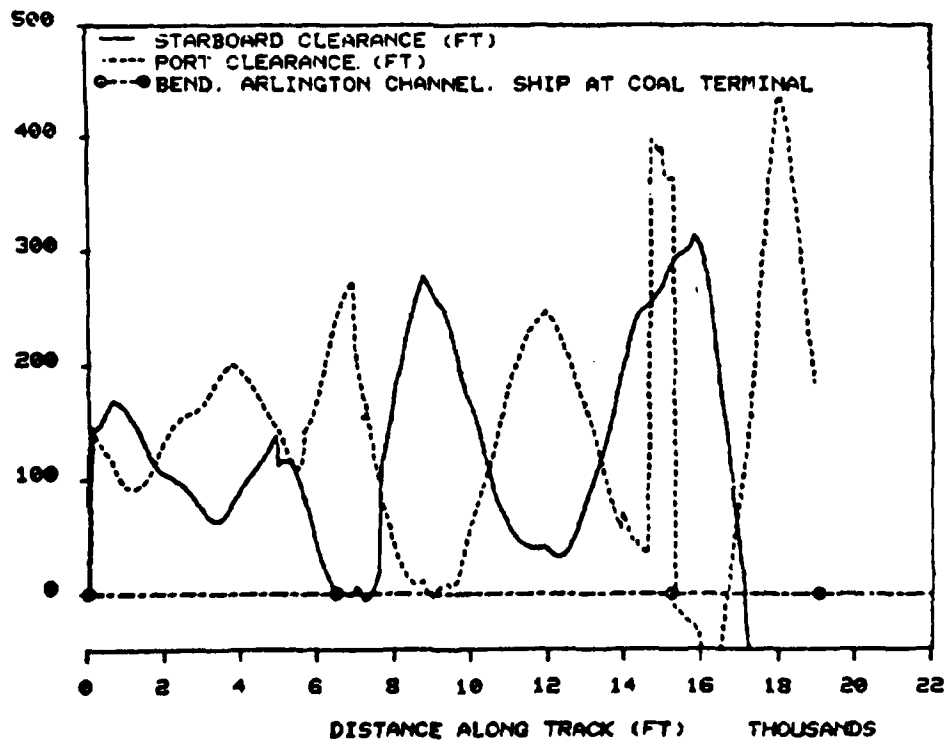
Figure A9c. Distance along track versus port and starboard clearance, Test 9 (trial 1 2 1)

A27
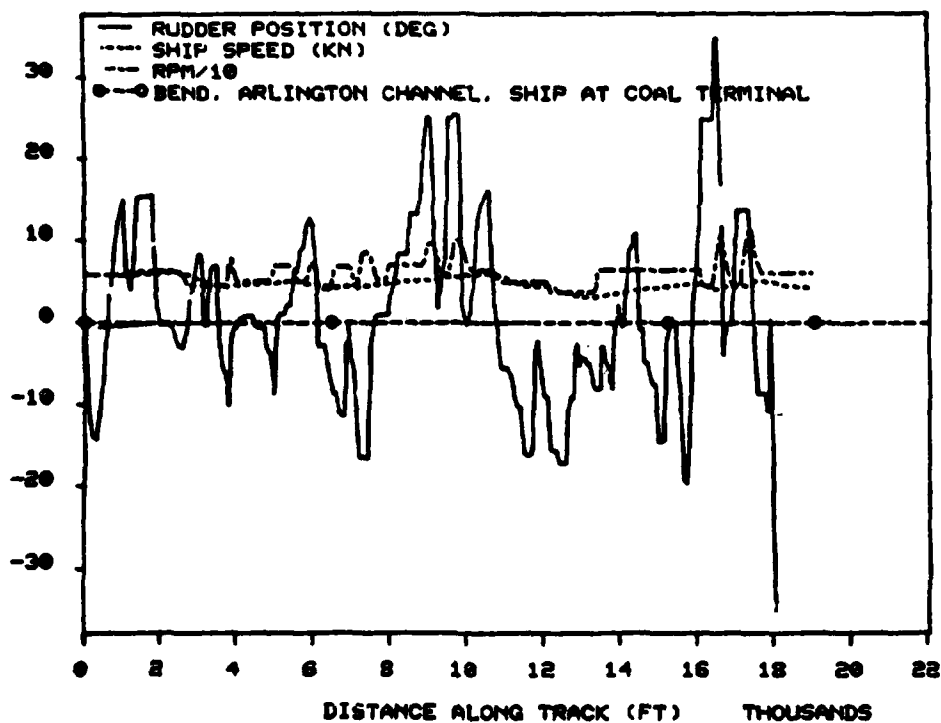
Figure A9d. Distance along track versus rudder, speed, and rpm/10, Test 9 (trial 1 2 1)
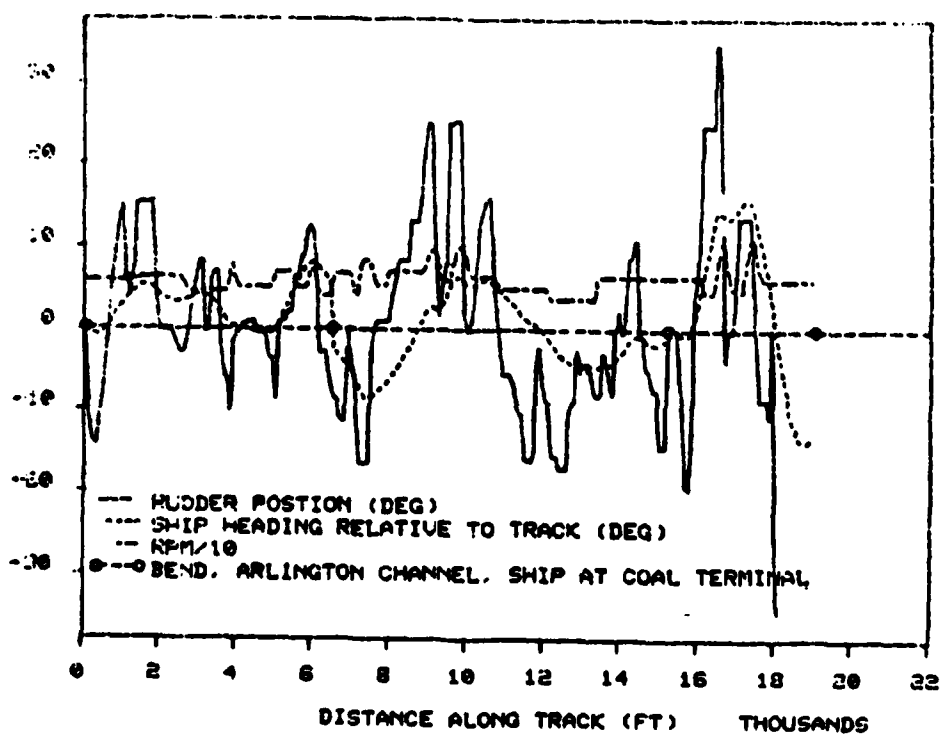
Figure A9e. Distance along track versus rudder, heading, and rpm/10, Test 9 (trial 1 2 1)
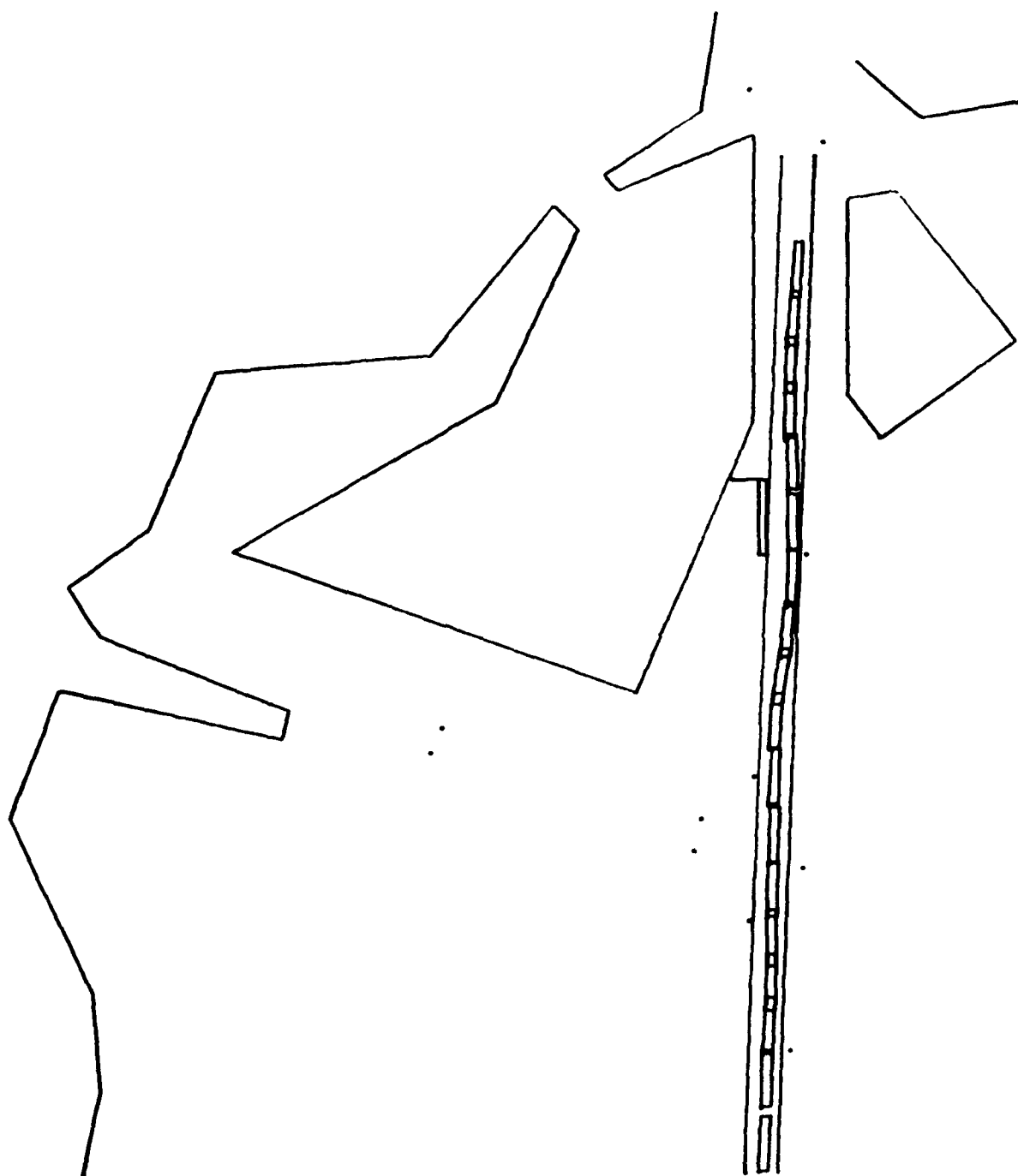
Figure A10a. Ship track for Test 10 (trial 1 2 2)
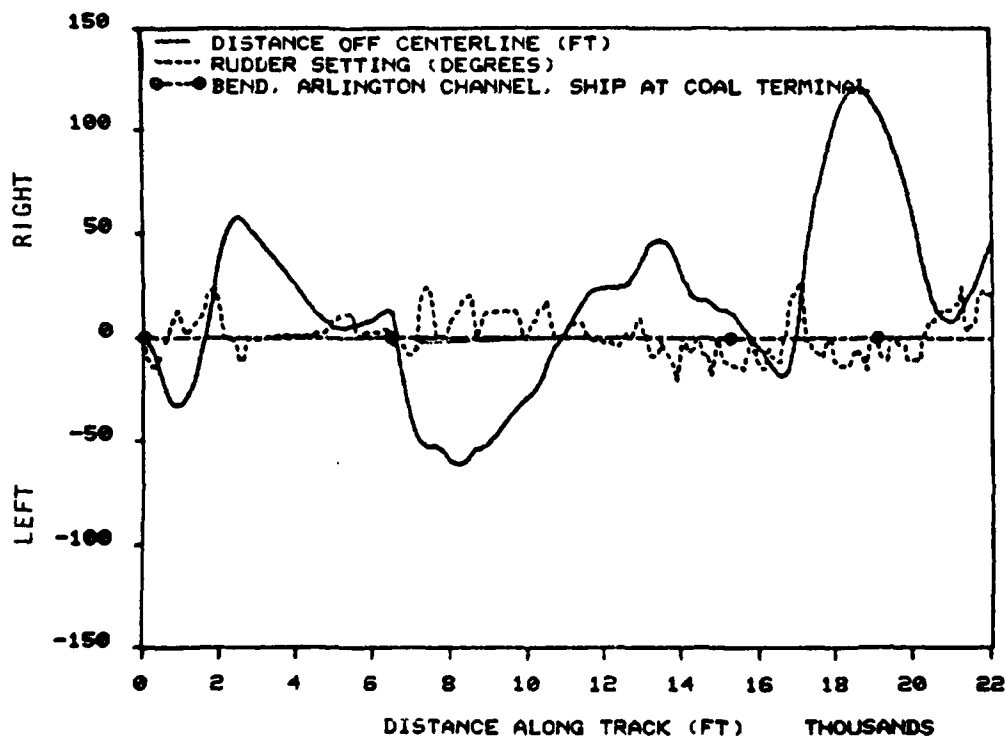
Figure A10b. Distance along track versus rudder setting
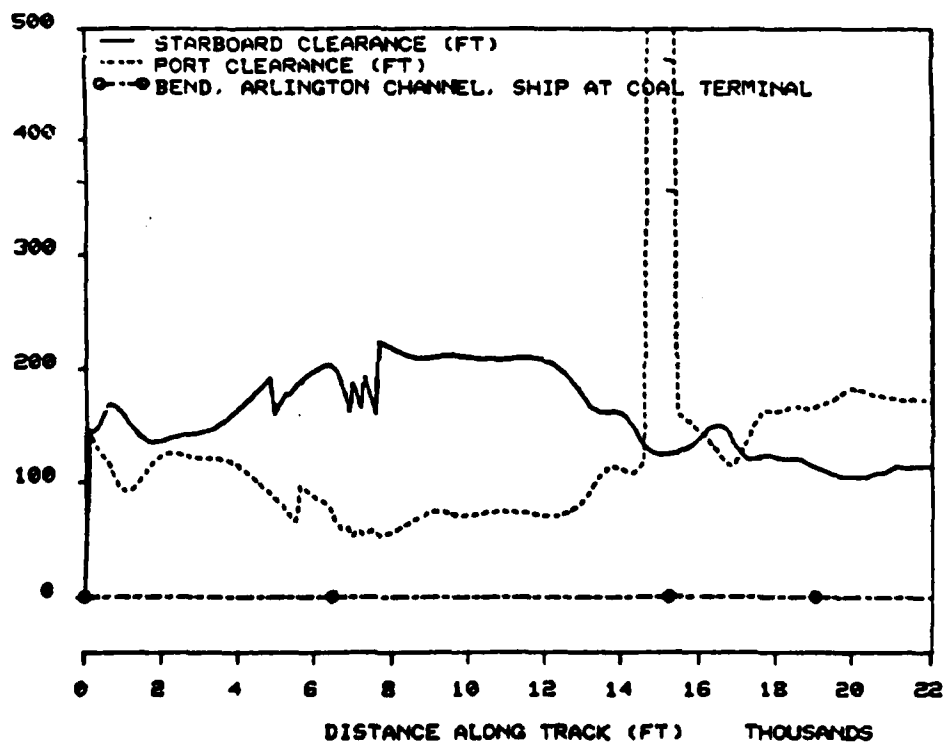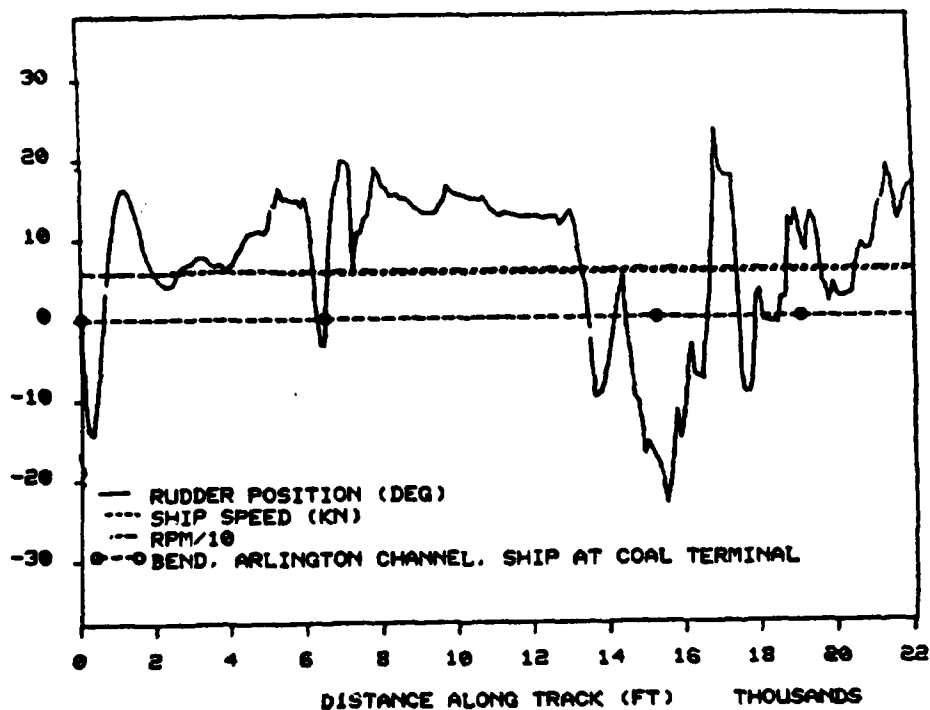and distance off track, Test 10 (trial 1 2 2)
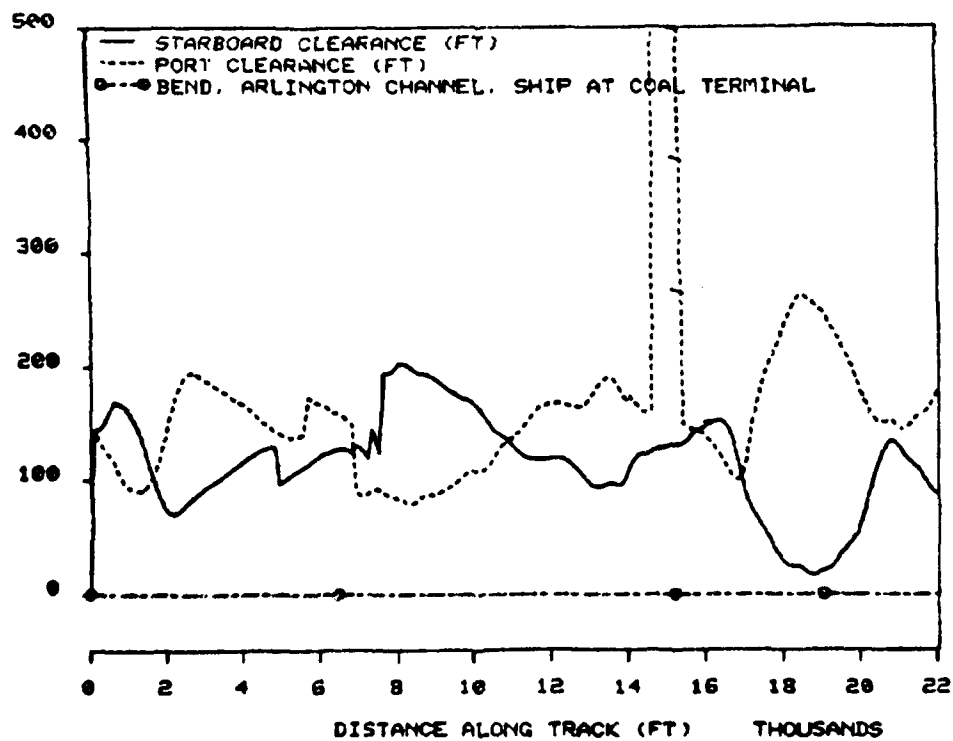
Figure A10c. Distance along track versus port and
starboard clearance, Test 10 (trial 1 2 2)

A30
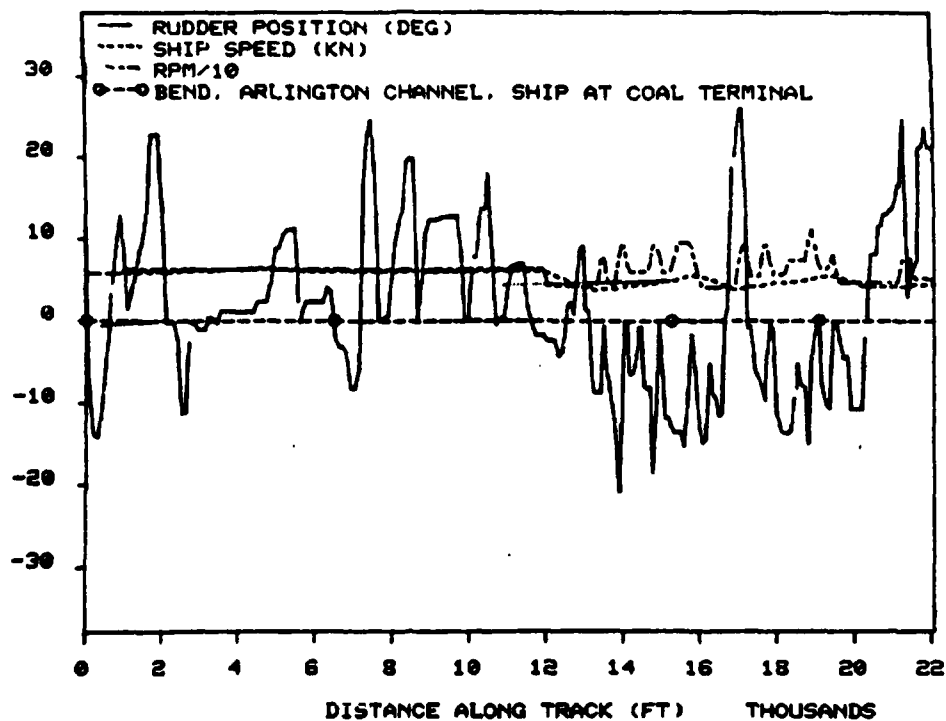
Figure A10d. Distance along track versus rudder, speed, and rpm/10, Test 10 (trial 1 2 2)
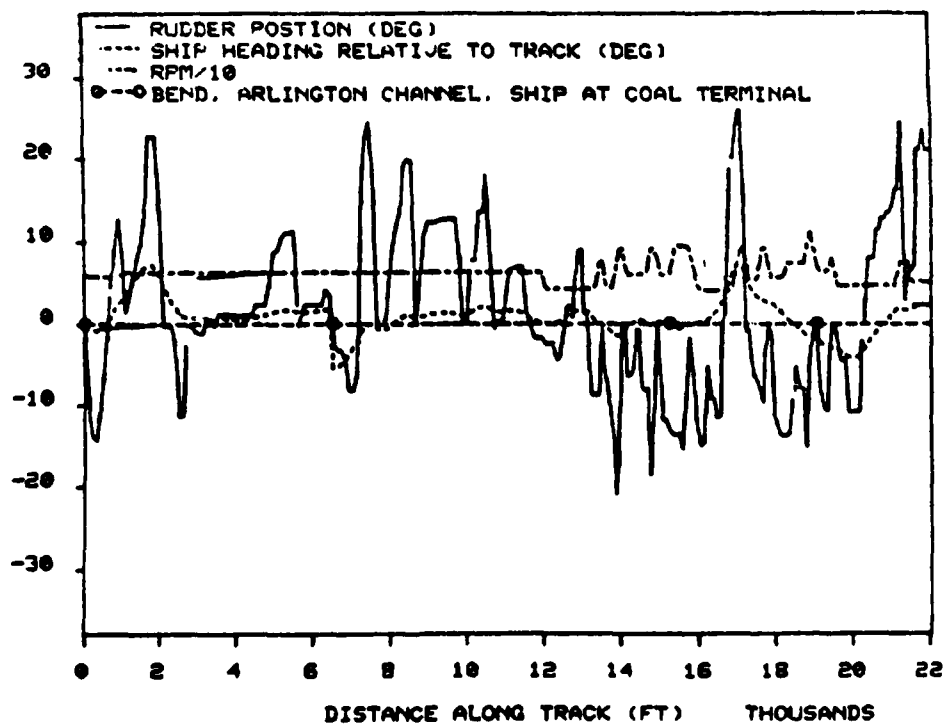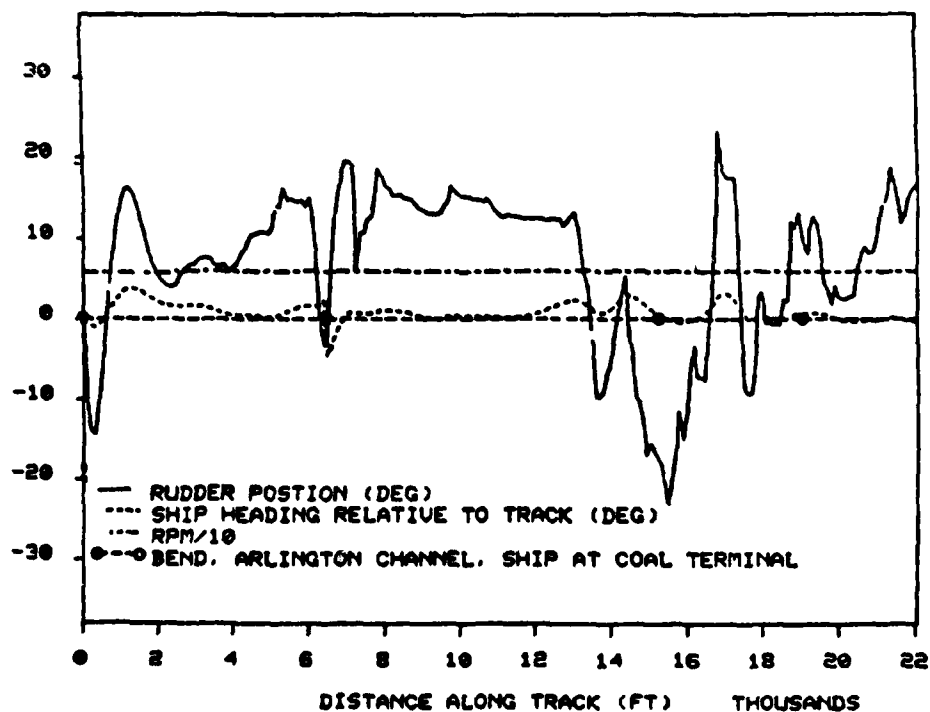

Figure A10e. Distance along track versus rudder, heading, and rpm/10, Test 10 (trial 1 2 2)
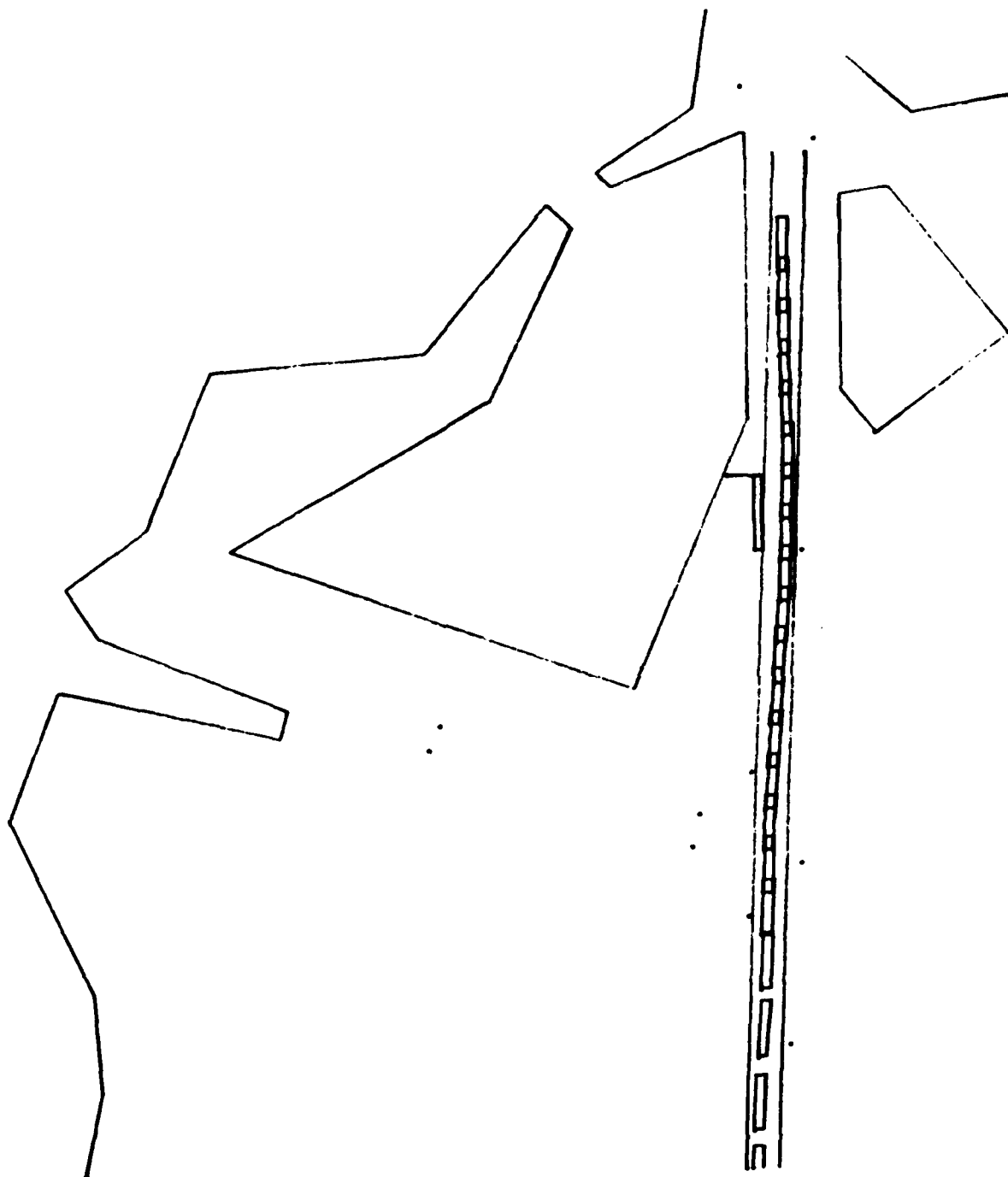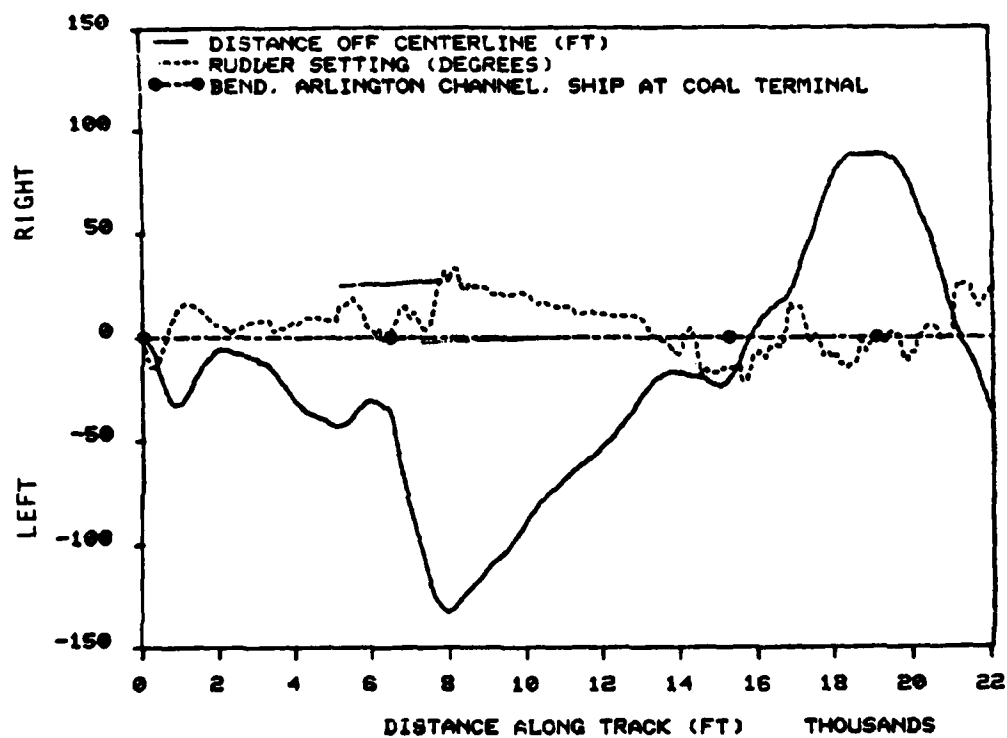
A31

Figure A11a. Ship track for Test 11 (trial 1 2 3)
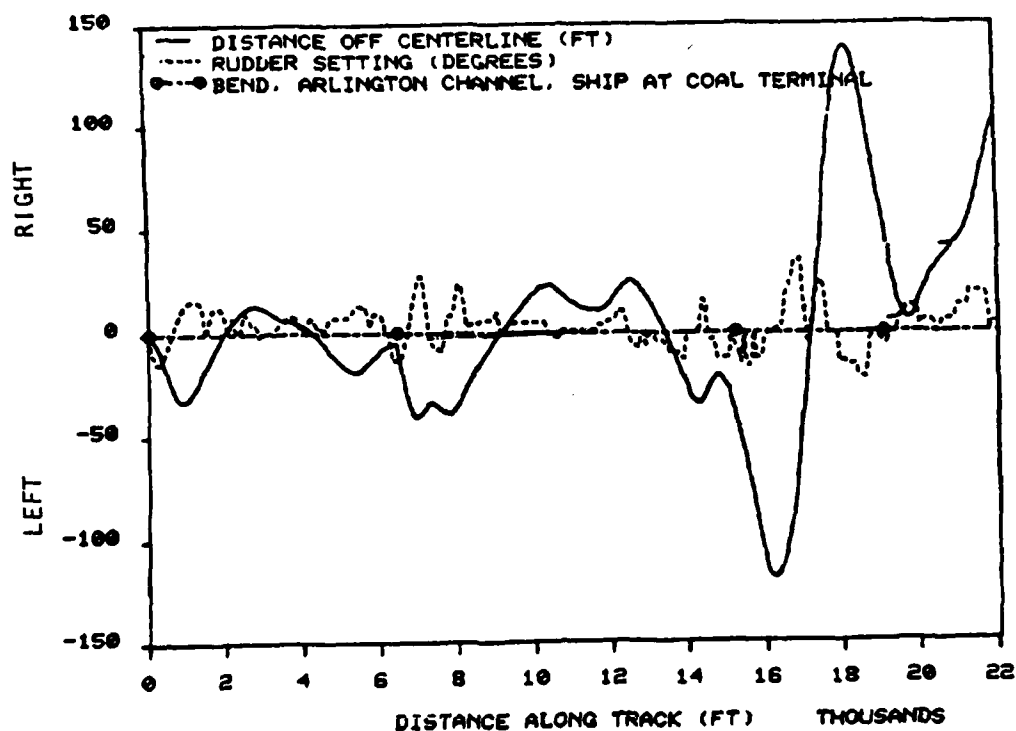
Figure A11b. Distance along track vesus rudder setting
and distance off track, Test 11 (trial 1 2 3)
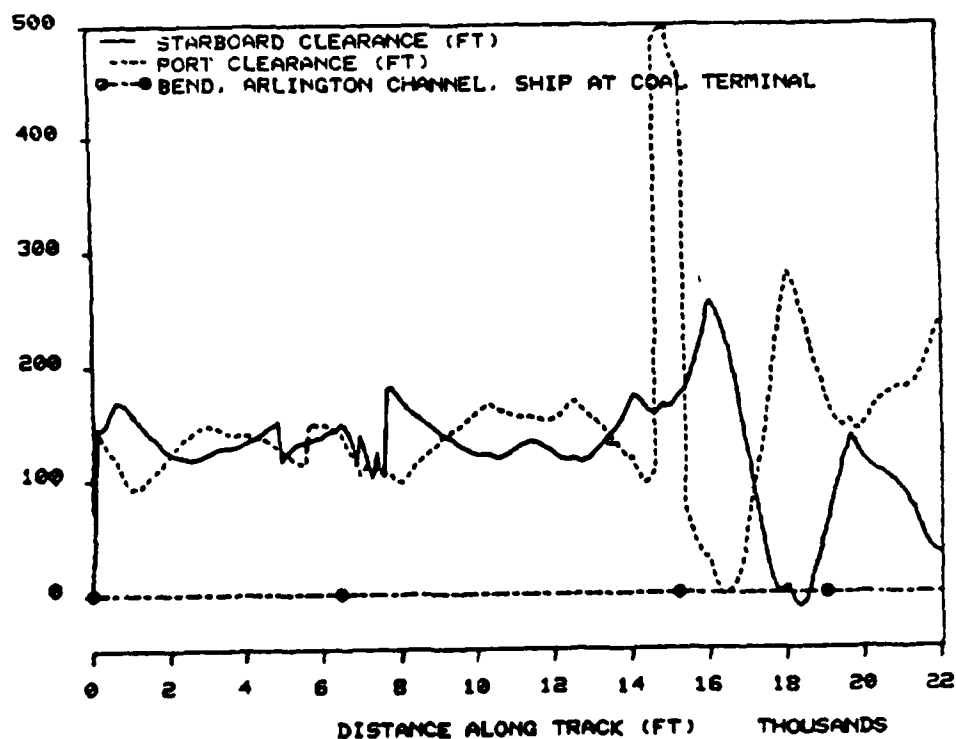
Figure A11c. Distance along track versus port and
starboard clearance, Test 11 (trial 1 2 3)

A33
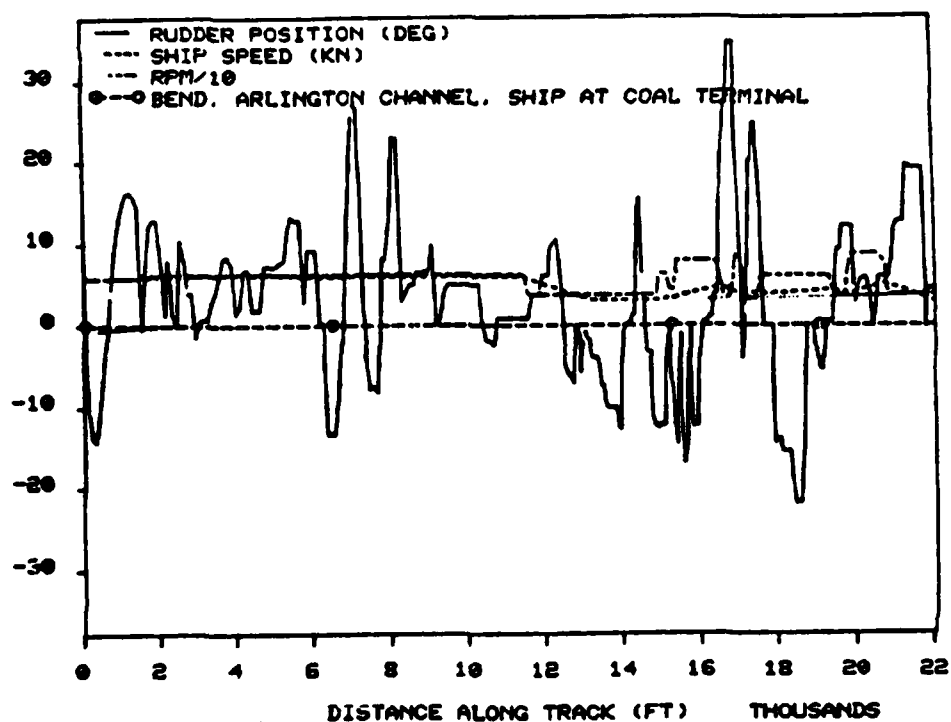
Figure A11d. Distance along track versus rudder, speed,
and rpm/10, Test 11 (trial 1 2 3)
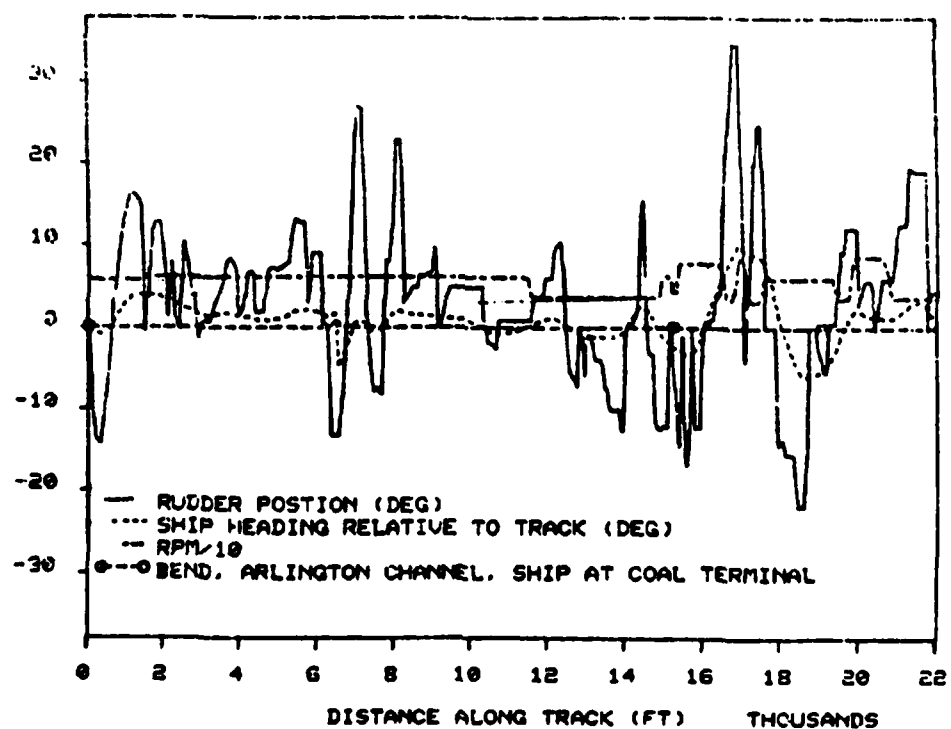
Figure A11e. Distance along track versus rudder, heading,
and rpm/10, Test 11 (trial 1 2 3)

A34

Figure A12a. Ship track for Test 12 (trial 1 2 4)
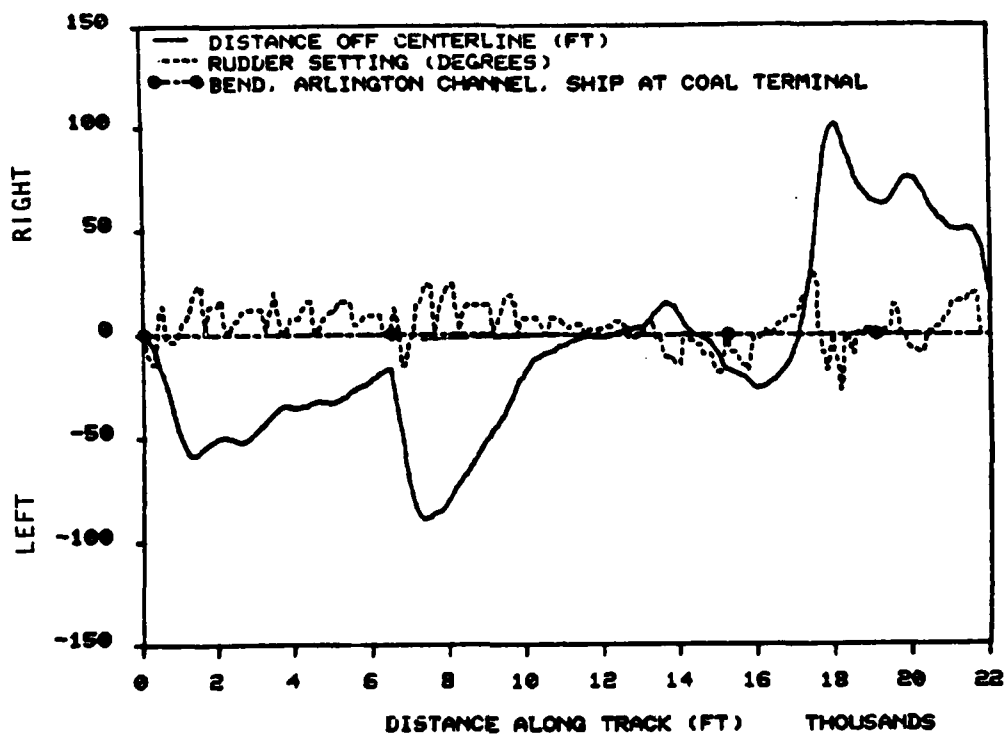
Figure A12b. Distance along track versus rudder setting
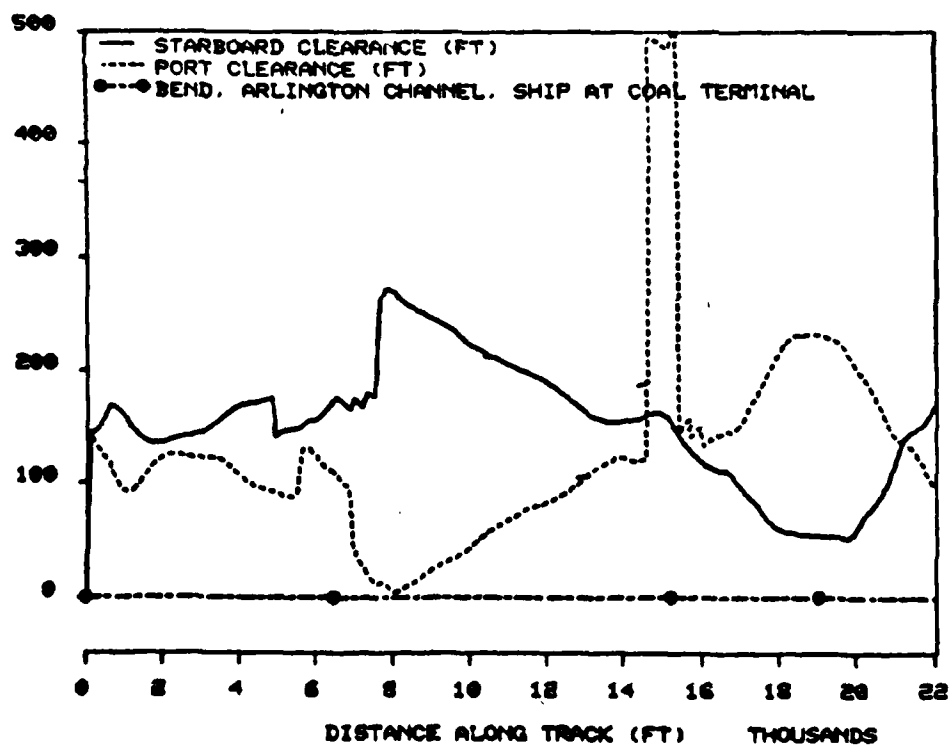and distance off track, Test 12 (trial 1 2 4)
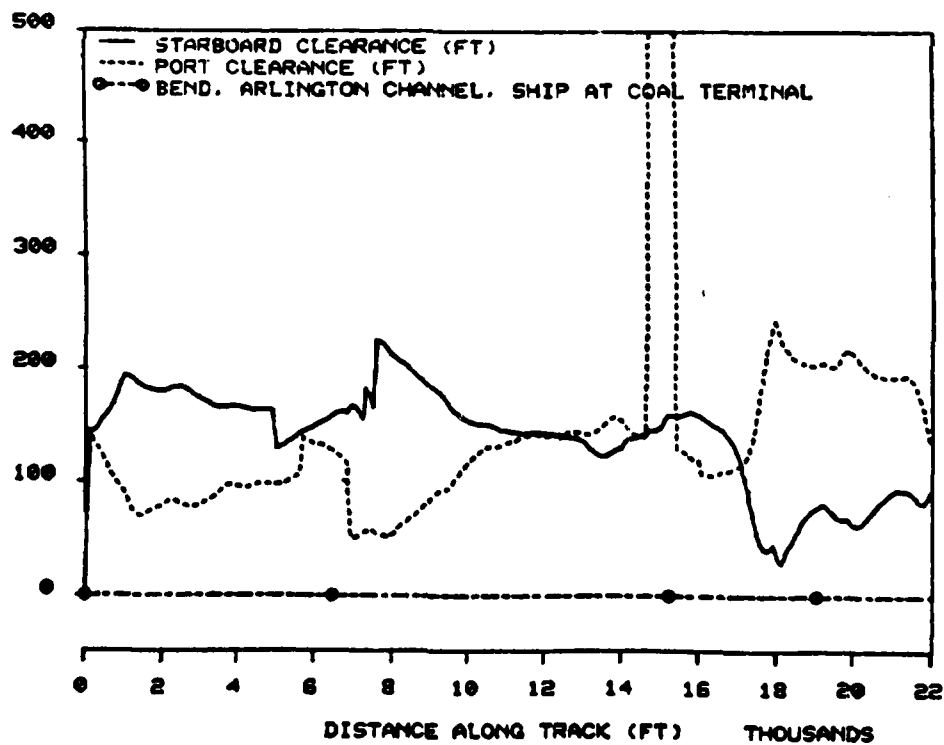
Figure A12c. Distance along track versus port and
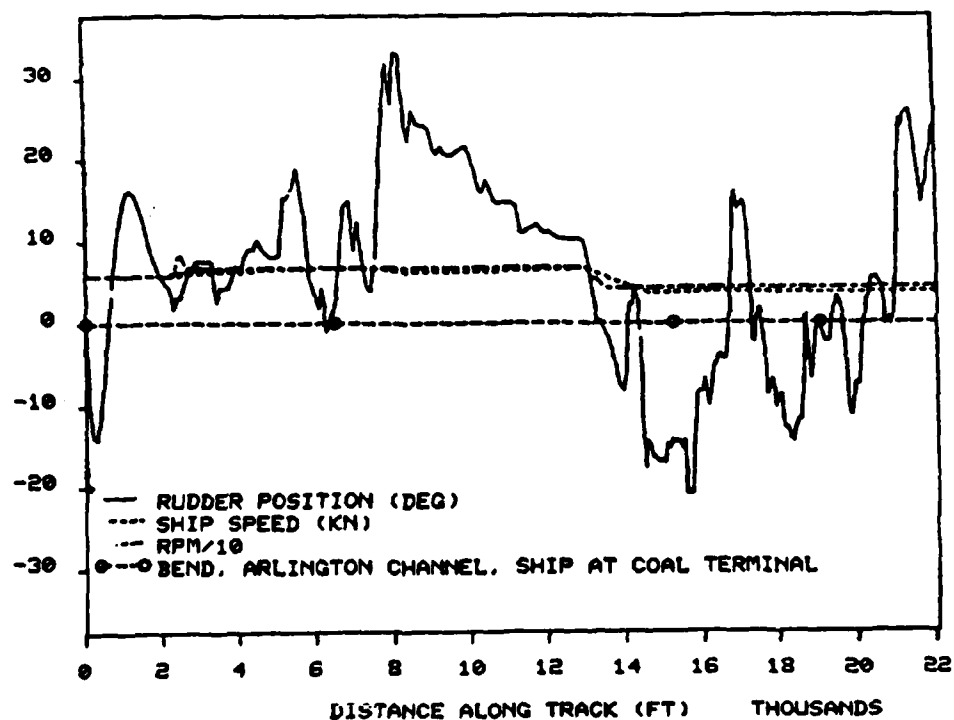starboard clearance, Test 12 (trial 1 2 4)

A36
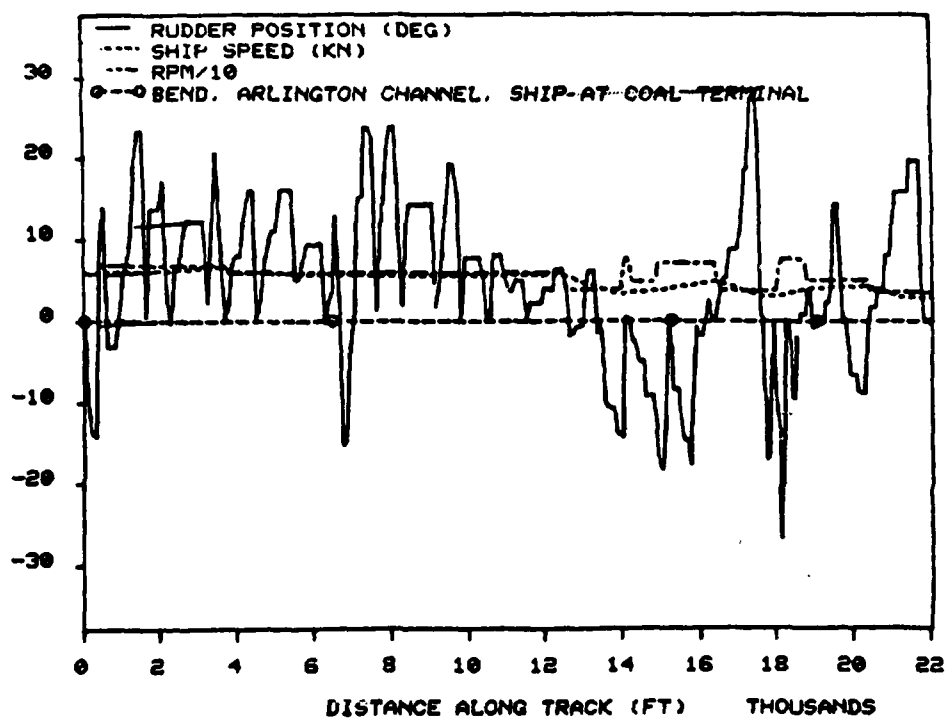
Figure A12d. Distance along track versus rudder, speed, and rpm/10, Test 12 (trial 1 2 4)
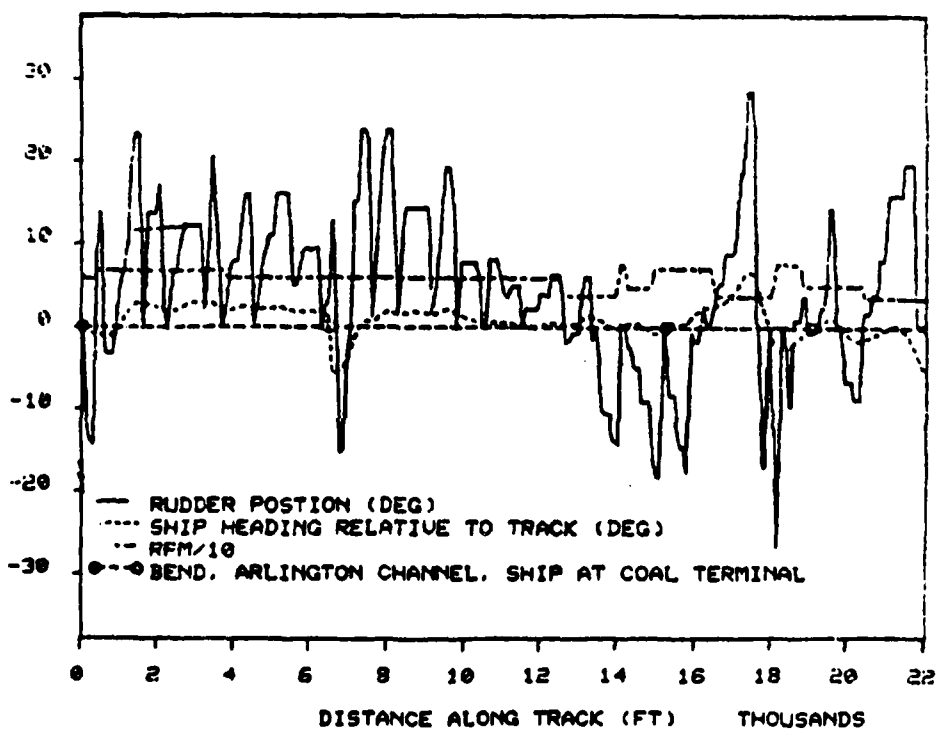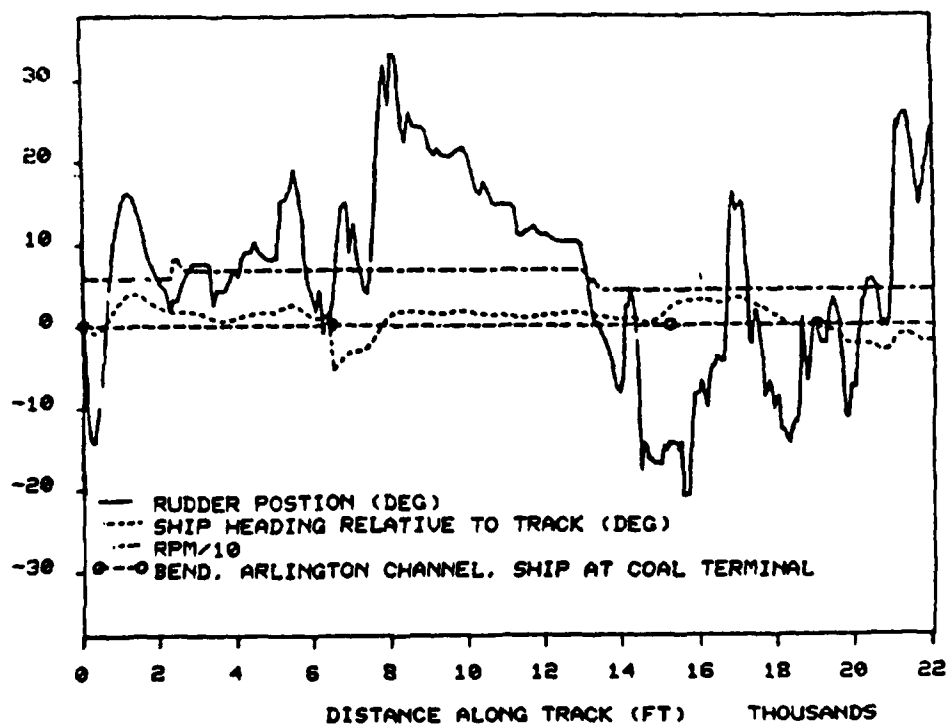

Figure A12e. Distance along track versus rudder, heading, and rpm/10, Test 12 (trial 1 2 4)
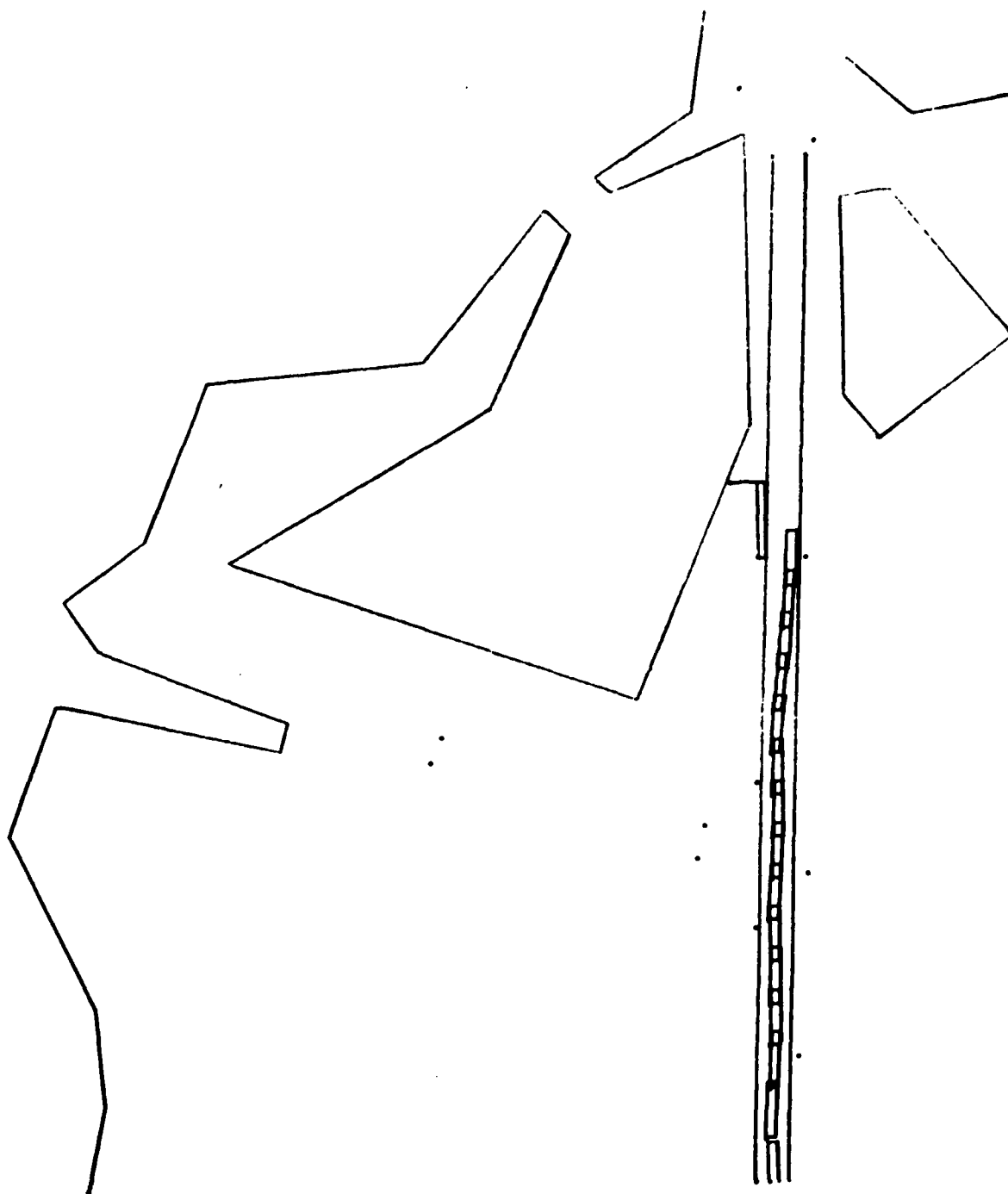
A37
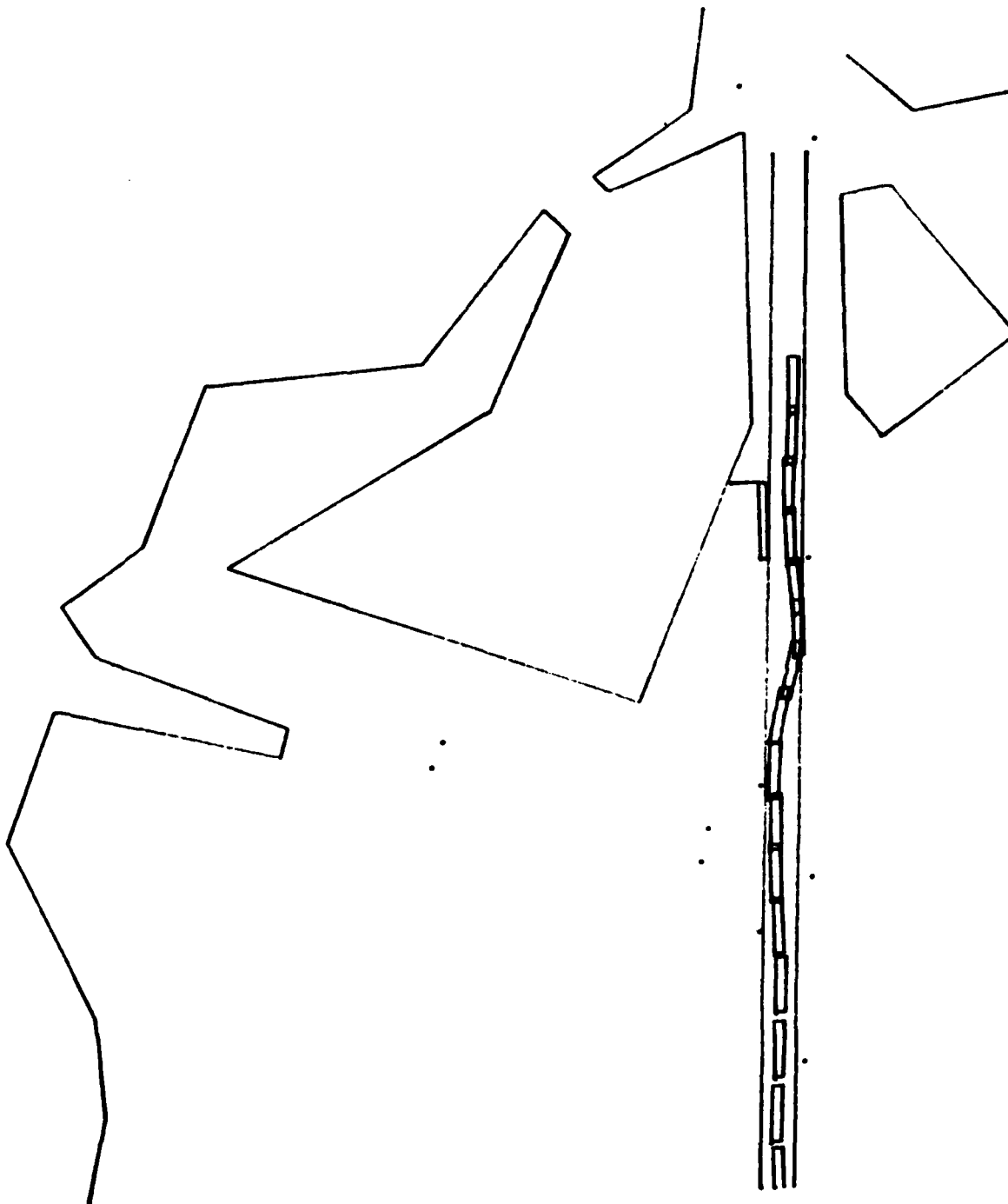
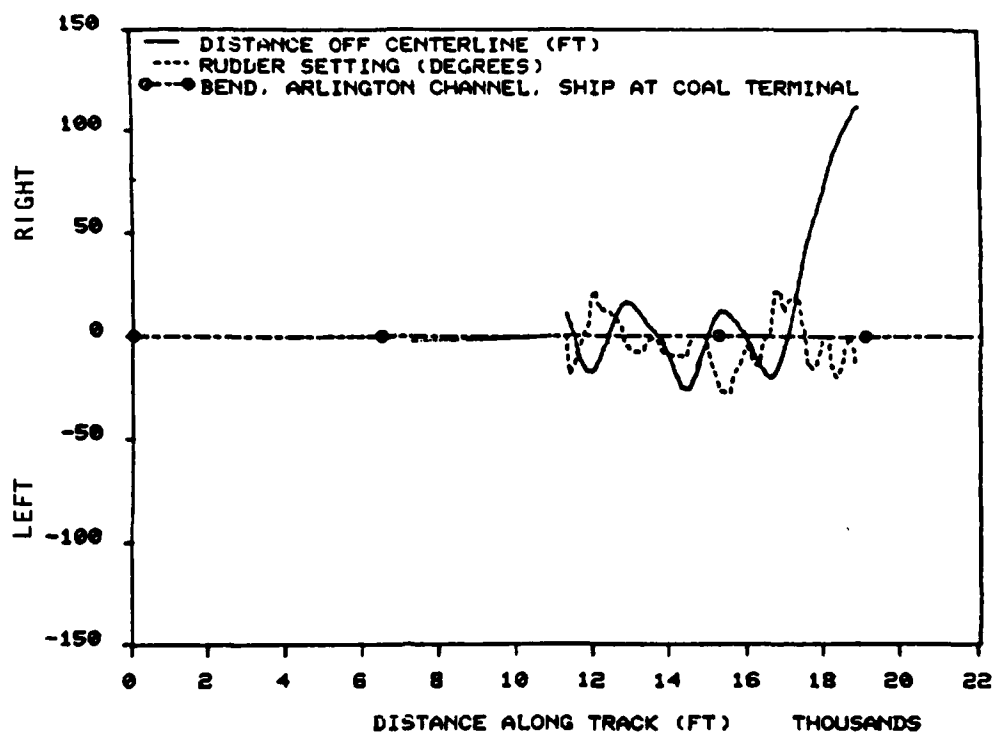Figure A13a. Ship track for Test 13 (trial 2 2 5)

A38
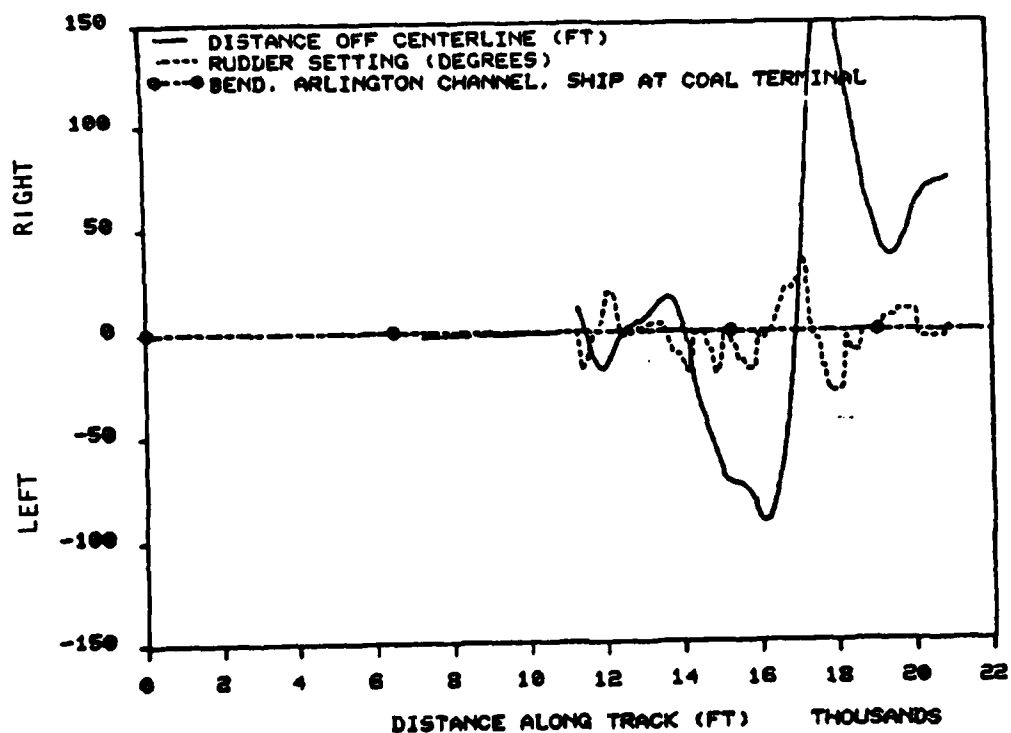
Figure A13b. Distance along track versus rudder setting
and distance off track, Test 13 (trial 2 2 5)
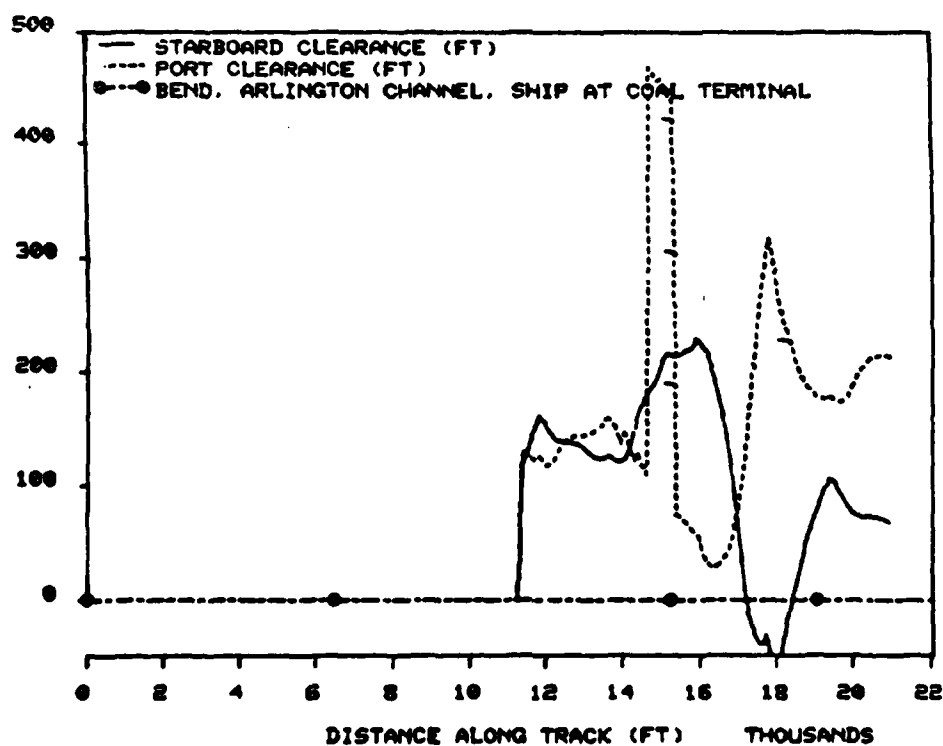
Figure A13c. Distance along track versus port and
starboard clearance, Test 13 (trial 2 2 5)

A39
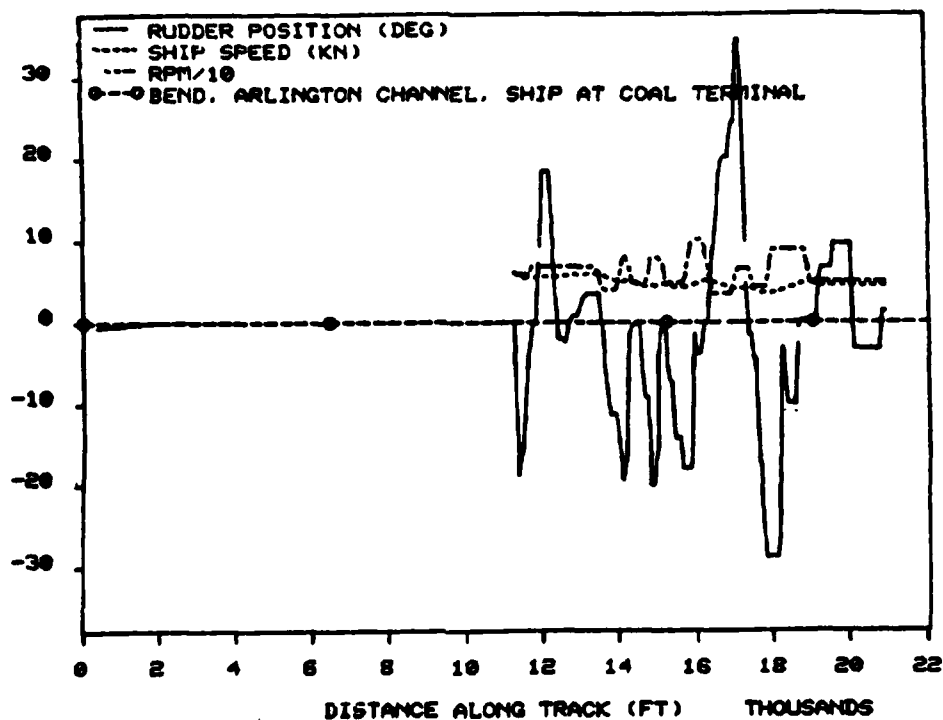
Figure A13d. Distance along track versus rudder, speed,
and rpm/10, Test 13 (trial 2 2 5)
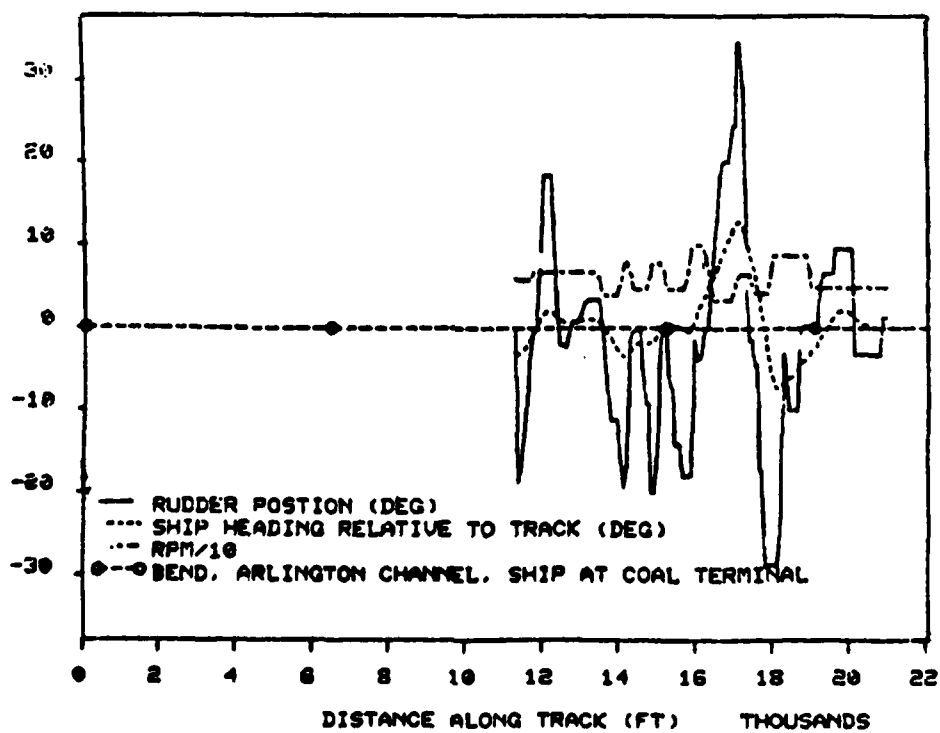
Figure A13e. Distance along track versus rudder, heading,
and rpm/10, Test 13 (trial 2 2 5)

A 40
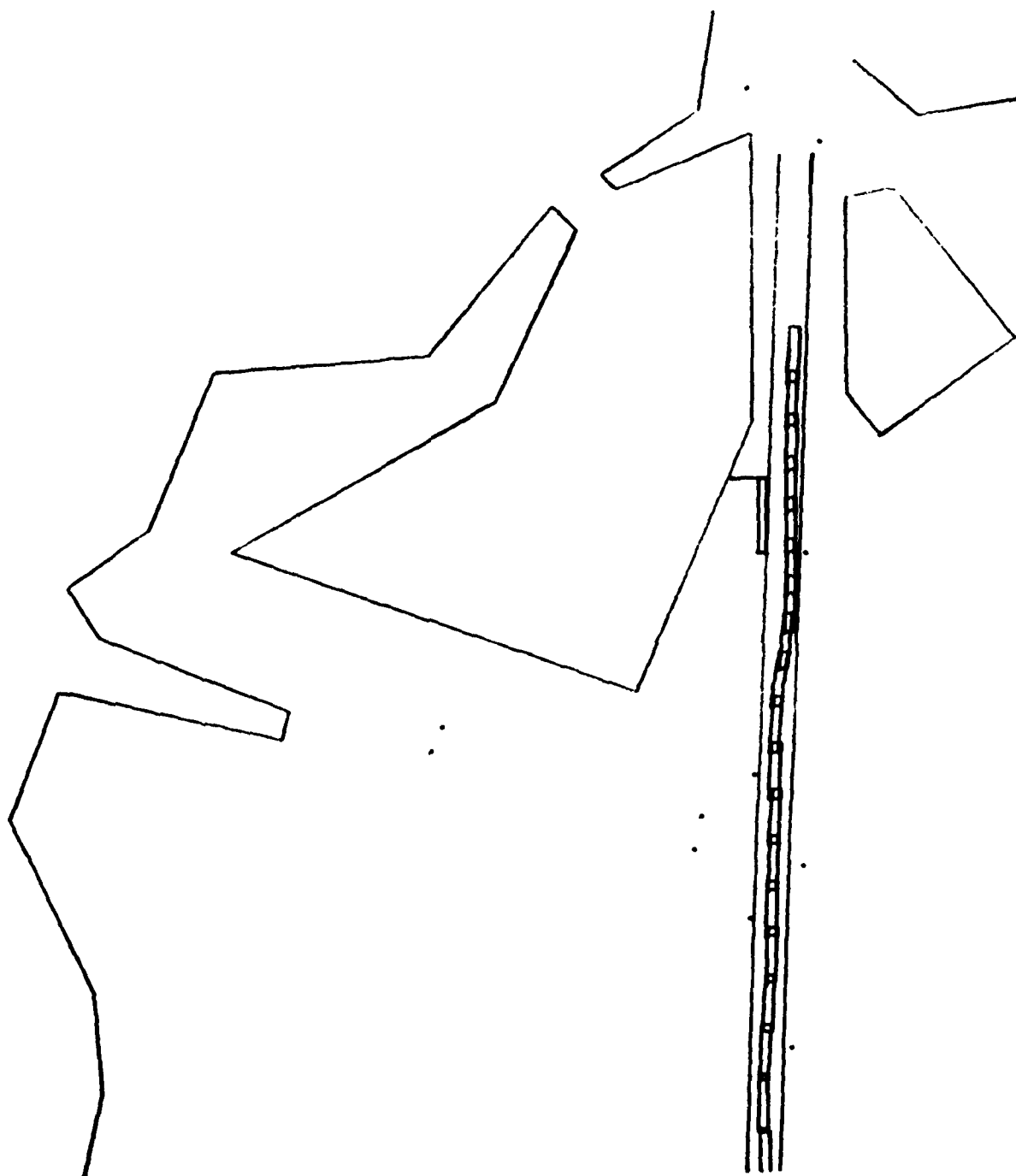
Figure A14a. Ship track for Test 14 (trial 2 2 6)

A41
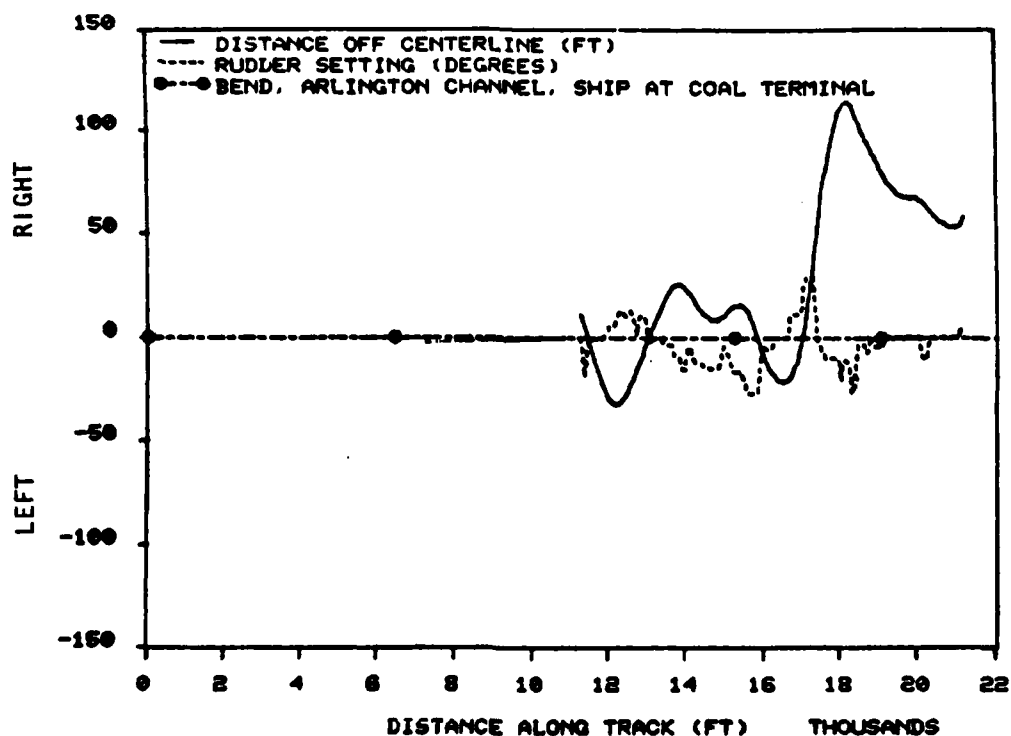
Figure A14b. Distance along track versus rudder setting
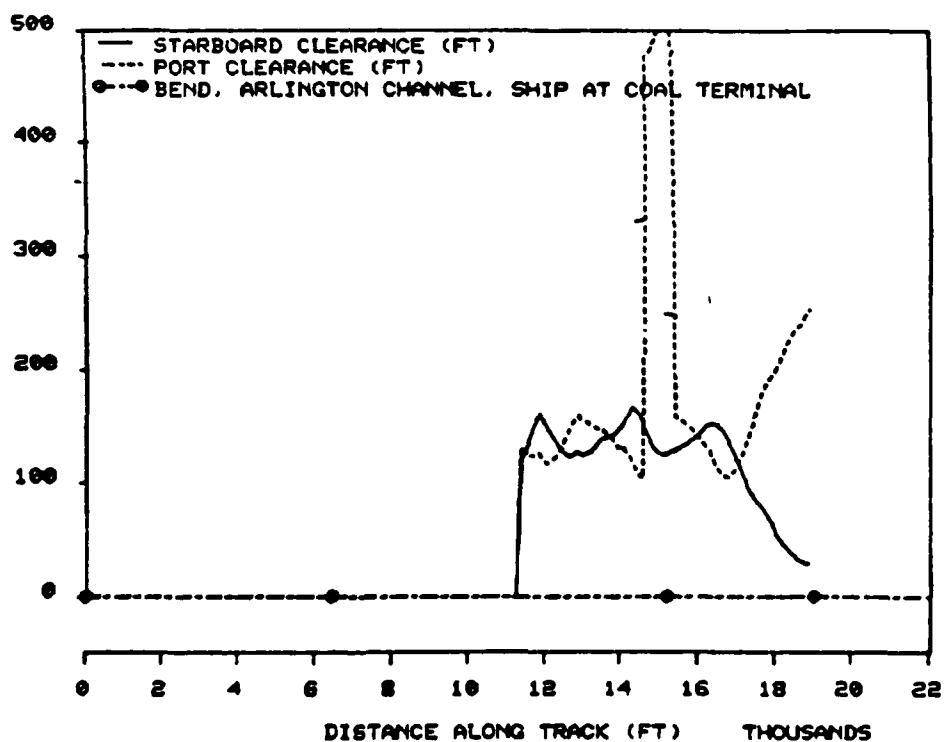and distance off track, Test 14 (trial 2 2 6)
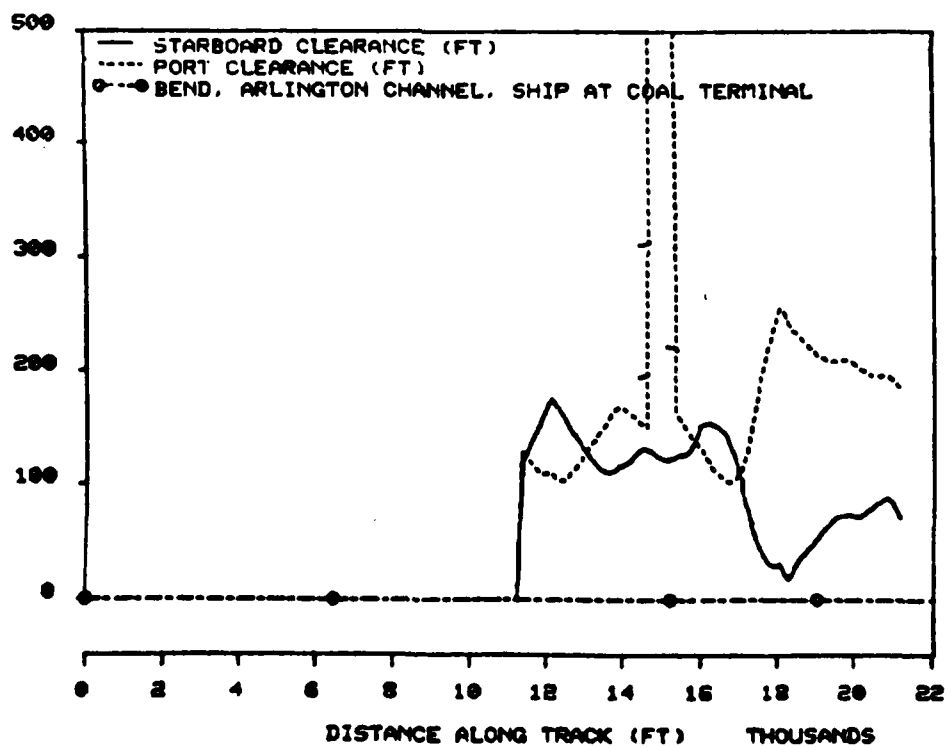
Figure A14c. Distance along track versus port and
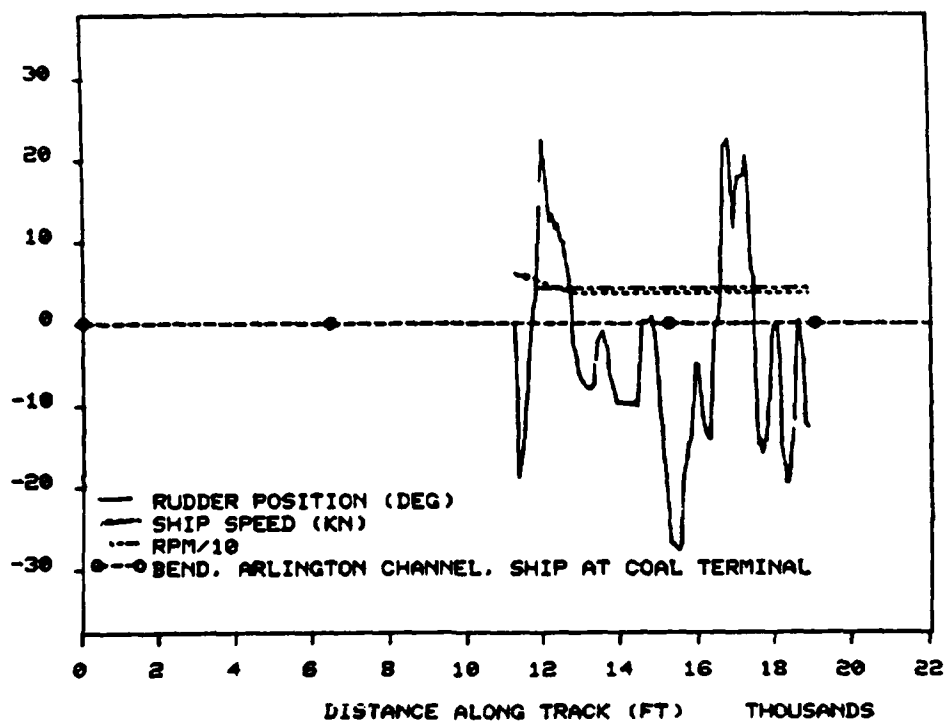starboard clearance, Test 14 (trial 2 2 6)

A42
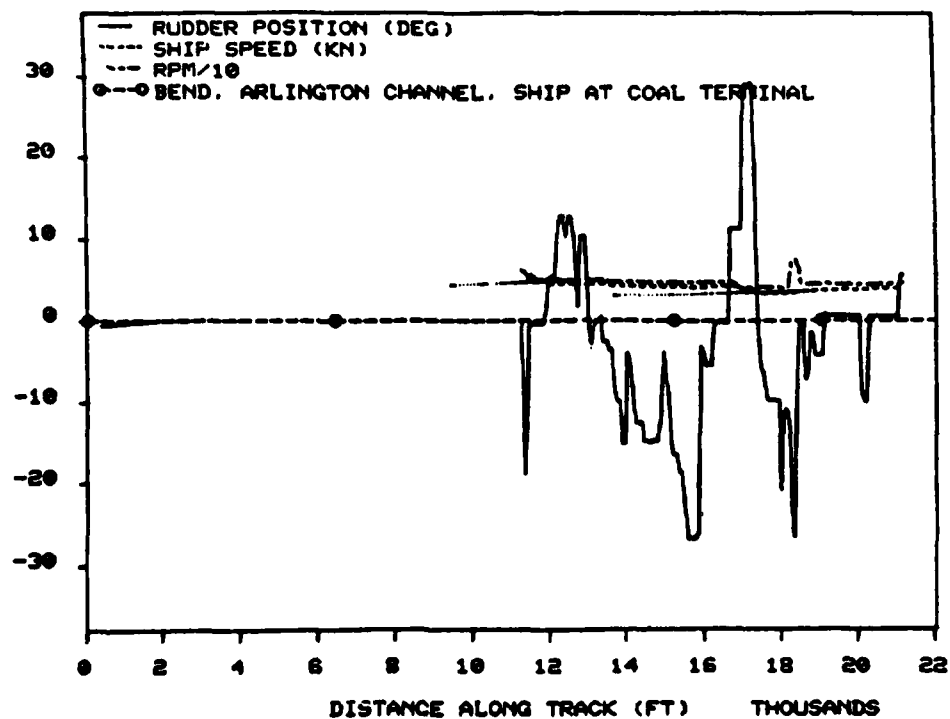
Figure A14d. Distance along track versus rudder, speed,
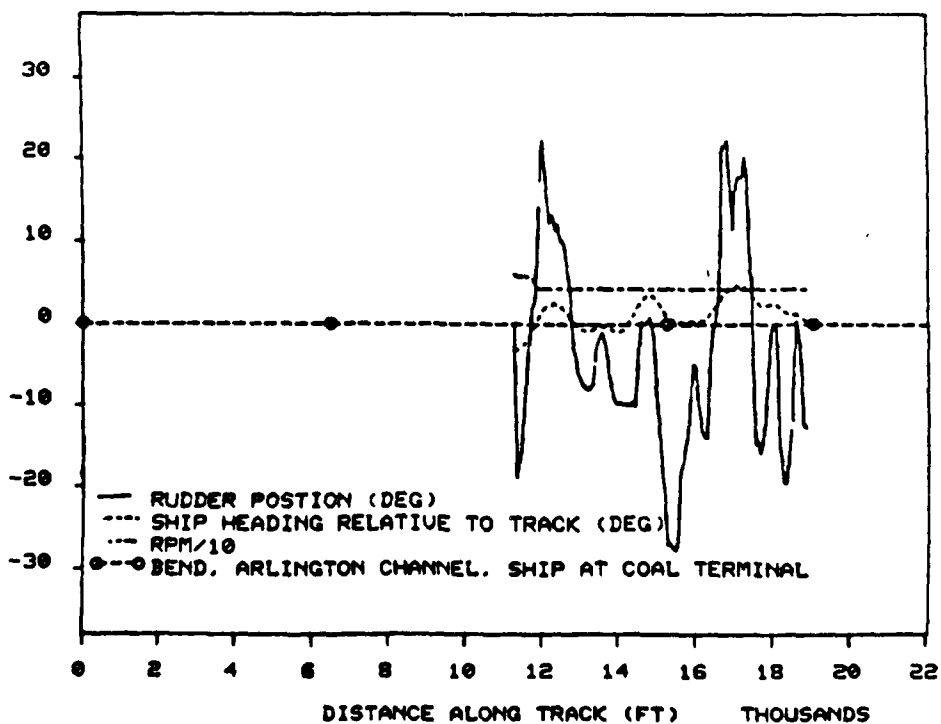and rpm/10, Test 14 (trial 2 2 6)

Figure A14e. Distance along track versus rudder, heading,
and rpm/10, Test 14 (trial 2 2 6)

A43

Figure A15a. Ship track for Test 15 (trial 3 2 1)

Figure A15b. Distance along track versus rudder setting
and distance off track, Test 15 (trial 3 2 1)

Figure A15c. Distance along track versus port and
starboard clearance, Test 15 (trial 3 2 1)

A45
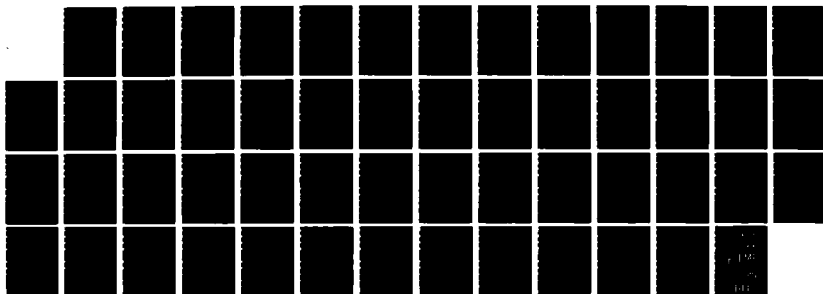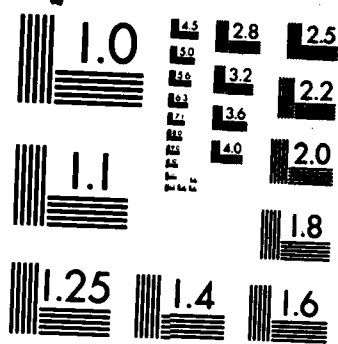
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Figure A15d. Distance along track versus rudder, speed, and rpm/10, Test 15 (trial 3 2 1)

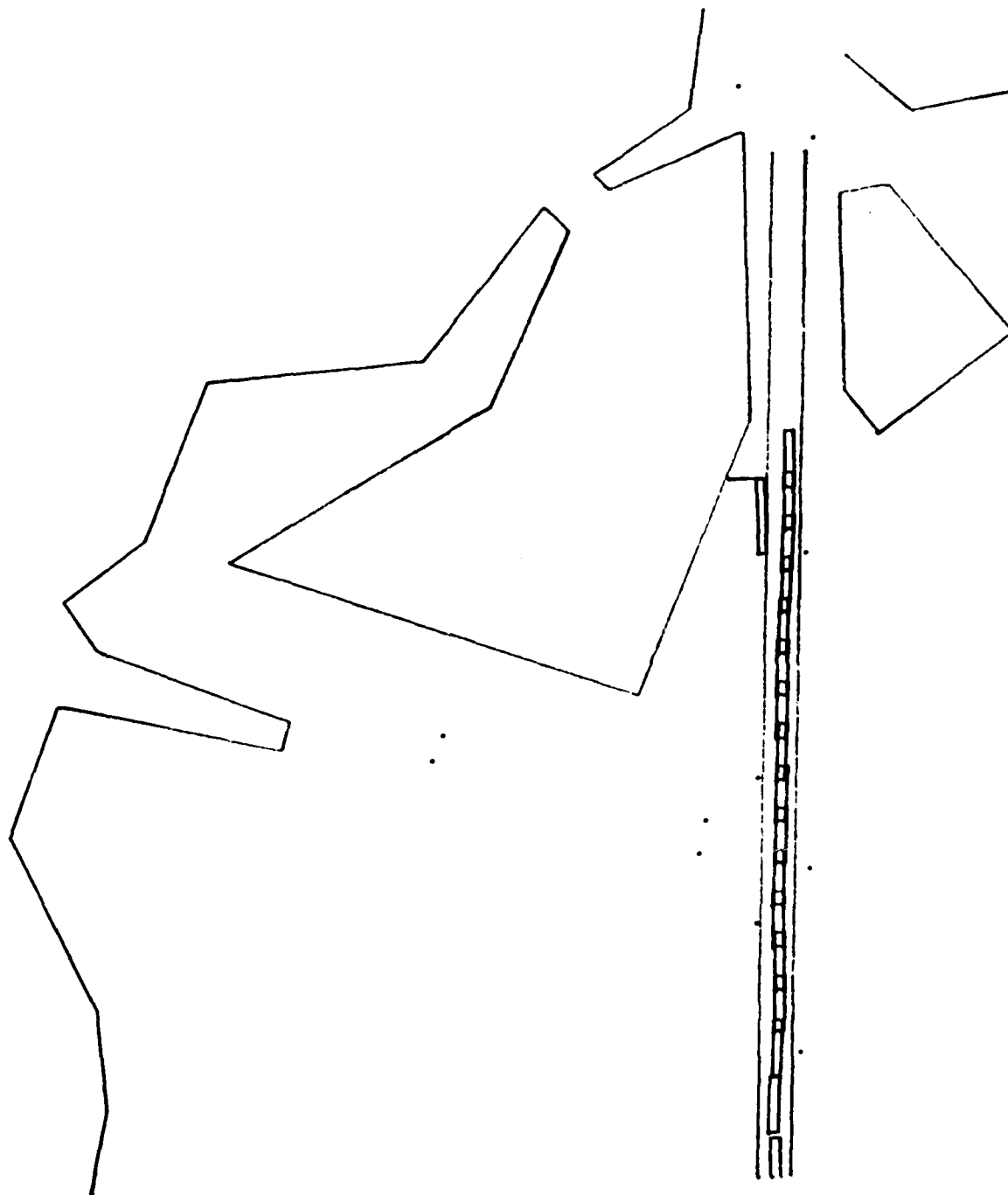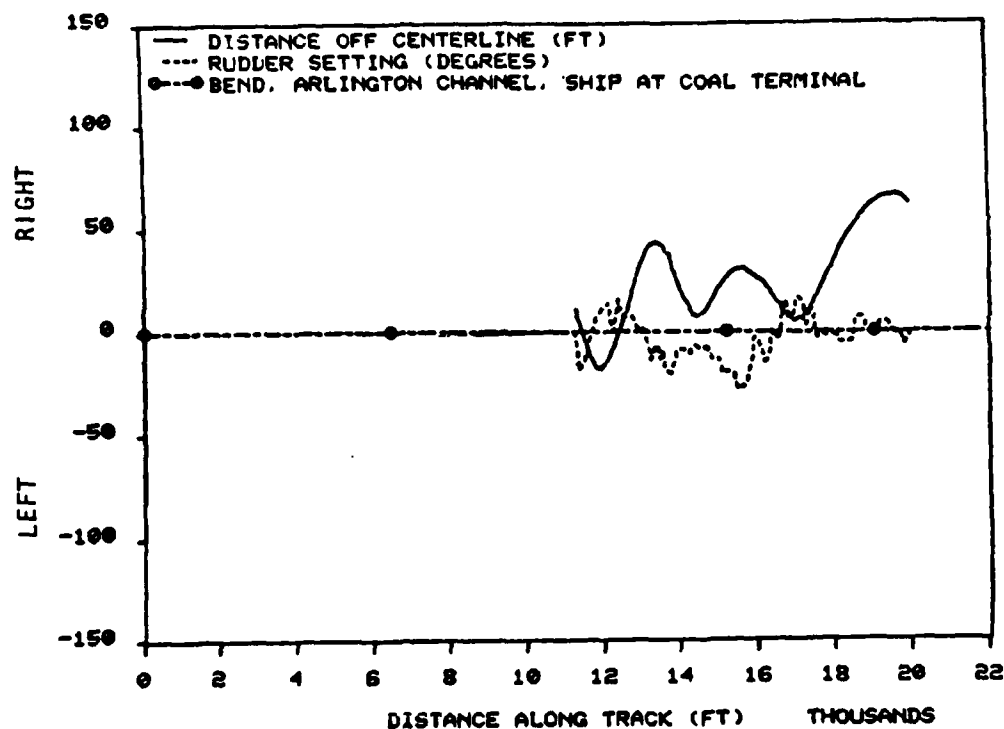Figure A15e. Distance along track versus rudder, heading, and rpm/10, Test 15 (trial 3 2 1)

A 46

Figure A16a. Ship track for Test 16 (trial 3 2 2)

A47

Figure A16b.   Distance along track versus rudder setting
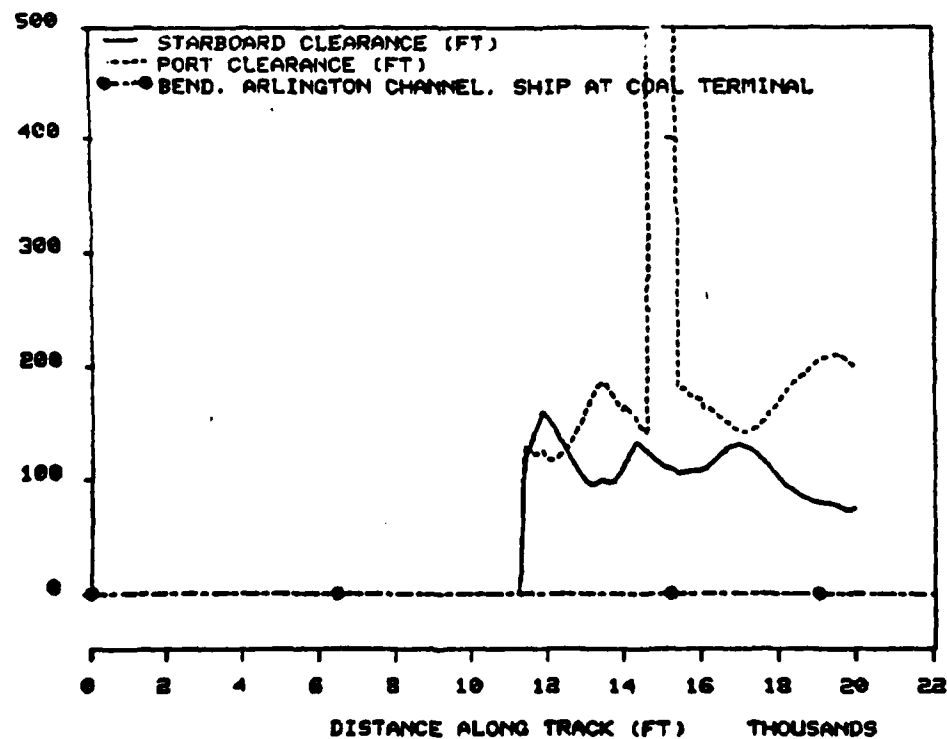and distance off track, Test 16 (trial 3 2 2)

Figure A16c.   Distance along track versus port and
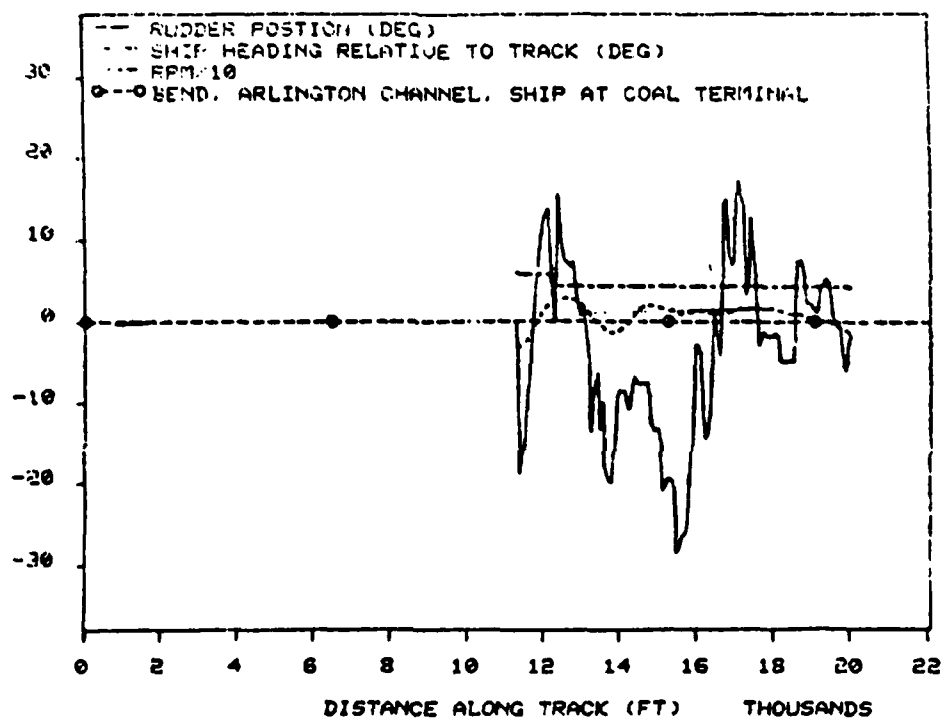starboard clearance, Test 16 (trial 3 2 2)

A48

Figure A16d. Distance along track versus rudder, speed, and rpm/10, Test 16 (trial 3 2 2)

Figure A16e. Distance along track versus rudder, heading, and rpm/10, Test 16 (trial 3 2 2)
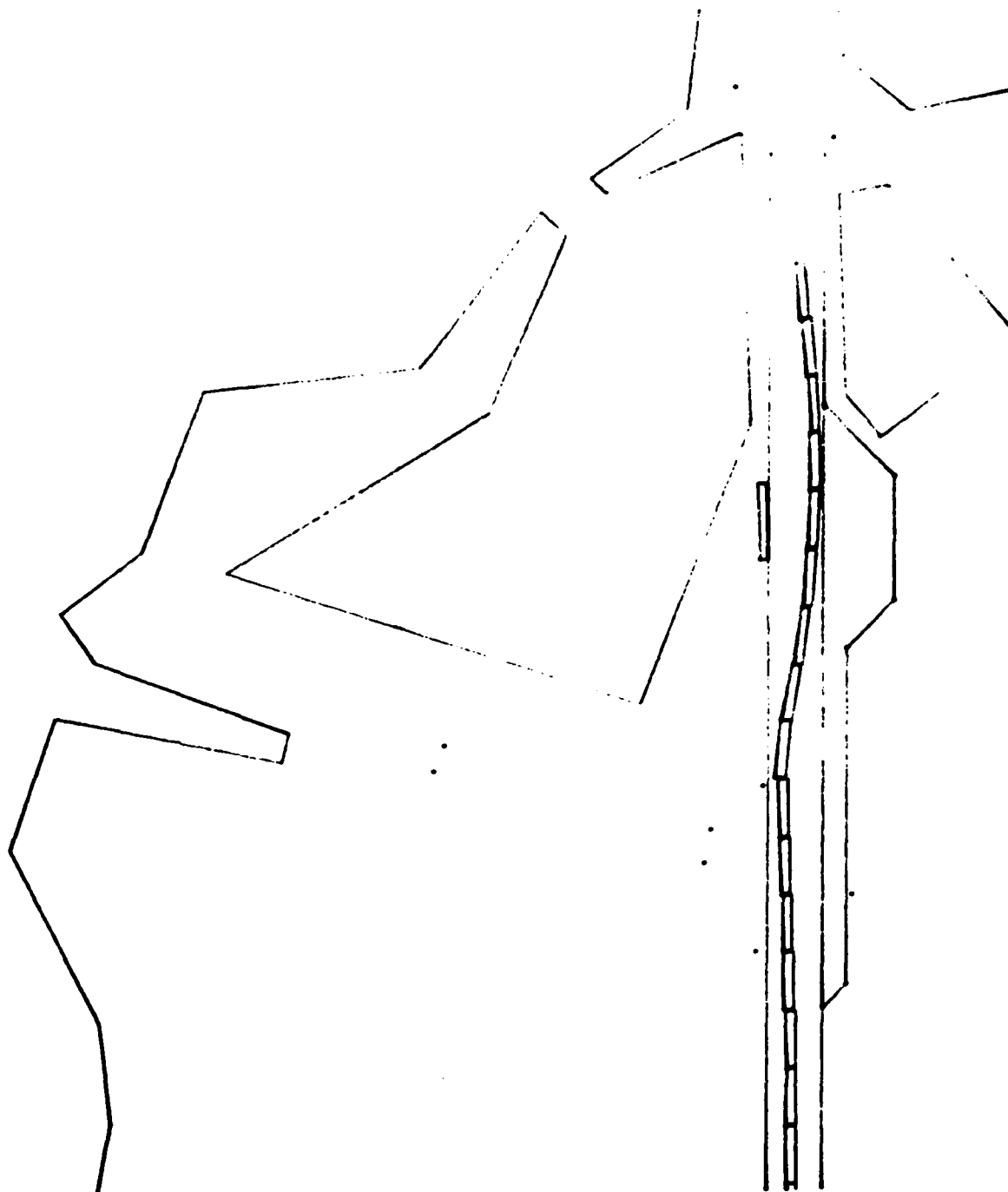
A49

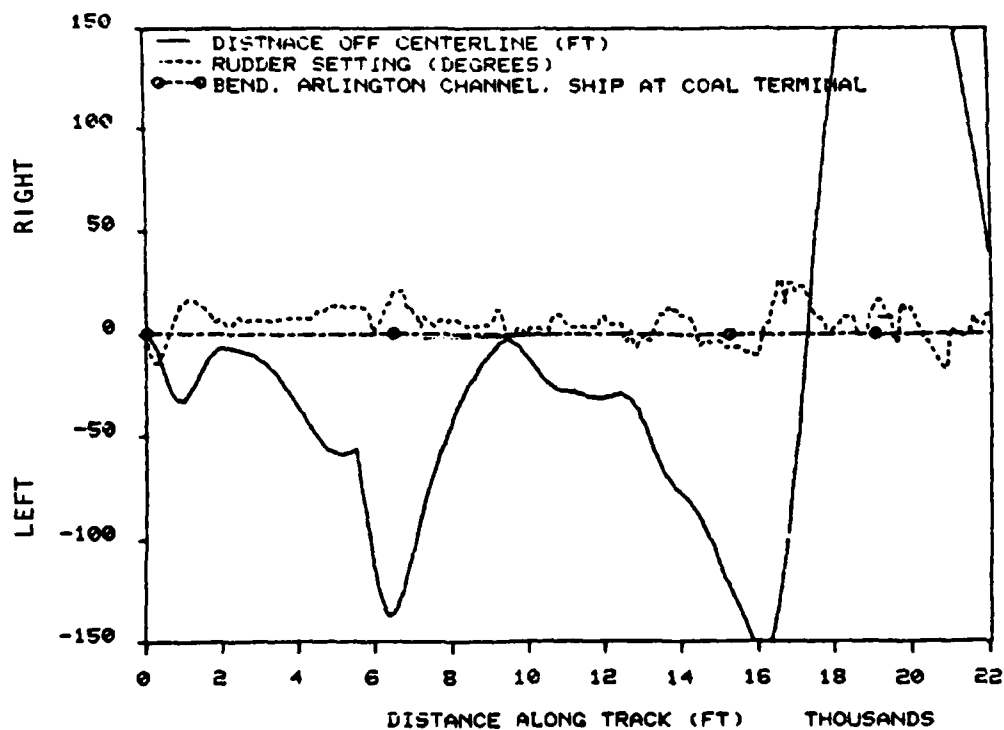Figure A17a. Ship track for Test 17 (trial 1 4 1)

A50
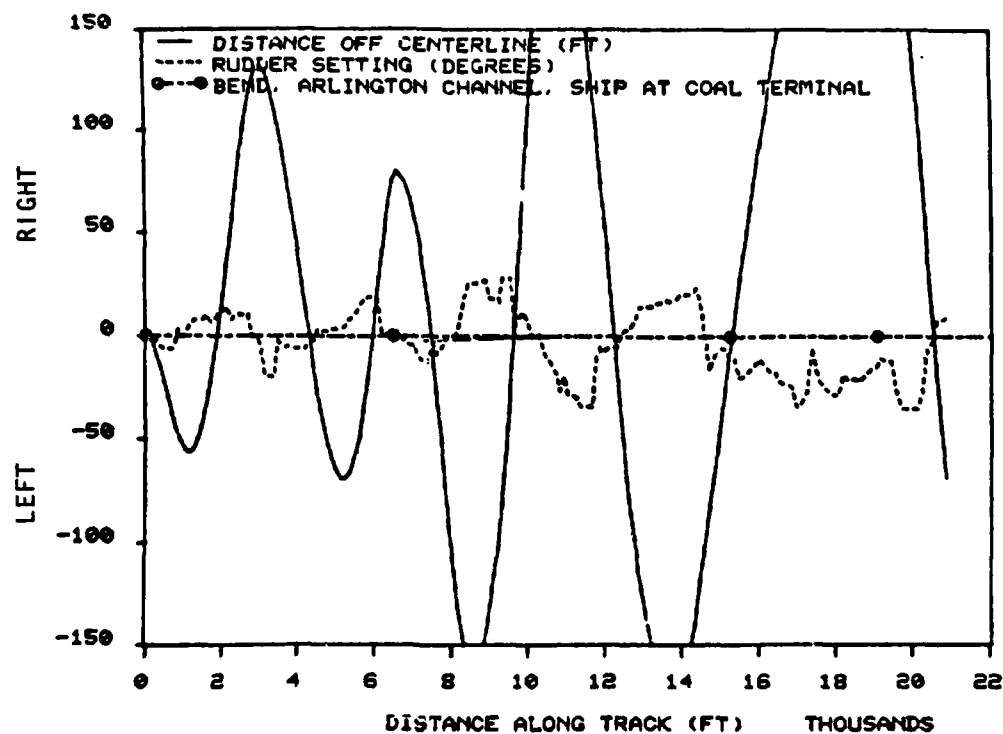
Figure A17b. Distance along track versus rudder setting and distance off track, Test 17 (trial 1 4 1)
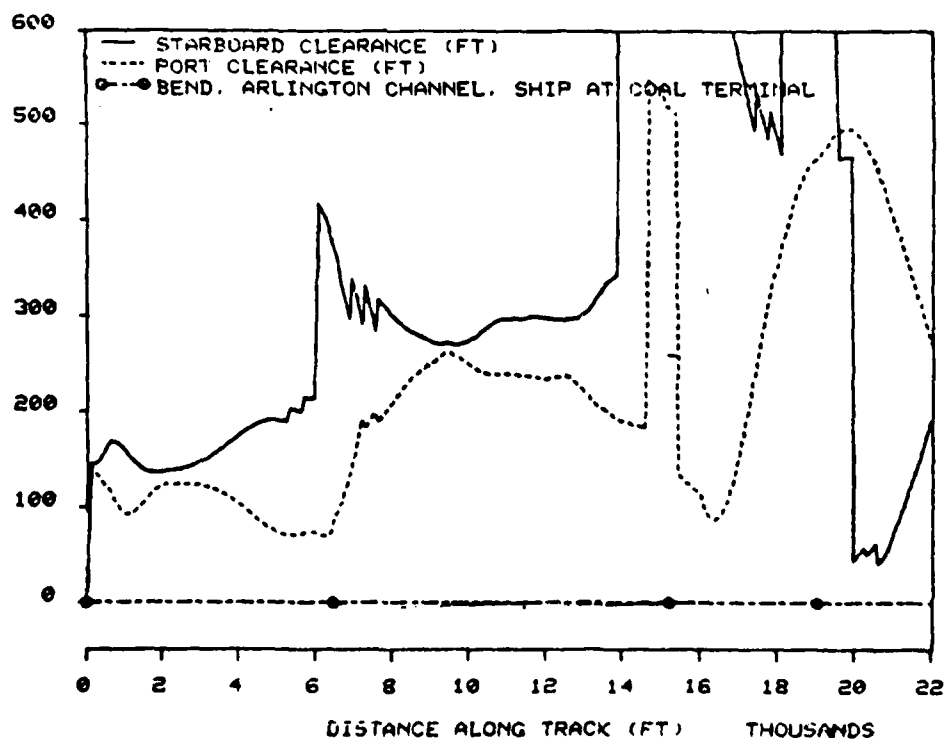

Figure A17c. Distance along track versus port and starboard clearance, Test 17 (trial 1 4 1)
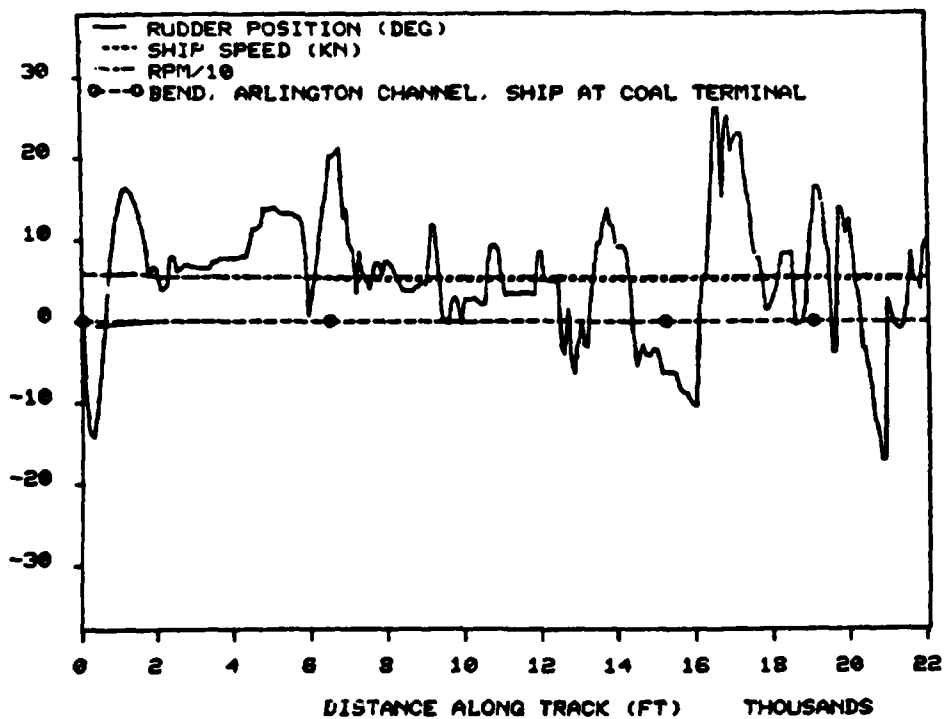
A51

Figure A17d. Distance along track versus rudder, speed, and rpm/10, Test 17 (trial 1 4 1)

Figure A17e. Distance along track versus rudder, heading, and rpm/10, Test 17 (trial 1 4 1)

A52

Figure A18a. Ship track for Test 18 (trial 1 4 2)

453
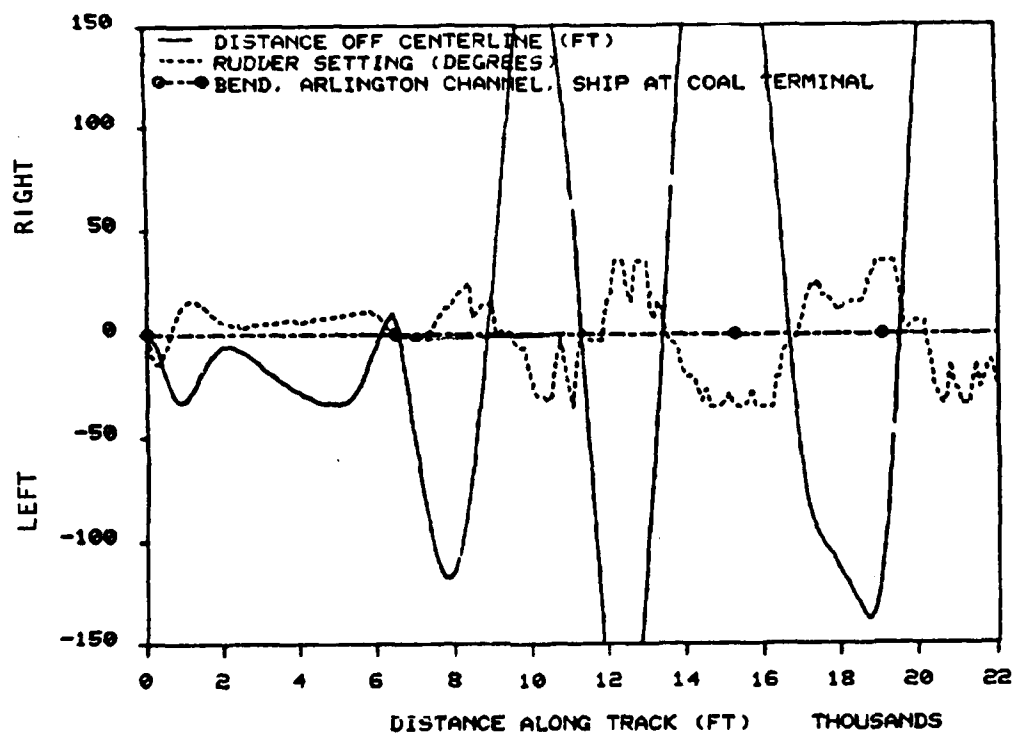
Figure A18b.   Distance along track versus rudder setting
and distance off track, Test 18 (trial 1 " 2)

Figure A18c.   Distance along track versus port and
starboard clearance, Test 18 (trial 1 4 2)

A54

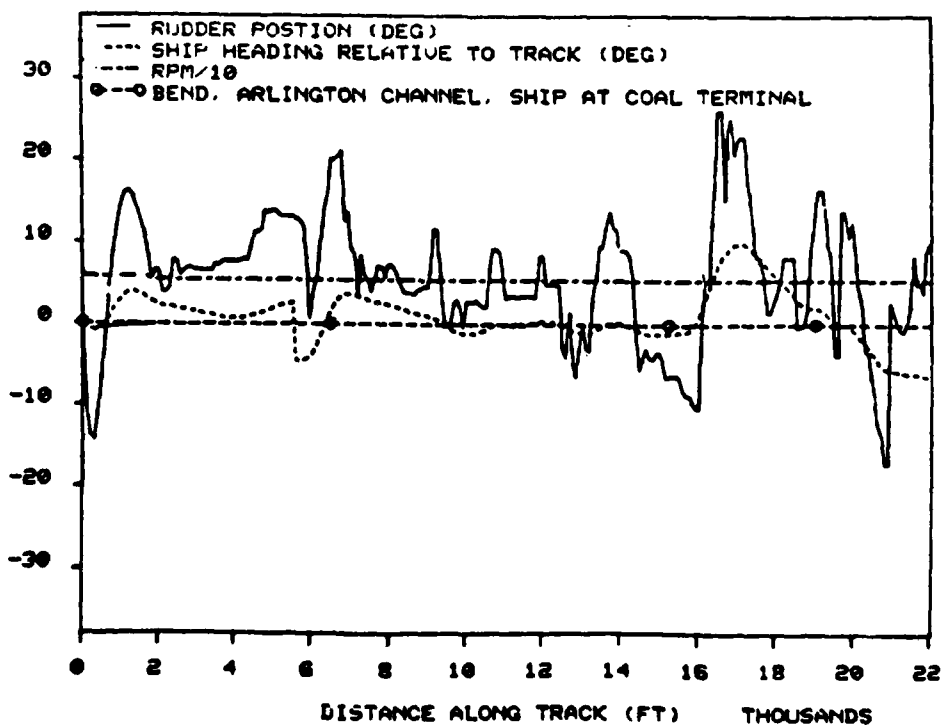Figure A18d. Distance along track versus rudder, speed, and rpm/10, Test 18 (trial 1 4 2)

Figure A18e. Distance along track versus rudder, heading, and rpm/10, Test 18 (trial 1 4 2)
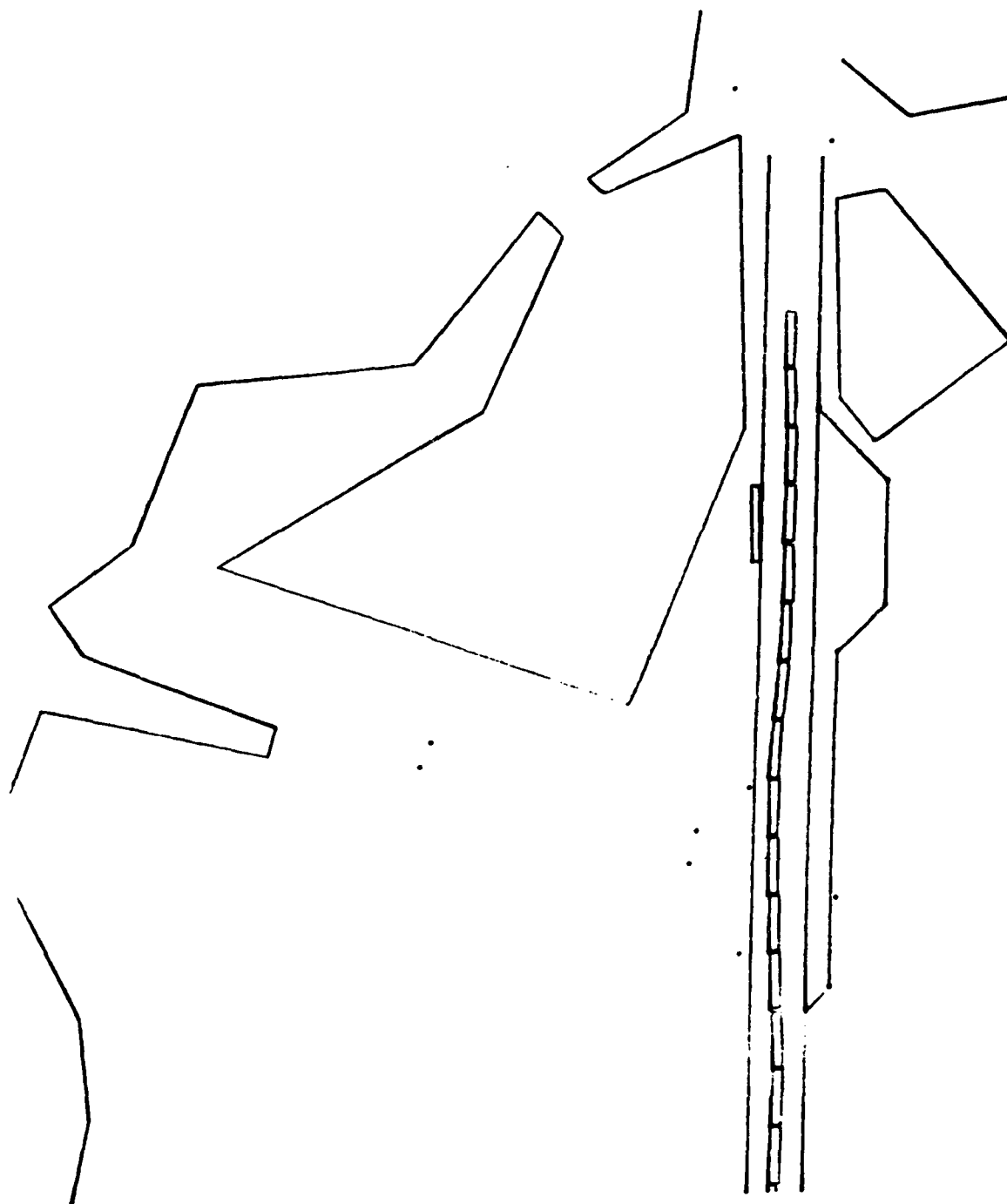
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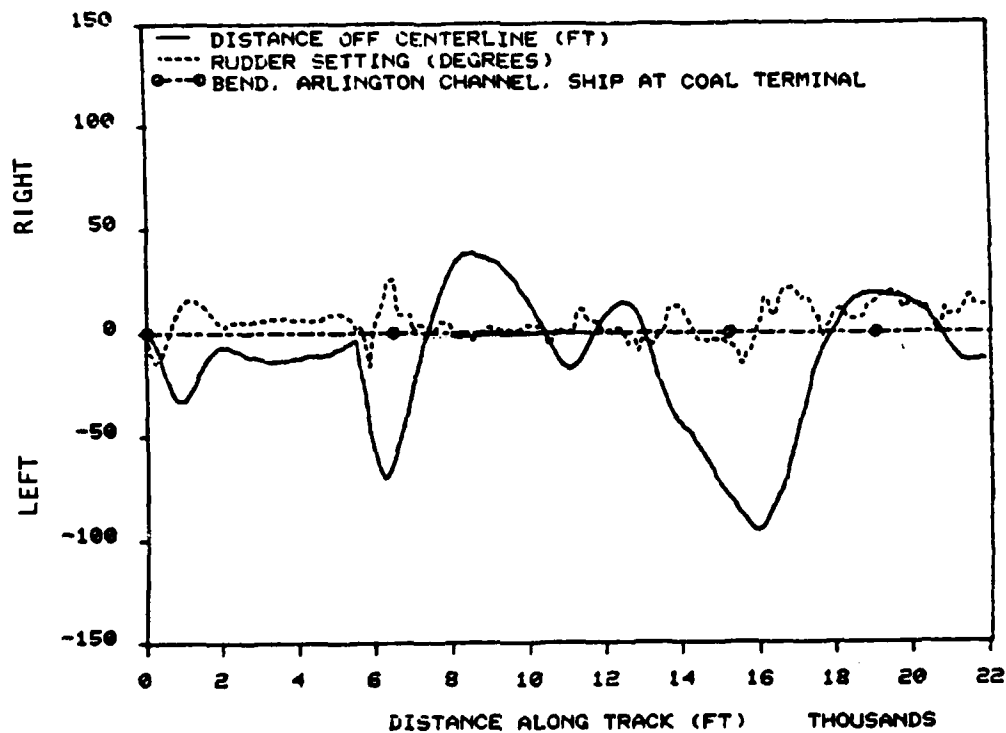Figure A19a. Ship track for Test 19 (trial 1 4 3)

A56

Figure A19b. Distance along track versus rudder setting and distance off track, Test 19 (trial 1 4 3)
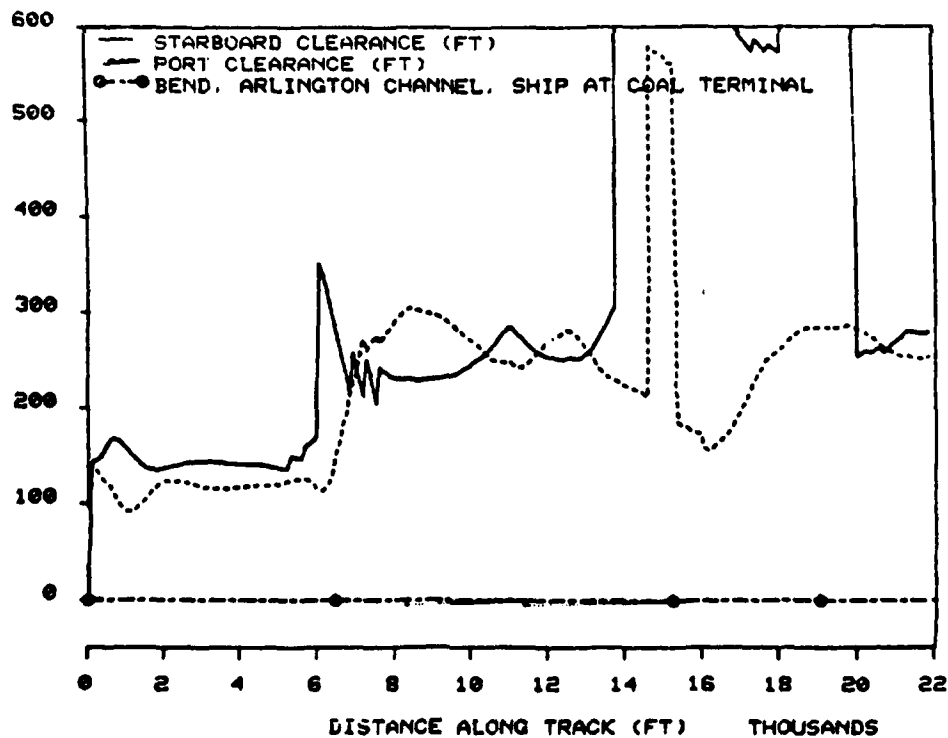

Figure A19c. Distance along track versus port and starboard clearance, Test 19 (trial 1 4 3)

Figure A19d. Distance along track versus rudder, speed,
and rpm/10, Test 19 (trial 1 4 3)

Figure A19e. Distance along track versus rudder, heading,
and rpm/10, Test 19 (trial 1 4 3)

A58

Figure A20a. Ship track for Test 20 (trial 1 4 4)

A59

Figure A20b. Distance along track versus rudder setting and distance off track, Test 20 (trial 1 4 4)

Figure A20c. Distance along track versus port and starboard clearance, Test 20 (trial 1 4 4)
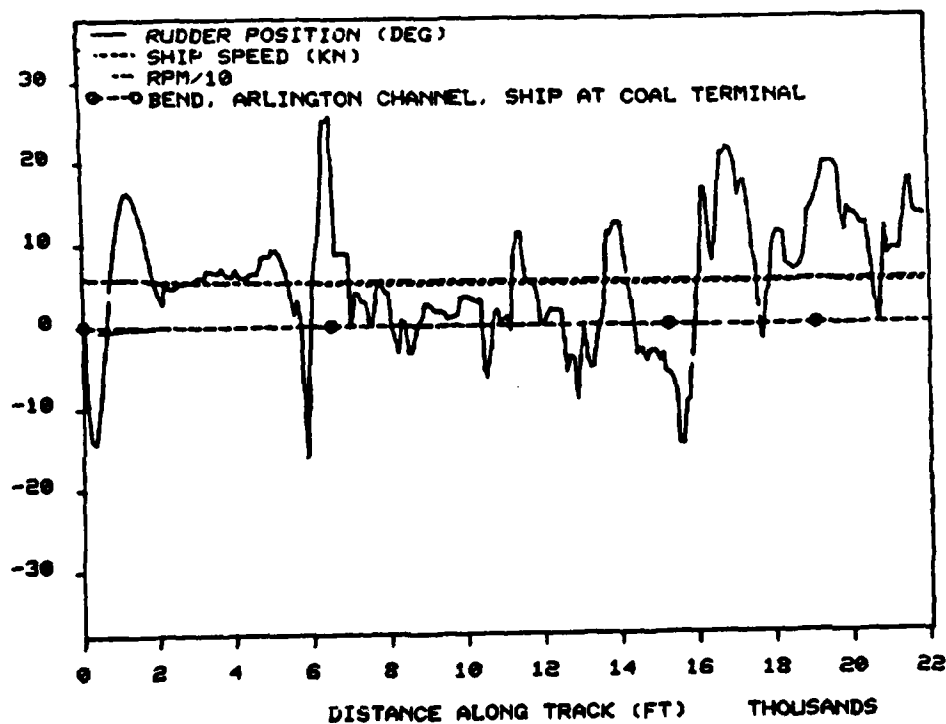
A60

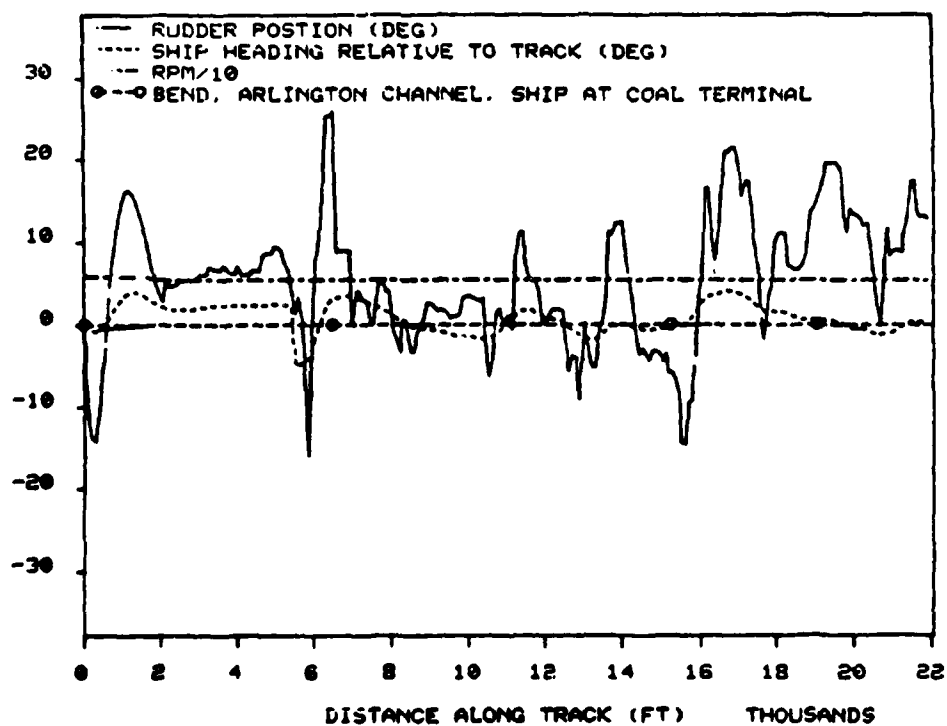Figure A20d. Distance along track versus rudder, speed, and rpm/10, Test 20 (trial 1 4 4)

Figure A20e. Distance along track versus rudder, heading, and rpm/10, Test 20 (trial 1 4 4)

A61

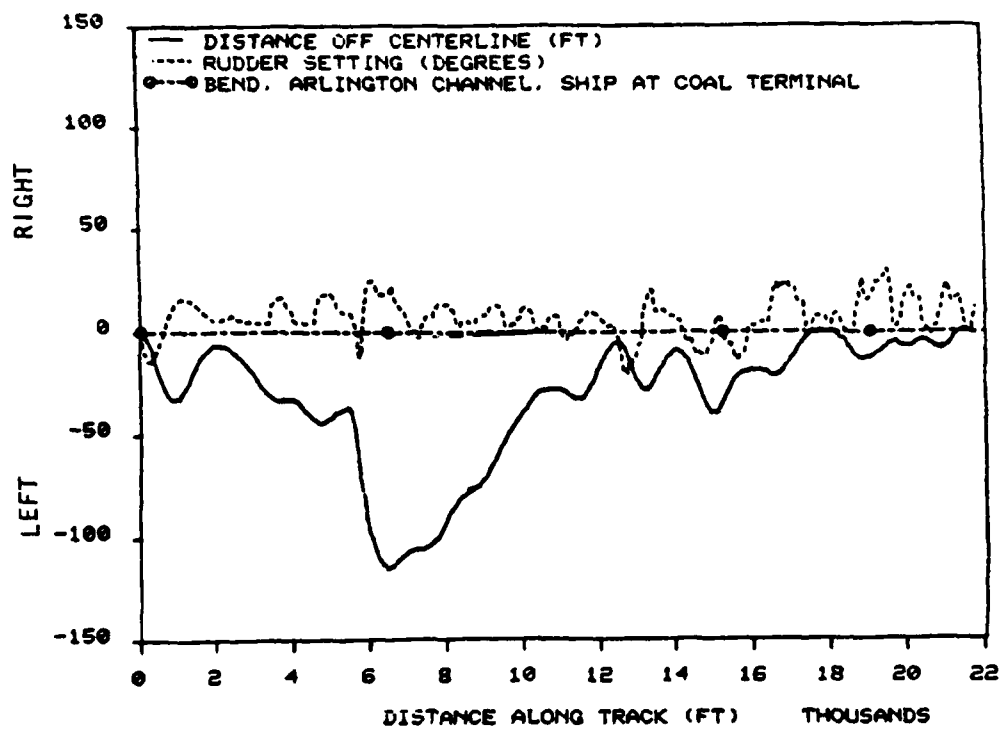Figure A21a. Ship track for Test 21 (trial 1 4 5)

Figure A21b. Distance along track versus rudder setting
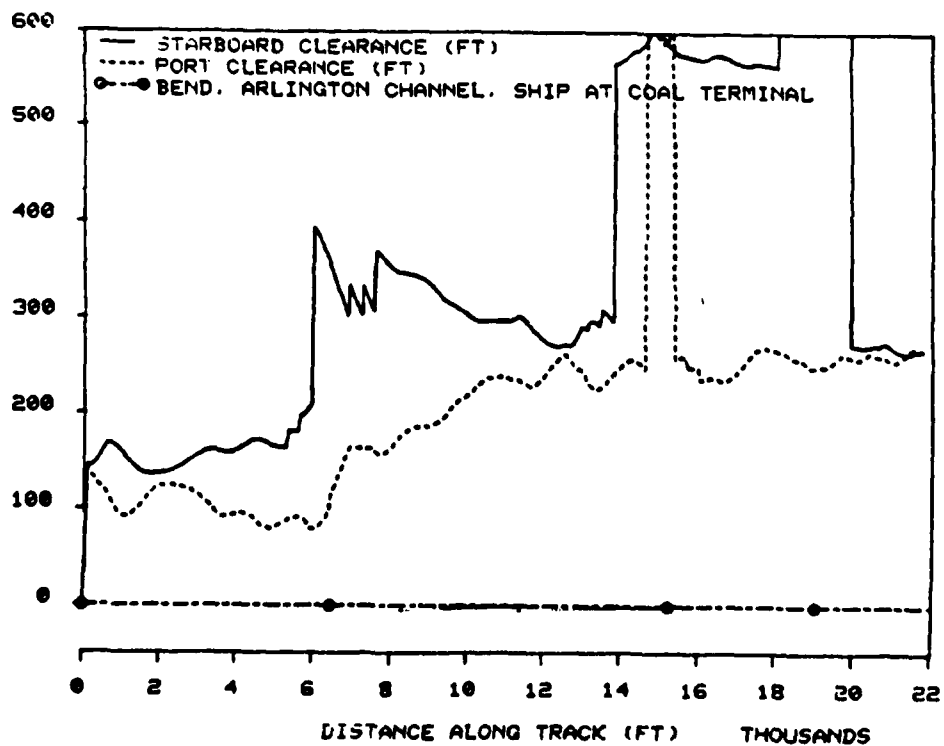and distance off track, Test 21 (trial 1 4 5)

Figure A21c. Distance along track versus port and
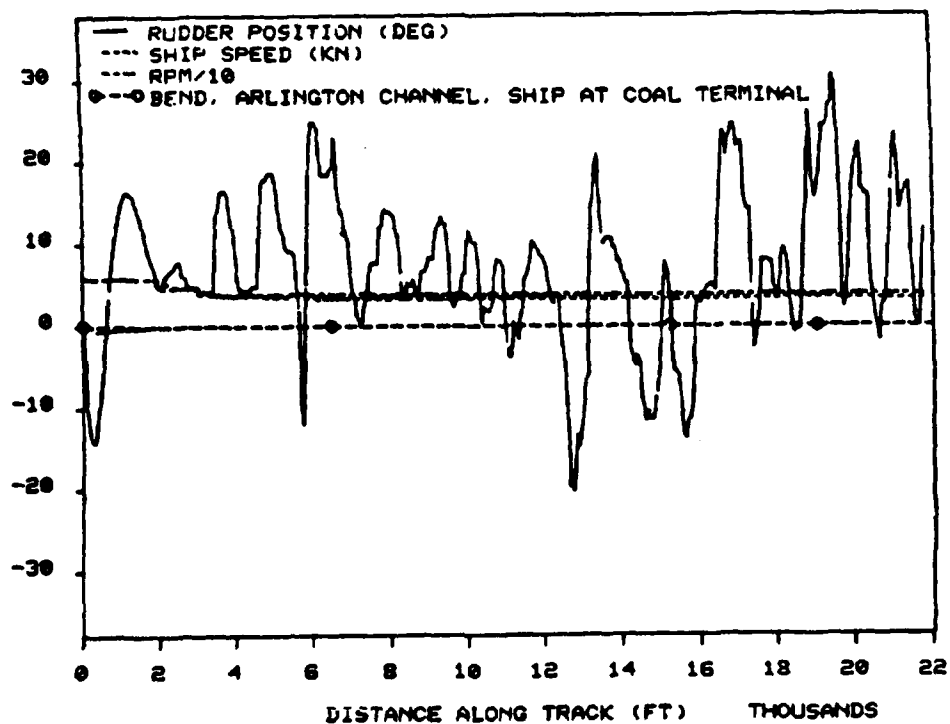starboard clearance, Test 21 (trial 1 4 5)

A63

Figure A21d. Ditance along rack versus rudder, speed,
and rpm/10, Test 21 (trial 1 4 5)

Figure A21e. Distance along track versus rudder, heading,
and rpm/10, Test 21 (trial 1 4 5)

A64

Figure A22a. Ship track for Test 22 (trial 1 4 6)

A65

Figure A22b.   Distance along track versus rudder setting
and distance off track, Test 22 (trial 1 4 6)

Figure A22c.   Distance along track versus port and
starboard clearance, Test 22 (trial 1 4 6)

Figure A22d. Distance along track versus rudder, speed, and rpm/10, Test 22 (trial 1 4 6)
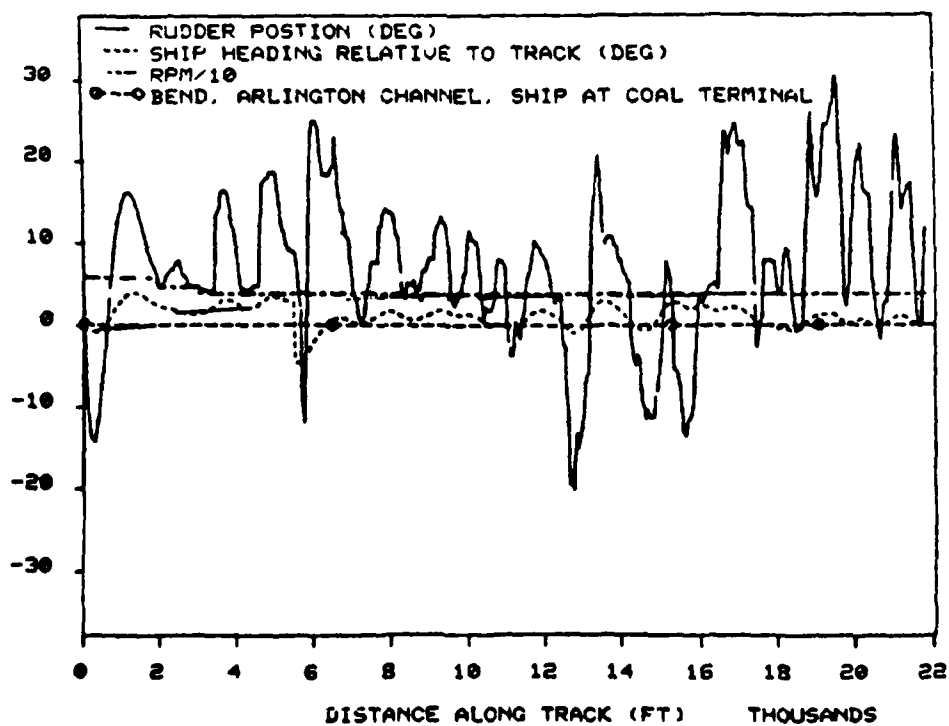

Figure A22e. Distance along track versus rudder, heading, and rpm/10, Test 22 (trial 1 4 6)
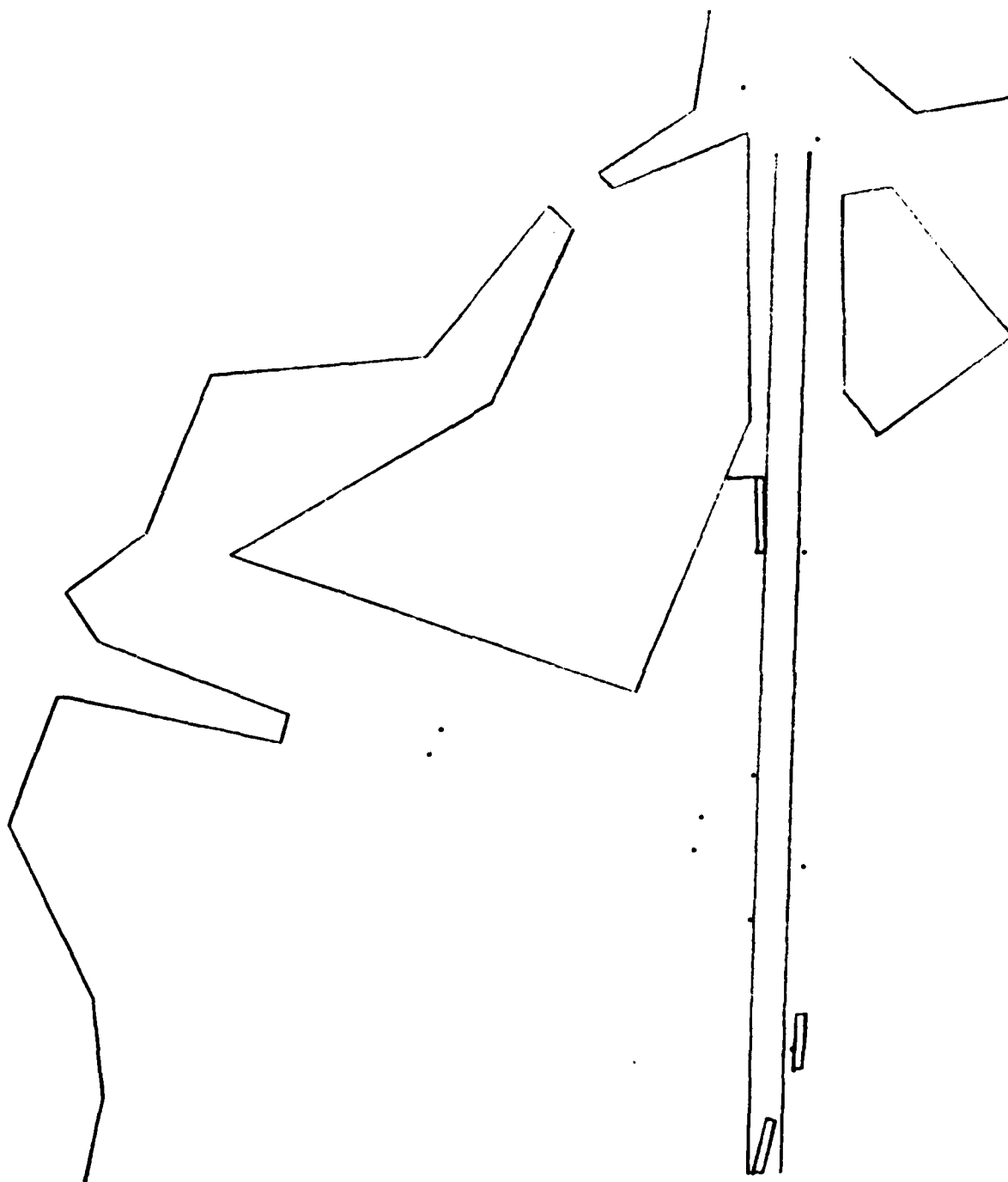
A67

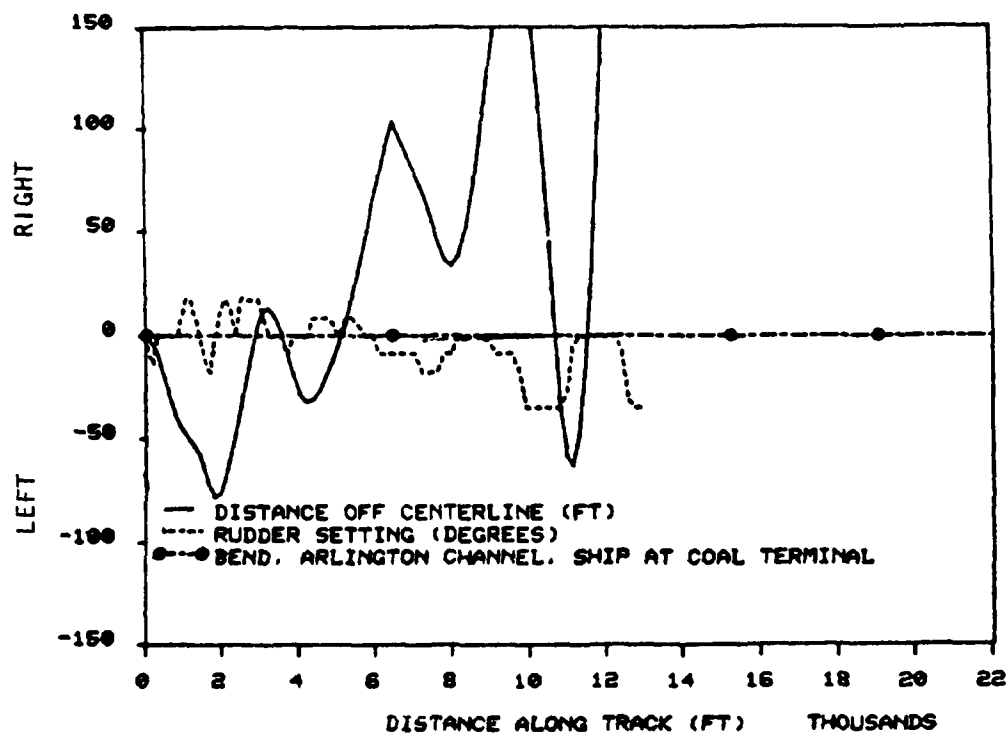Figure A23a.   Ship track for Test 23 (trial 2 4 7)

A68

Figure A23b. Distance along track versus rudder setting
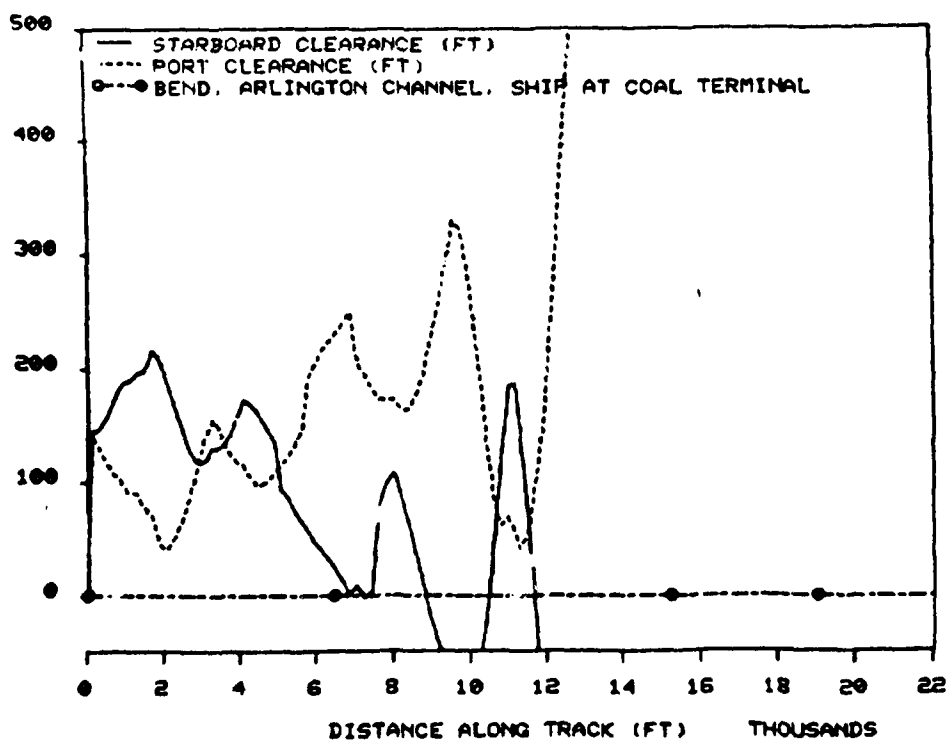and distance off track, Test 23 (trial 2 4 7)

Figure A23c. Distance along track versus port and
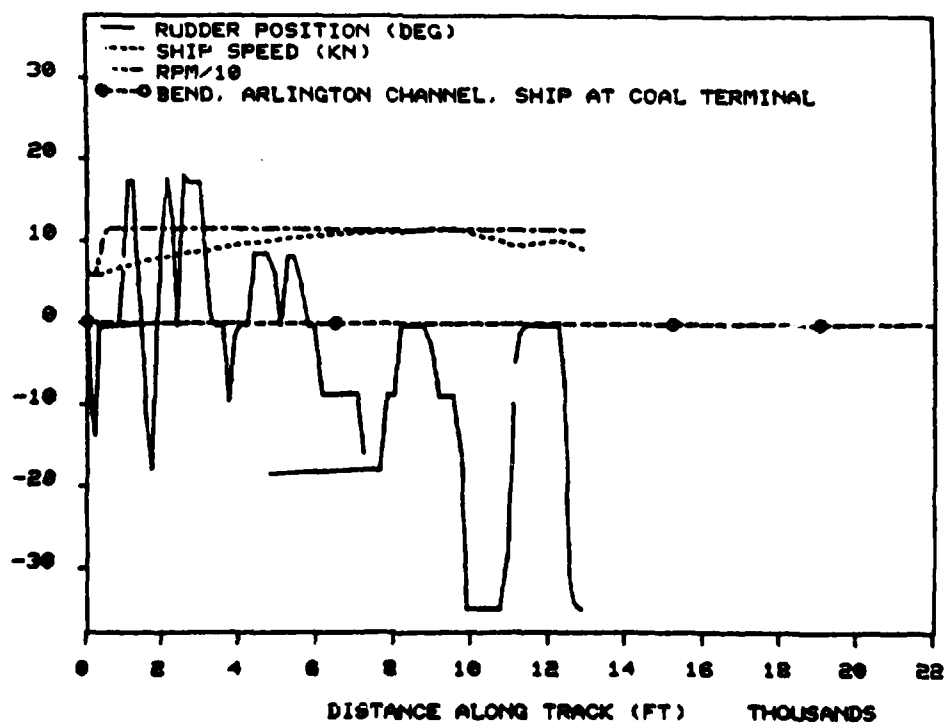starboard clearance, Test 23 (trial 2 4 7)

A69

Figure A23d. Distance along track versus rudder, speed, and rpm/10, Test 23 (trial 2 4 7)

Figure A23e. Distance along track versus rudder, heading, and rpm/10, Test 23 (trial 2 4 7)

Figure A24a. Ship track for Test 24 (trial 2 4 8)

Figure A24b. Distance along track versus rudder setting
and distance off track, Test 24 (trial 2 4 8)

Figure A24c. Distance along track versus port and
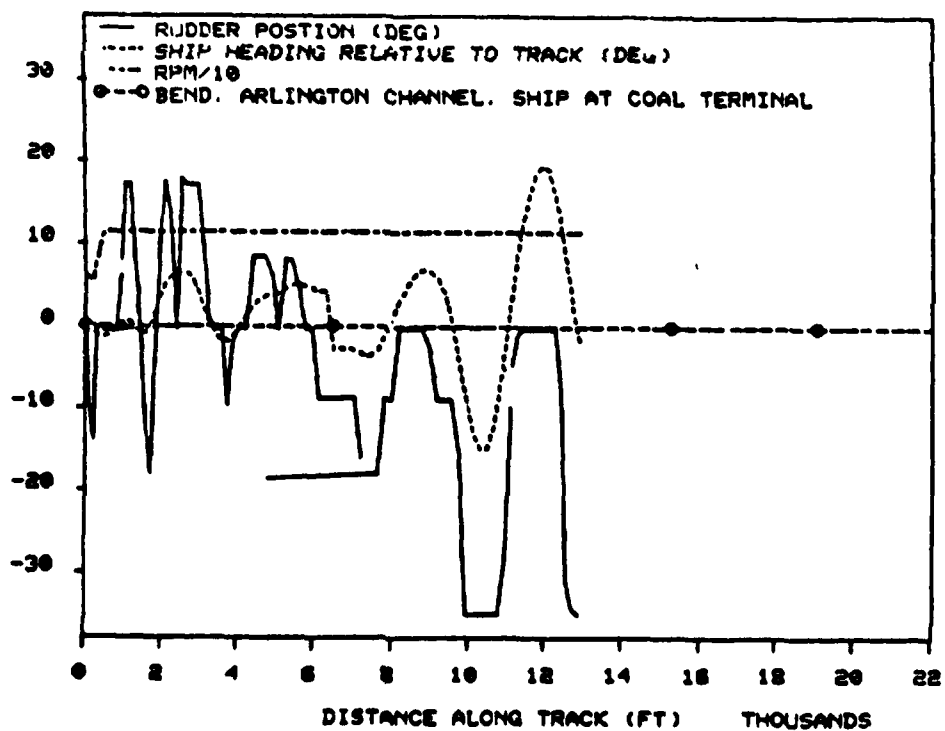starboard clearance, Test 24 (trial 2 4 8)

A72

Figure A24d. Distance along track versus rudder, heading, and rpm/10, Test 24 (trial 2 4 8)

A73

Figure A25a. Ship track for Test 25 (trial 3 4 1)

Figure A25b. Distance along track versus rudder setting
and distance off track, Test 25 (trial 3 4 1)

Figure A25c. Distance along track versus port and
starboard clearance, Test 25 (trial 3 4 1)

A75

Figure A25d. Distance along track versus rudder, speed, and rpm/10, Test 25 (trial 3 4 1)

Figure A25e. Distance along track versus rudder, heading, and rpm/10, Test 25 (trial 3 4 1)
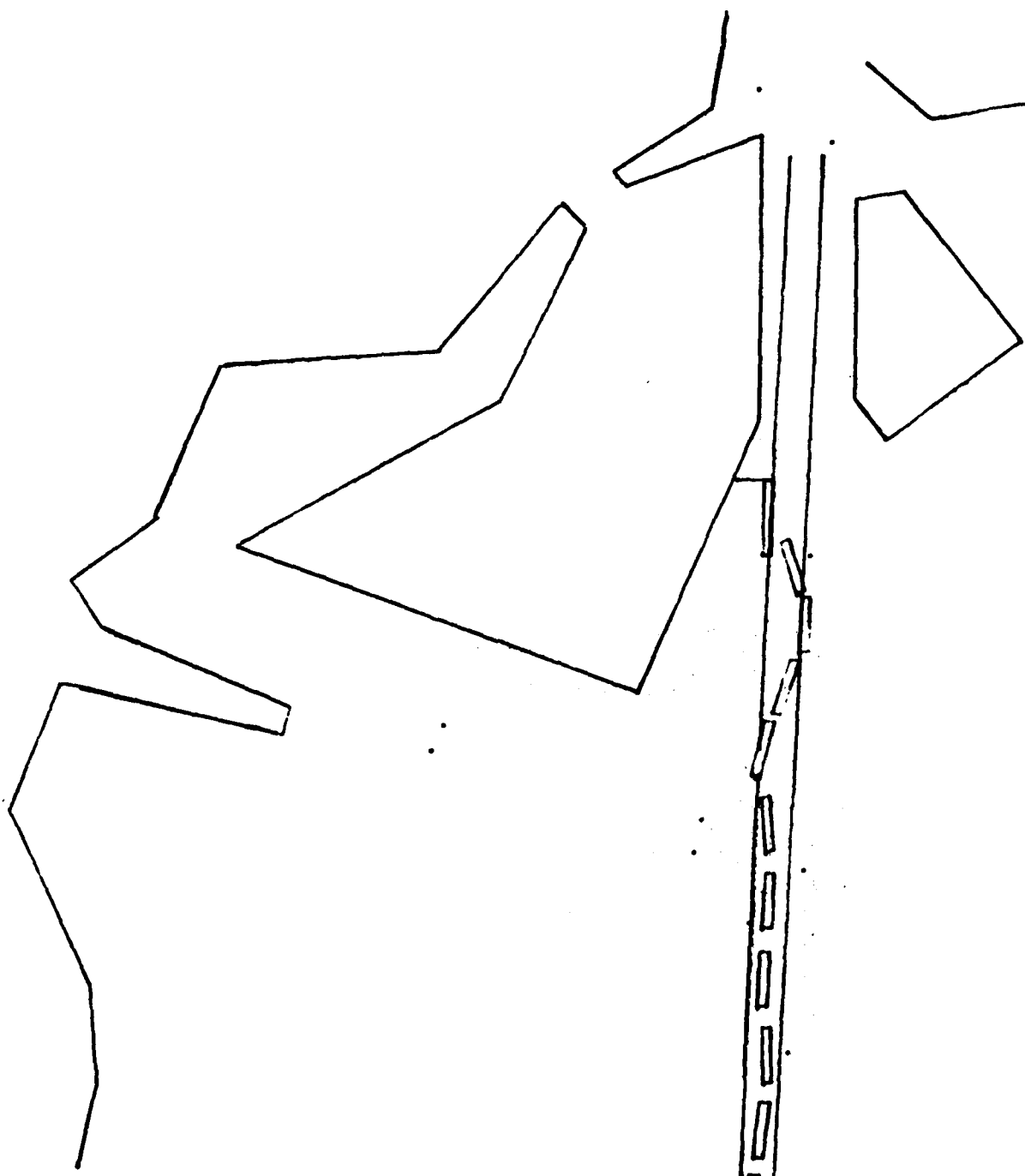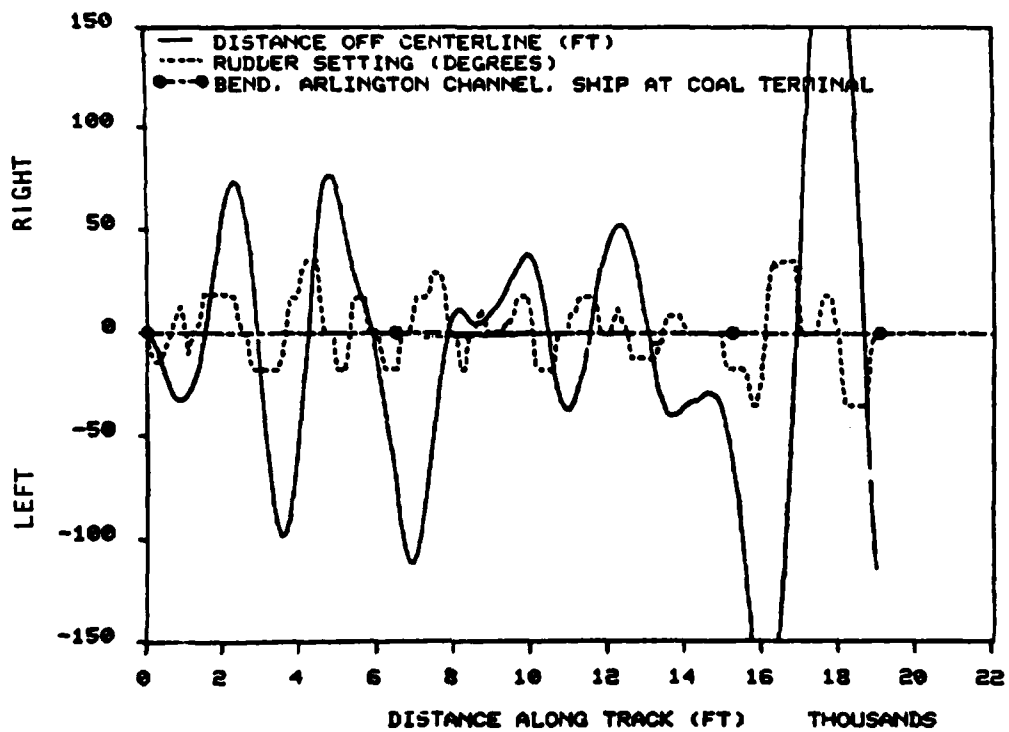
Figure A26a. Ship track for Test 26 (trial 3 4 2)

A77

Figure A26b. Distance along track versus rudder setting
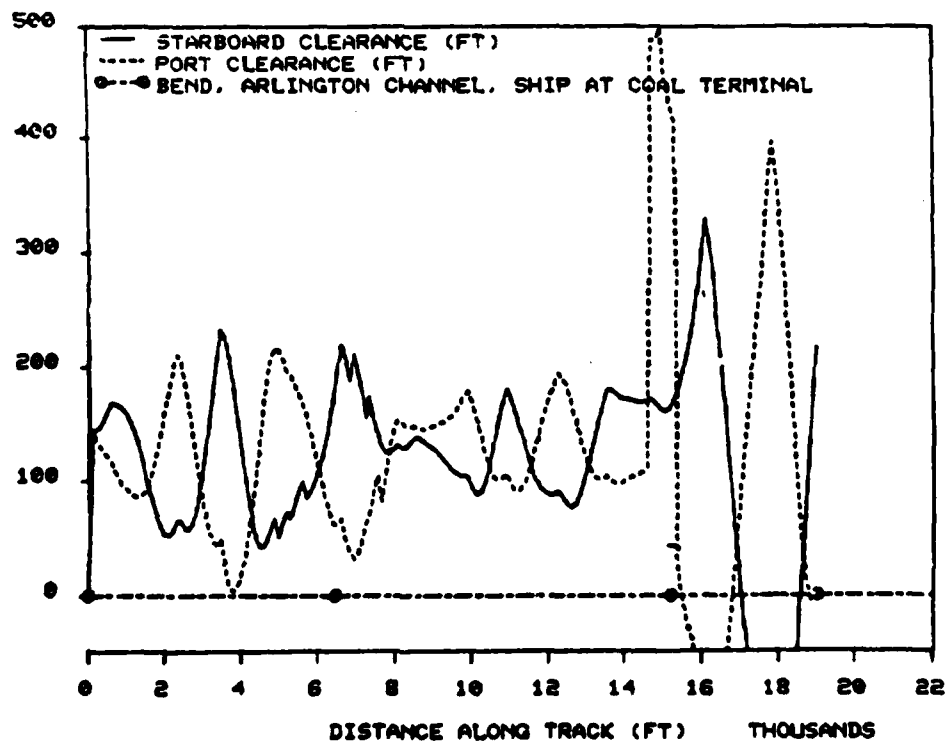and distance off track, Test 26 (trial 3 4 2)

Figure A26c. Distance along track versus port and
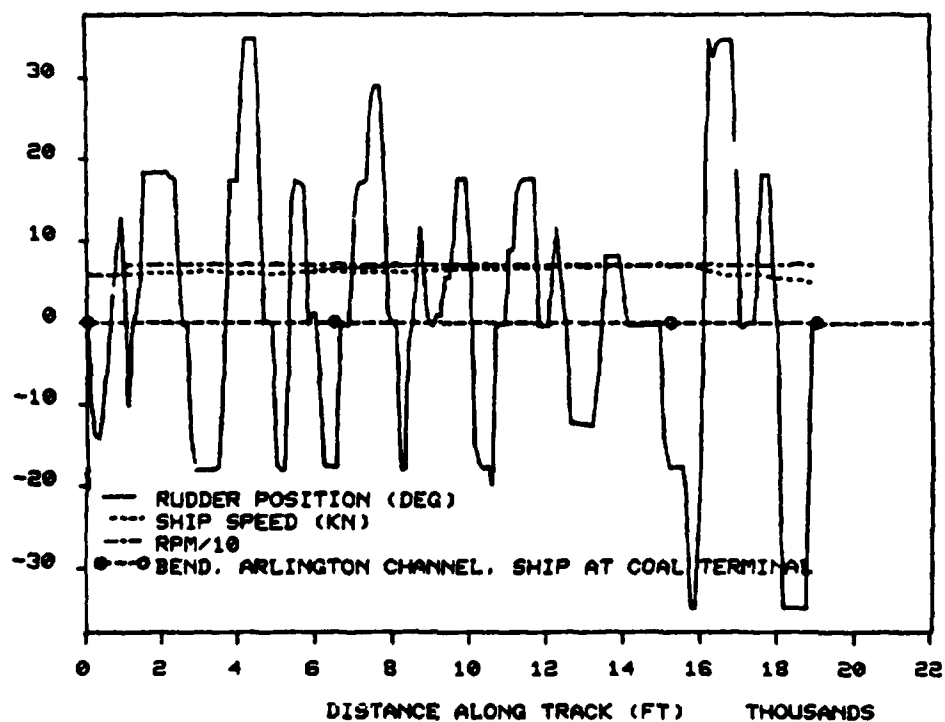starboard clearance, Test 26 (trial 3 4 2)

Figure A26d. Distance along track versus rudder, speed,
and rpm/10, Test 26 (trial 3 4 2)

Figure A26e. Distance along track versus rudder, heading,
and rpm/10, Test 26 (trial 3 4 2)

A79

Figure A27a. Ship track for Test 27 (trial 3 4 3)

A80

Figure A27b. Distance along track versus rudder setting
and distance off track, Test 27 (trial 3 4 3)

Figure A27c. Distance along track versus port and
starboard clearance, Test 27 (trial 3 4 3)

A81

Figure A27d. Distance along track versus rudder, speed,
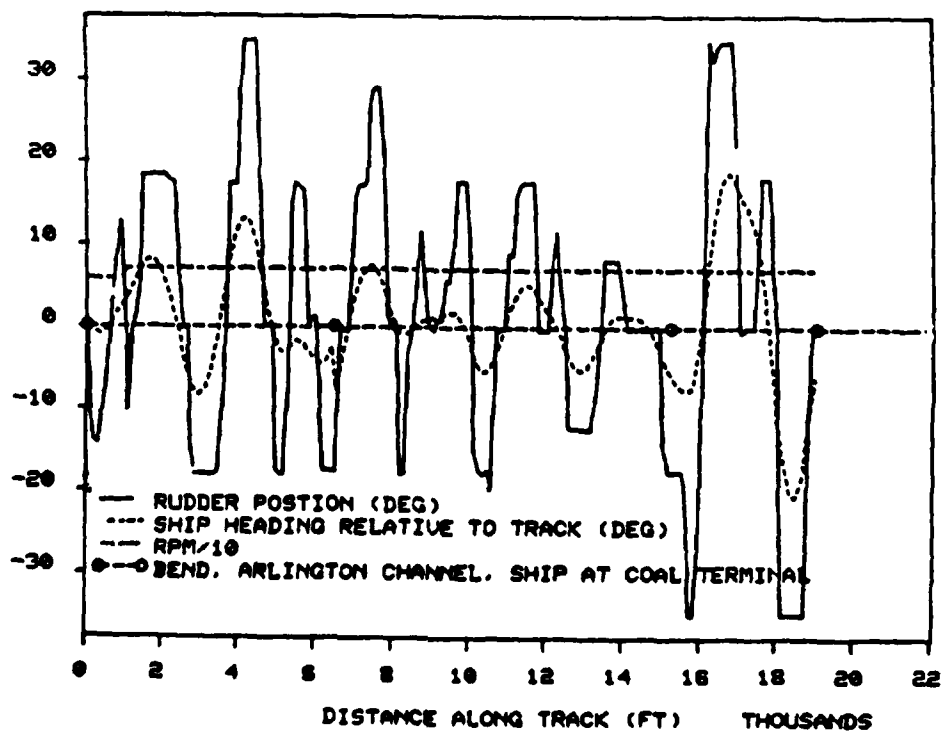and rpm/10, Test 27 (trial 3 4 3)

Figure A27e. Distance along track versus rudder, heading,
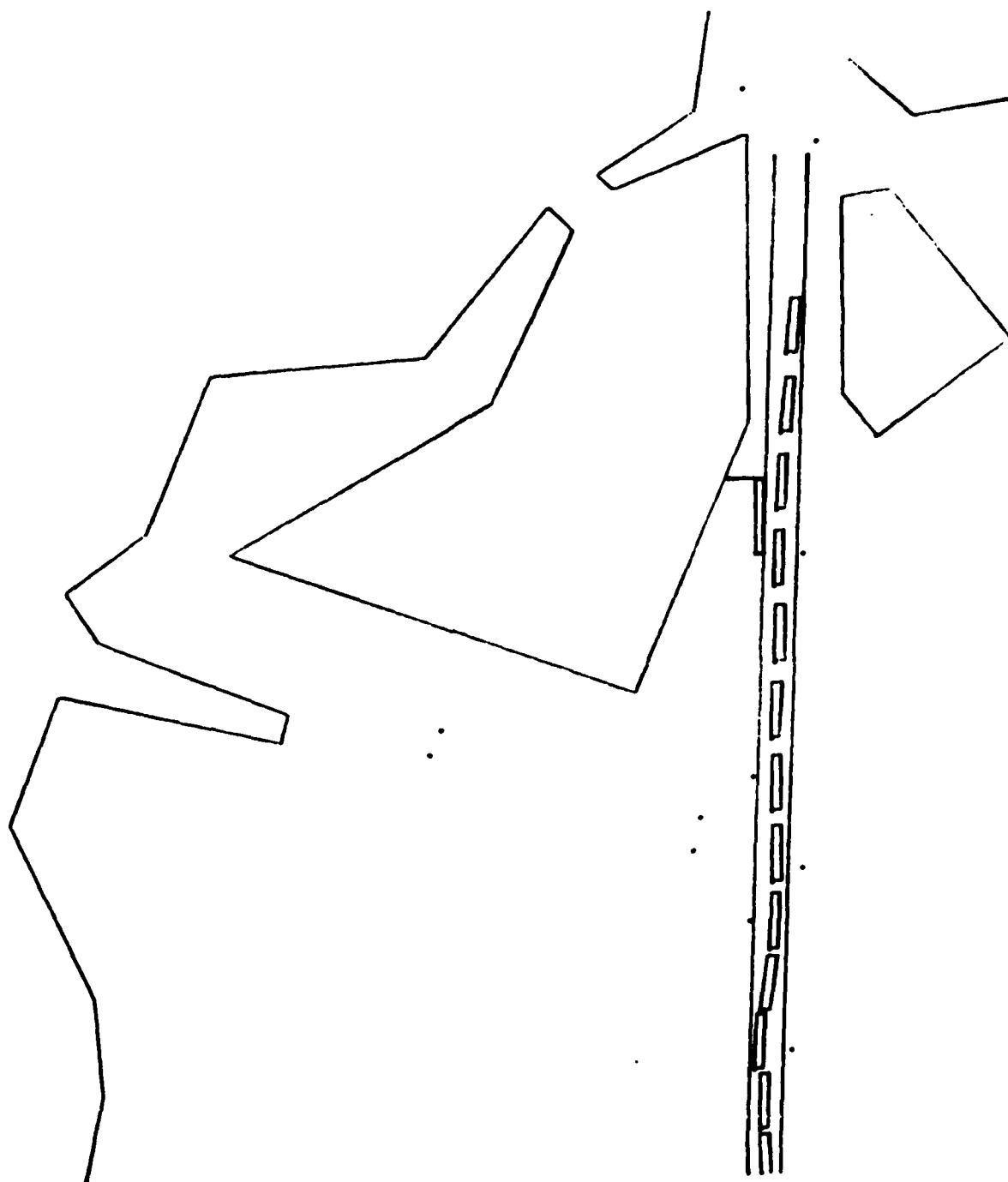and rpm/10, Test 27 (trial 3 4 3)

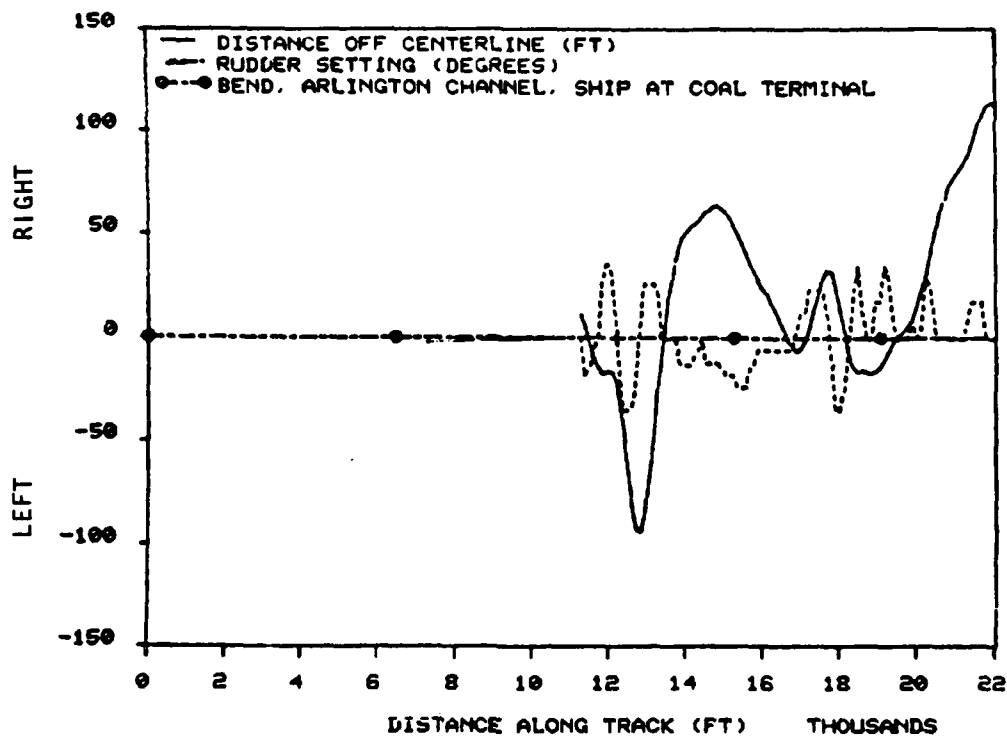Figure A28a. Ship track for Test 28 (trial 1 3 1)

A83

Figure A28b. Distance along track versus rudder setting
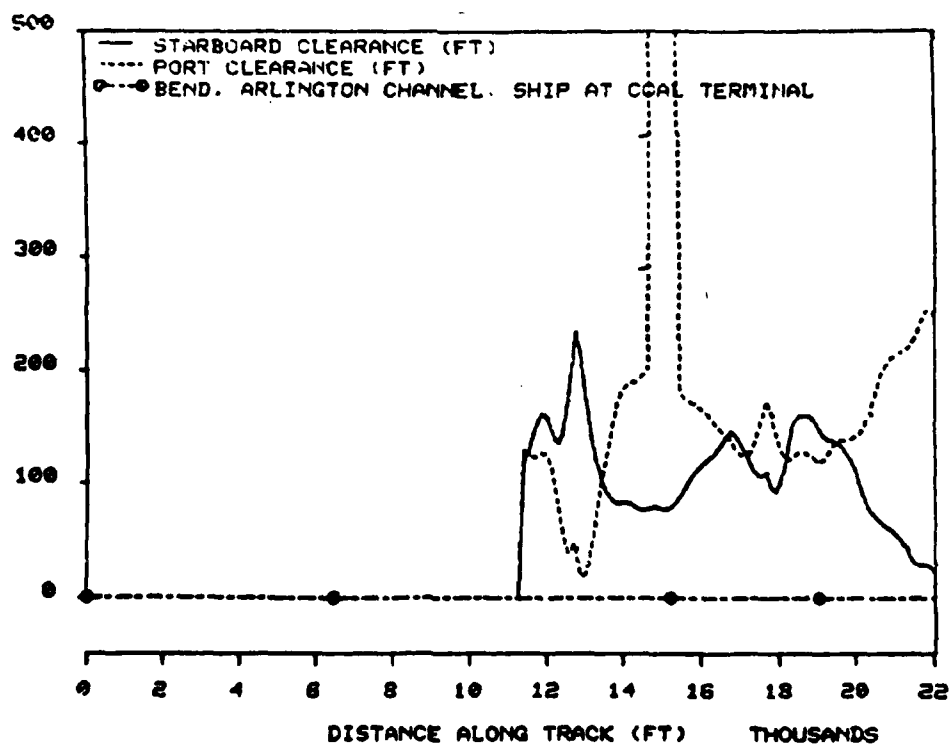and distance off track, Test 28 (trial 1 3 1)

Figure A28c. Distance along track versus port and
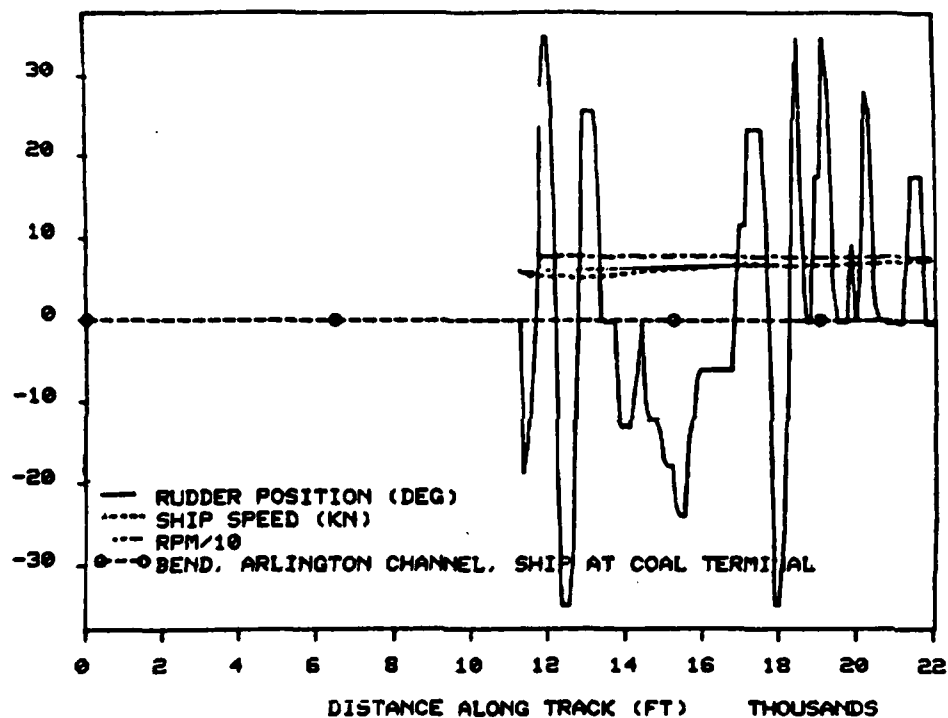starboard clearance, Test 28 (trial 1 3 1)

A84

Figure A28d. Distance along track versus rudder, speed, and rpm/10, Test 28 (trial 1 3 1)

Figure A28e. Distance along track versus rudder, heading, and rpm/10, Test 28 (trial 1 3 1)

A85

Figure A29a. Ship track for Test 29 (trial 1 3 2)

A86

Figure A29b. Distance along track versus rudder setting
and distance off track, Test 29 (trial 1 3 2)

Figure A29c. Distance along track versus port and
starboard clearance, Test 29 (trial 1 3 2)

A87

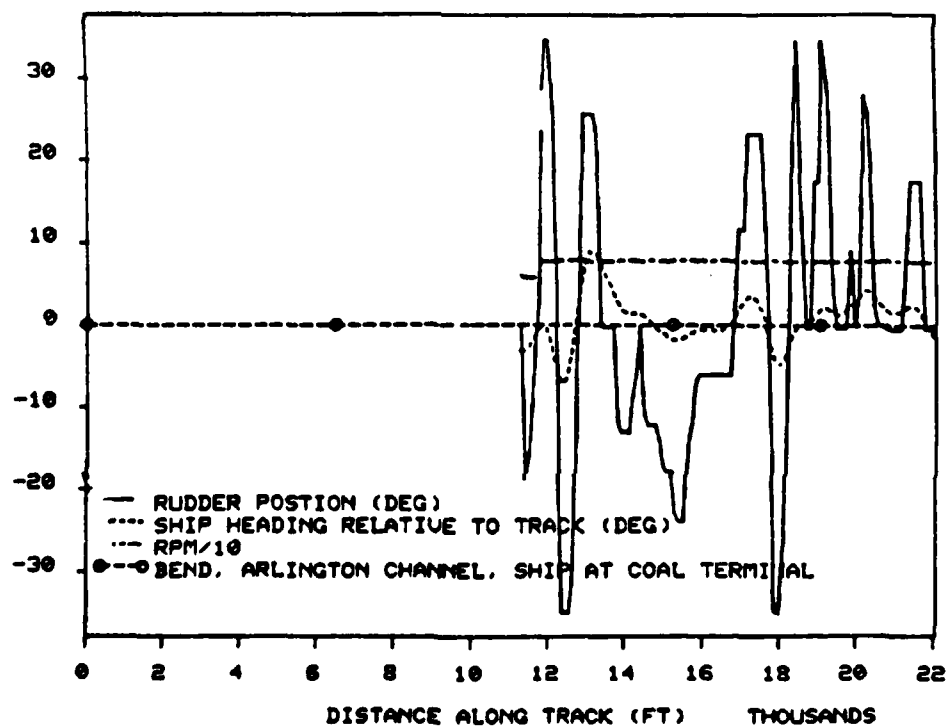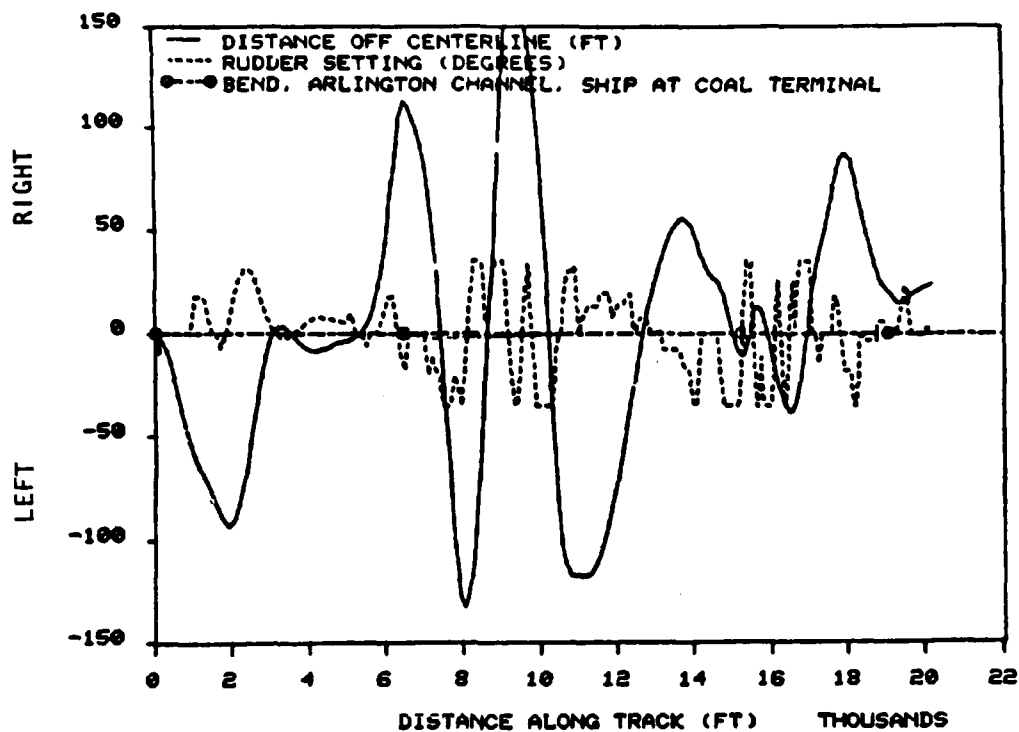Figure A29d. Distance along track versus rudder, speed, and rpm/10, Test 29 (trial 1 3 2)

Figure A29e. Distance along track versus rudder, heading, and rpm/10, Test 29 (trial 1 3 2)

A88

Figure A30a. Ship track for Test 30 (trial 2 3 3)

Figure A30b. Distance along track versus rudder setting
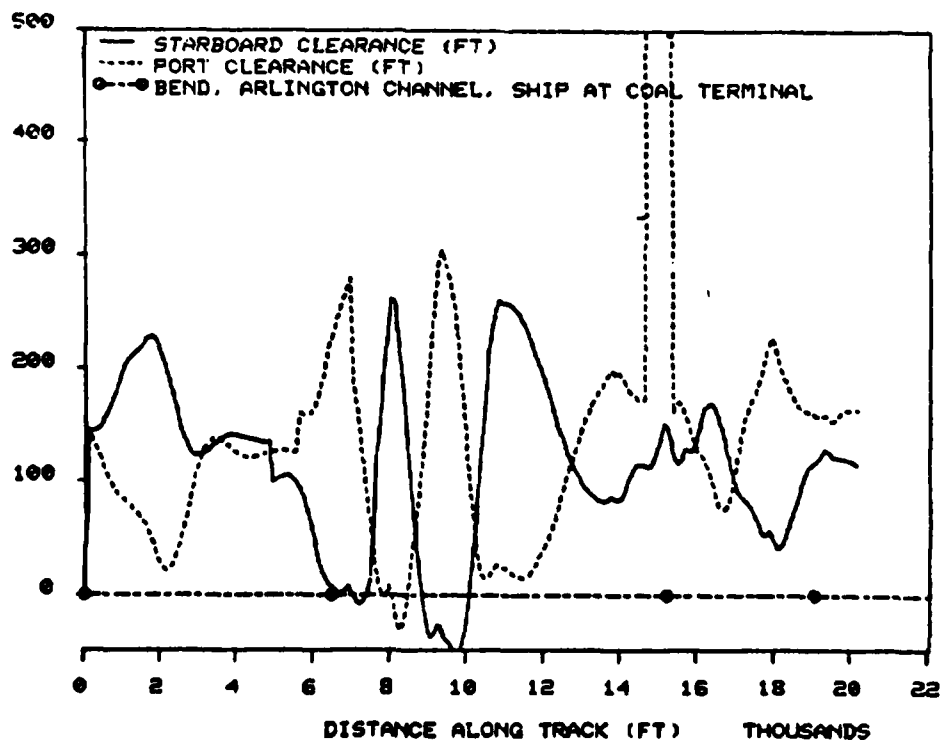and distance off track, Test 30 (trial 2 3 3)

Figure A30c. Distance along track versus port and
starboard clearance, Test 30 (trial 2 3 3)

A90

Figure A30d. Distance along track versus rudder, speed,
and rpm/10, Test 30 (trial 2 3 3)

Figure A30e. Distance along track versus rudder, heading,
and rpm/10, Test 30 (trial 2 3 3)

Figure A31a. Ship track for Test 31 (trial 1 3 4)

Figure A31b. Distance along track versus rudder setting and distance off track, Test 31 (trial 1 3 4)

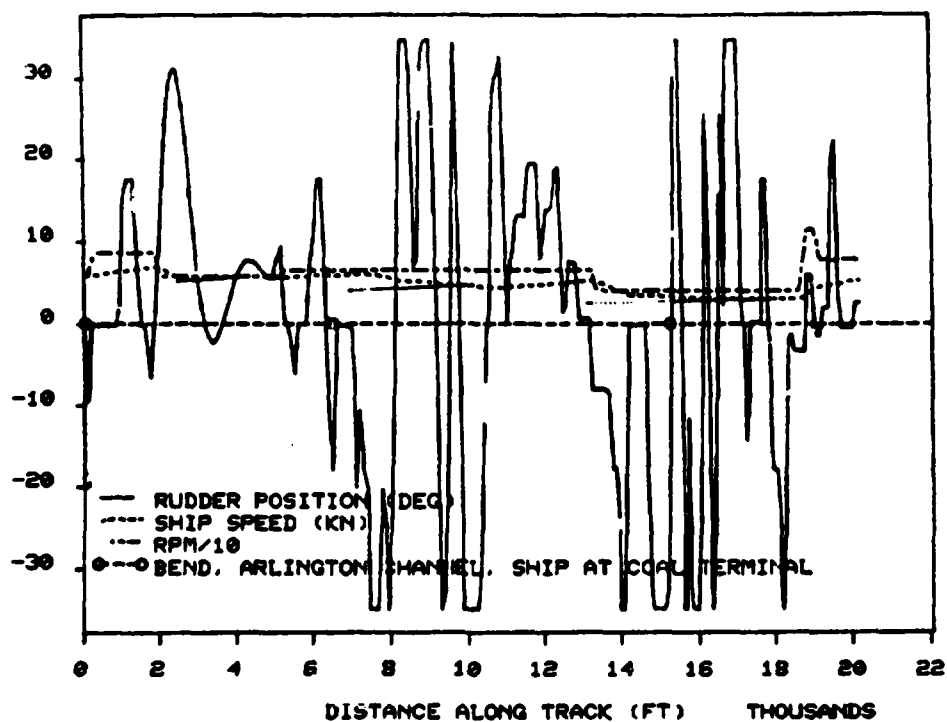Figure A31c. Distance along track versus port and starboard clearance, Test 31 (trial 1 3 4)

A93

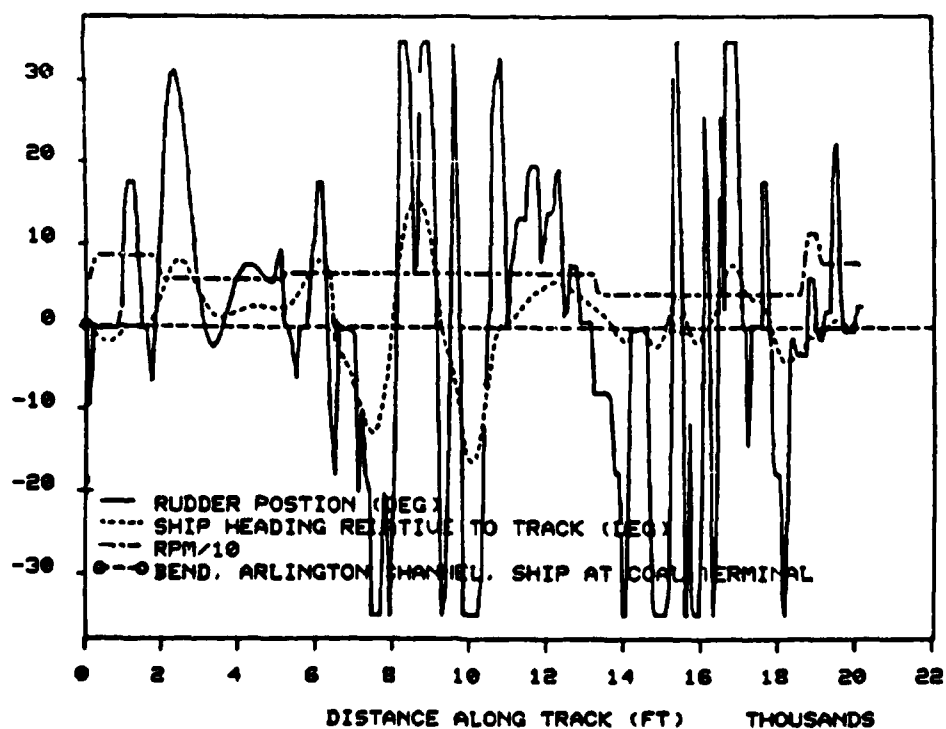Figure A31d. Distance along track versus rudder, speed,
and rpm/10, Test 31 (trial 1 3 4)

Figure A31e. Distance along track versus rudder, heading,
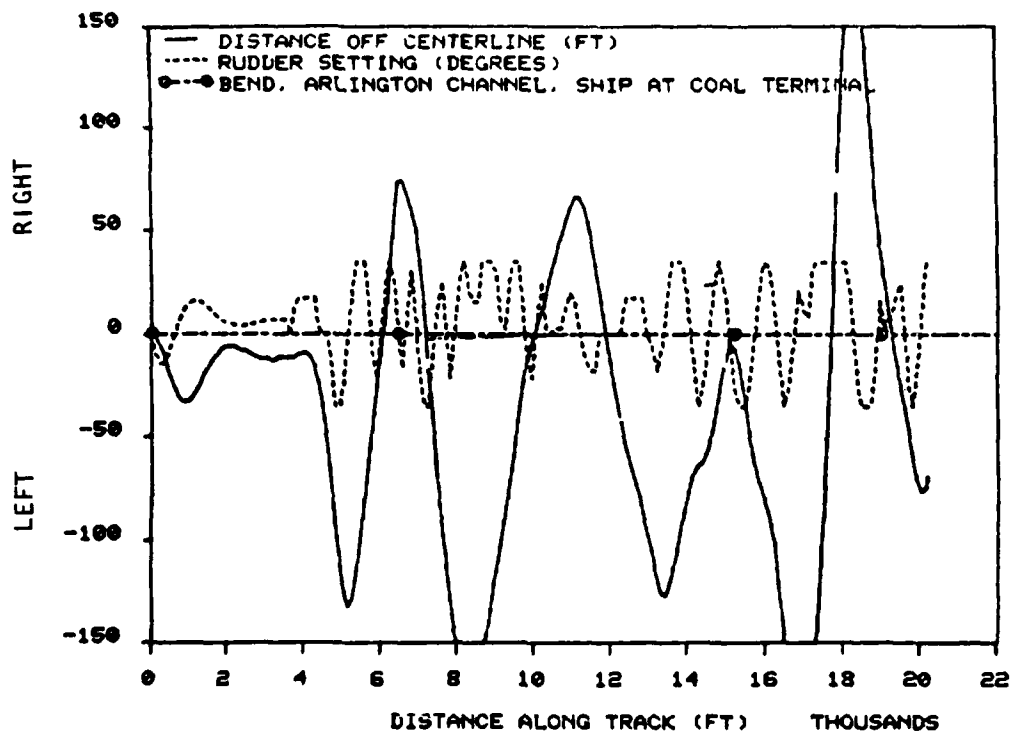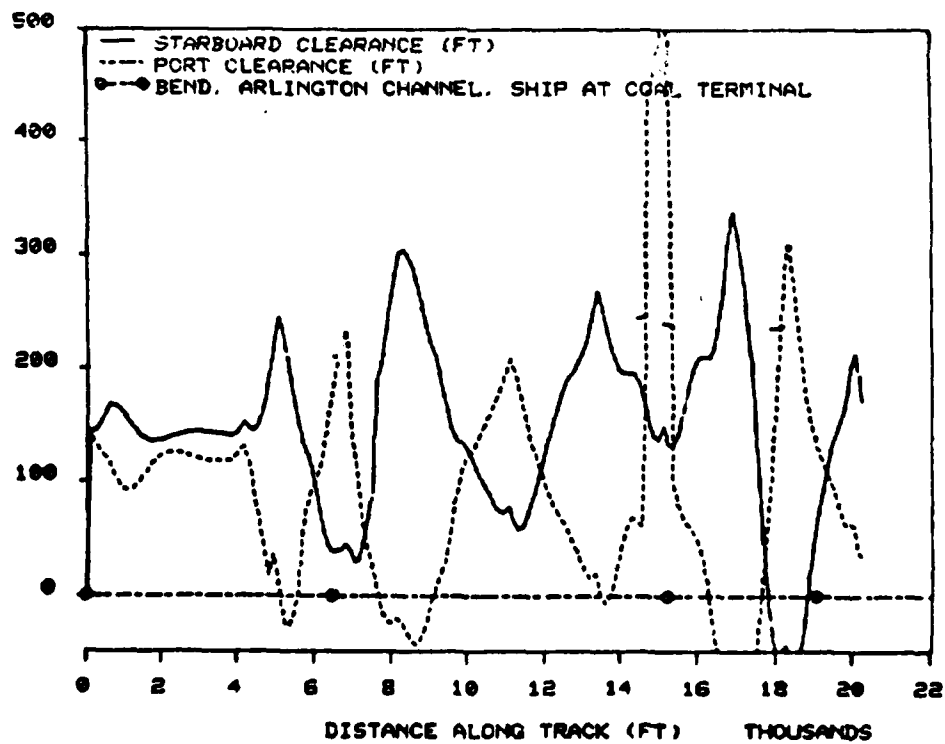and rpm/10, Test 31 (trial 1 3 4)

A94

Figure A32a. Ship track for Test 32 (trial 1 3 5)

A95

Figure A32b. Distance along track versus rudder setting
and distance off track, Test 32 (trial 1 3 5)

Figure A32c. Distance along track versus port and
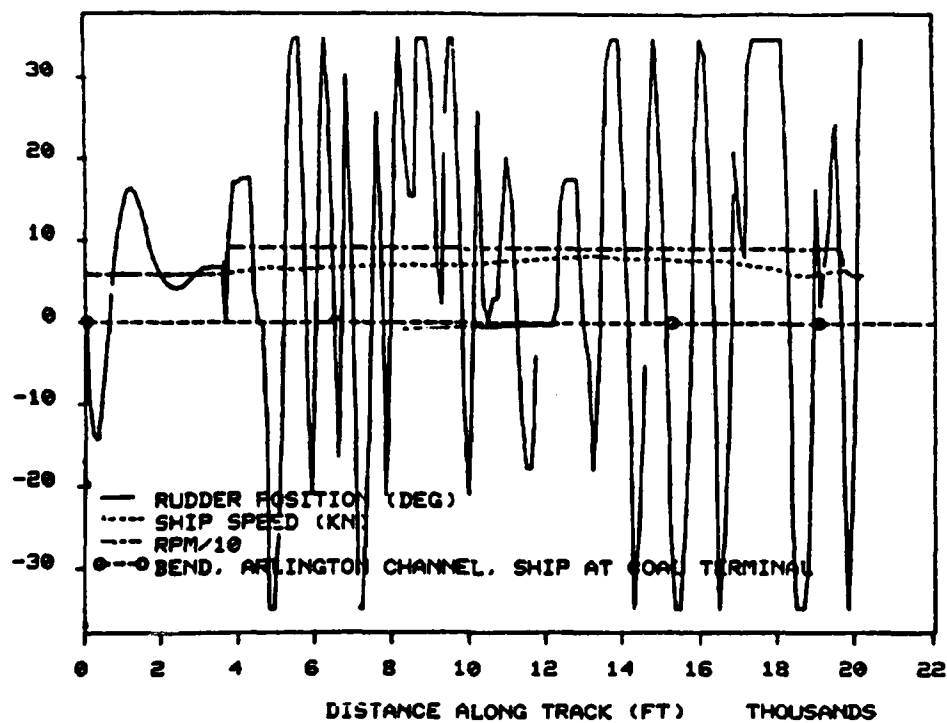starboard clearance, Test 32 (trial 1 3 5)

A96

Figure A32d. Distance along track versus rudder, speed, and rpm/10, Test 32 (trial 1 3 5)
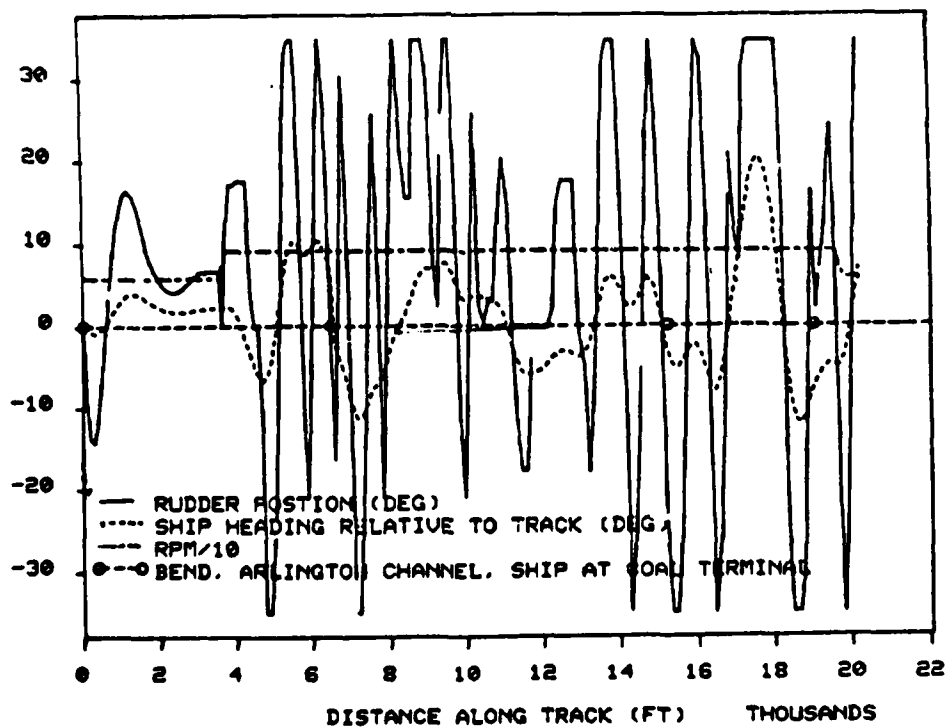

Figure A32e. Distance along track versus rudder, heading, and rpm/10, Test 32 (trial 1 3 5)

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