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September 1994

Ship Navigation Simulation Study, Houston-Galveston Navigation Channels, Texas

Report 3
Galveston Ship Channel and Houston-Galveston Entrance Channels

by Dennis W. Webb

Prepared for U.S. Army Engineer District, Galveston

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Report 3 of a series

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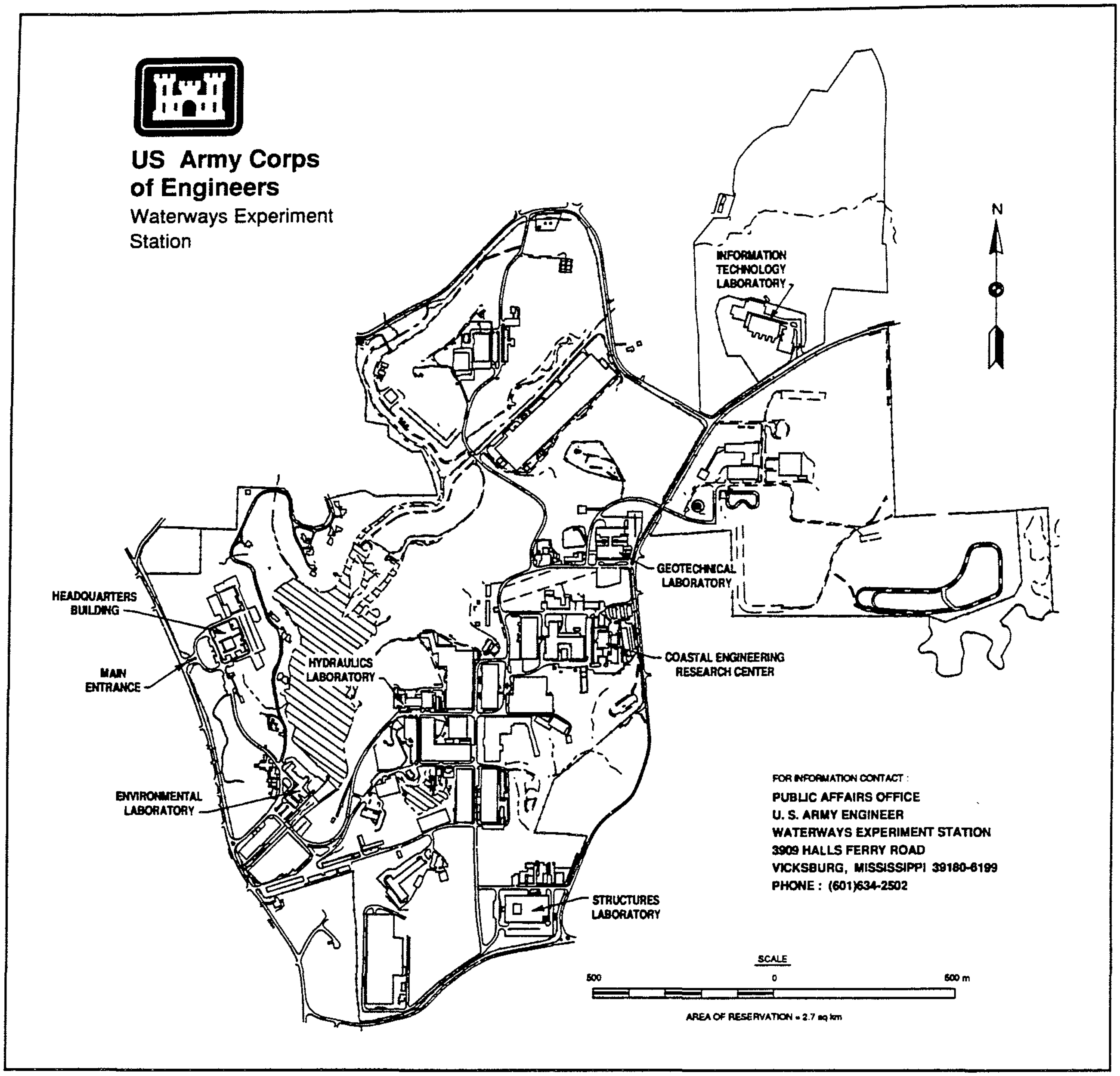
Galveston, TX 77553



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Contents

Preface

This investigation was performed by the Hydraulics Laboratory (HL), U.S. Army Engineer Waterways Experiment Station (WES), for the U.S. Army Engineer District, Galveston (SWG). The study was conducted with the WES research ship simulator during the period April 1990-June 1991. SWG provided survey data of the prototype area. Current modeling was conducted by the Estuarine Processes Branch, Estuaries Division, HL, and by the University of Notre Dame Civil Engineering Department. This is Report 3 of a series. Reports 1 and 2 discuss the navigation study for the bay and bayou segments of the Houston Ship Channel, respectively.

The investigation was conducted by Mr. Dennis W. Webb, Navigation Branch, Waterways Division, HL, under the general supervision of Messrs. Frank A. Herrmann, Jr., Director, HL; Richard A. Sager, Assistant Director, HL; M. B. Boyd, Chief of the Waterways Division, HL; and Dr. Larry L. Daggett, Chief of the Navigation Branch, HL. Ms. Phylis Birchett, Civil Engineering Technician, Navigation Branch, assisted in the study. This report was prepared by Mr. Webb.

Acknowledgment is made to Dr. Thomas Rennie and Mr. Al Meyer, Engineering Division, SWG, for cooperation and assistance at various times throughout the investigation. Special thanks go to the Galveston/Texas City Pilots Association for participating in the study.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

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

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots (international)	0.5144444	meters per second
miles (U.S. statute)	1.609347	kilometers

1 Introduction

The Houston-Galveston Navigation Channels are located along the Gulf of Mexico Coast in eastern Texas, Figure 1. These channels include the Entrance Channels, the Galveston Channel, the Bar Channels (the Inner and Outer Bar Channels and the Bolivar Roads Channel), the Texas City Channel, the Gulf Intracoastal Waterway, and the Houston Ship Channel (HSC) which branches off the Bar Channels, traverses Galveston Bay, and ends in Houston. This report focuses only on the Galveston Channel and the Entrance Channels, Figure 2. This report describes the navigation study conducted on these channels by the Waterways Experiment Station (WES) in 1992. Previous reports describe navigation studies conducted at WES on the Galveston Bay (Hewlett 1993) and the HSC Bayou Segment (Webb and Daggett 1993) of the Houston - Galveston Navigation Channels.

Existing Conditions

Entrance Channel/Bar Channels

The Houston/Galveston Entrance Channel/Bar Channel region is comprised of a series of straight reaches; the Bolivar Roads Channel, the Inner Bar Channel, the Outer Bar Channel (i.e., the Bar Channels), and the Entrance Channel. This is the only portion of the Houston-Galveston Navigation Channels project under the joint jurisdiction of both the Galveston/Texas City Pilots Association and the Houston Pilots Association. The present deep-draft navigation channel in the Bar Channel Reach, as maintained by the U.S. Army Engineer District (USAED), Galveston (the District), is 40 ft deep, below mean low tide (mlt), and 800 ft wide. The present deep-draft navigation channel in the Entrance Channel, as maintained by the District, is 42 ft deep, below mean low tide (mlt), and 800 ft wide. The additional 2 ft of depth in the Entrance Channel allows for the vertical motion of the ships due to waves.

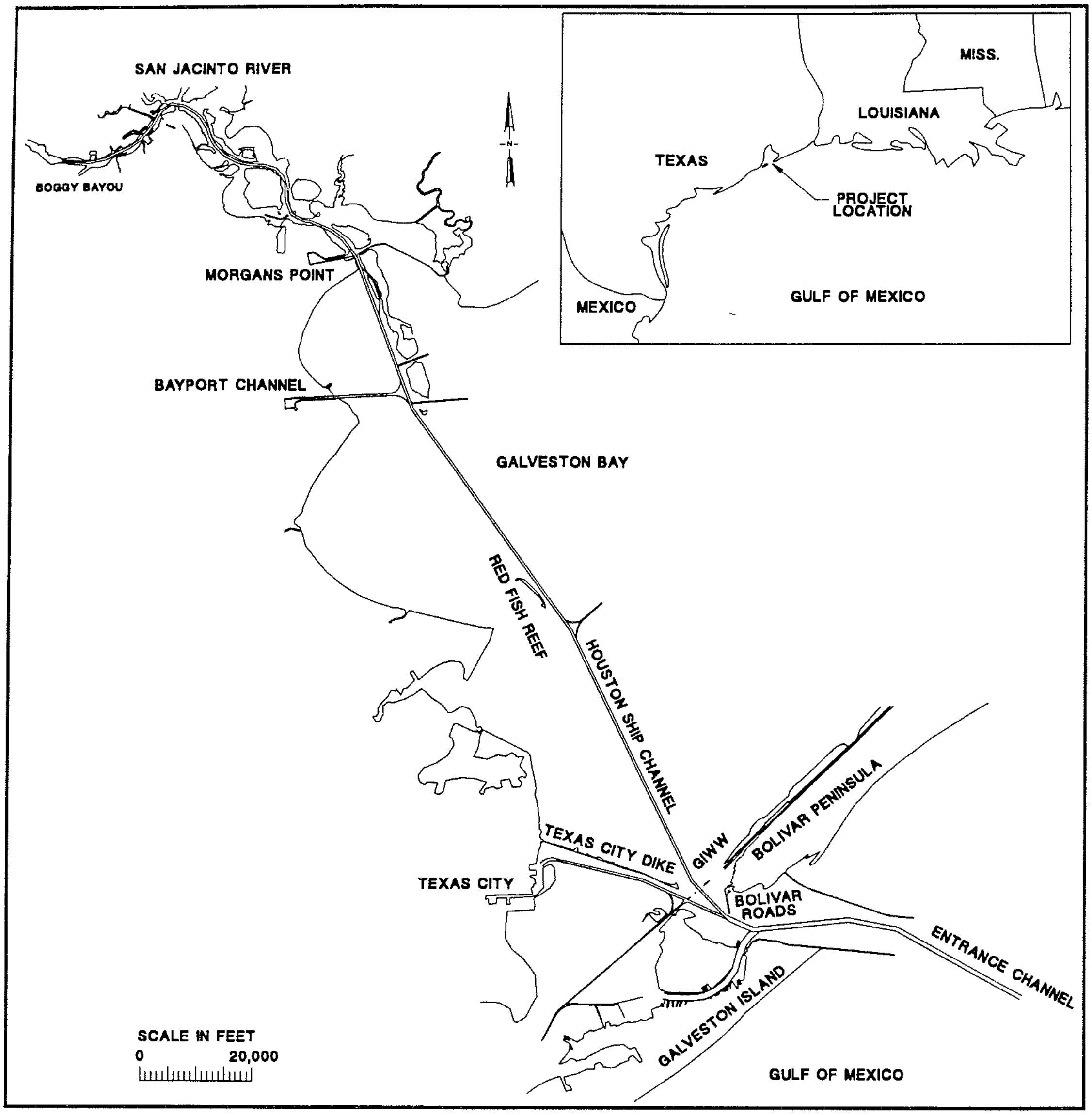

Figure 1. Project location map

Galveston Ship Channel

The Galveston Channel, which serves the Port of Galveston, as presently maintained by the District, is 40 ft deep and 1,100 ft wide. The Galveston Ship Channel has docking facilities on both sides of the channel, serving both deep- and shallow-draft vessels. Facilities include grain exporters, oil importers, and containerized cargo.

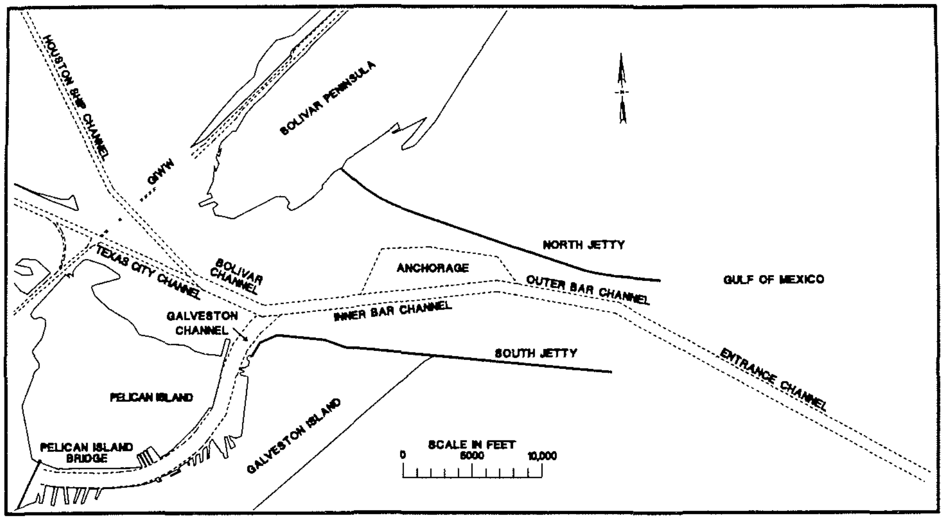

Figure 2. Galveston Channel/Entrance Channel/Bar Channels

Navigation Problems

Crosscurrents

Crosscurrents in the Gulf of Mexico provide problems to local pilots for two reasons. First, vessels experiencing the effects of crosscurrents in the Entrance Channel must steer at an angle into the currents to transit the reach. This means that the vessel is navigating at an angle in the channel, thus reducing the channel width available to other vessels. Second, ships are not affected by the crosscurrents while they are protected by the Galveston jetties. Therefore, as the ship exits the jetties, the bow of an outbound vessel is hit by crosscurrents while the stern is not. This causes the vessel to swing in the direction of the current. When the bow of the inbound ship enters the portion of the channel protected by the jetties, the crosscurrents are still pushing the stern. This causes the vessel to swing in the direction of the current. Crosscurrents from the north (which push the vessel south) are referred to by the local ship pilots as a Freeport set, and crosscurrents from the south (which push the vessel north) are known as a Sabine set. Sabine and Freeport are ports near Galveston, located north and south of Galveston, respectively. For an inbound ship, a Sabine set would cause the ship to turn into oncoming traffic at the jetties, while a Freeport set would make the turn at the jetties more difficult. Any problems in the Entrance Channel entering or leaving the jetties, are made even more significant by the turn between the Entrance Channel and the Outer Bar Channel just west of the gulf-side end of the jetties.

Turning in Galveston Channel

Vessels turning into the Galveston Channel can be subjected to strong crosscurrents when broadside in the channel. Flood currents are of particular concern because there is a danger that the vessel might be swept into the Pelican Island Bridge, located at the west end of the channel. There are several instances of vessels begin swept into the bridge while being turned. The Galveston/Texas City Pilots have recently installed a current meter at the bridge. They can access this meter via modem from their office for immediate current information.

Turning from the HSC into Galveston Channel

Sometimes, vessels will leave Houston and call at Galveston before going to sea. Usually this is not difficult because these vessels are light-loaded and therefore not restricted to the authorized channel. However, occasionally these vessels are approaching almost fully loaded and call at Galveston to "top-off" with additional grain. This is done if the elevator in Houston runs out of grain, or if the vessel is to carry a different type of grain not available at the dock in Houston. These vessels are turned in a naturally deep area southeast of the intersection of the Galveston Channel and the Inner Bar Channel.

Proposed Improvements

The District has proposed an improvement plan for the Houston-Galveston Navigation Channels. The feasibility report (USAED, Galveston 1987) recommended a single-phase 50-ft project. This project was later divided into two phases by Headquarters, U.S. Army Corps of Engineers (USACE).

Entrance/Bar Channels

Phase I entrance channels (Figure 3) are to be 47 ft deep and the Phase II channels are to be 52 ft deep (Figure 3). The additional 2 ft of depth allows for the vertical motion of the vessel due to wave action. The Entrance Channel will have to be extended 4 miles for Phase I and an additional 7 miles for Phase II (for a total of 11 miles), into naturally deep water. Both the Phase I and Phase II Entrance Channel extensions are at a different alignment than the existing Entrance Channel alignment. This change in heading occurs near the end of the existing Entrance Channel and reduces the channel length required to reach naturally deep water for both the Phase I and Phase II extensions. The channel is widened to 1,000 ft at the turn in the proposed Entrance Channel extensions. The Phase I extension channel remains at the existing channel width of 800 ft.

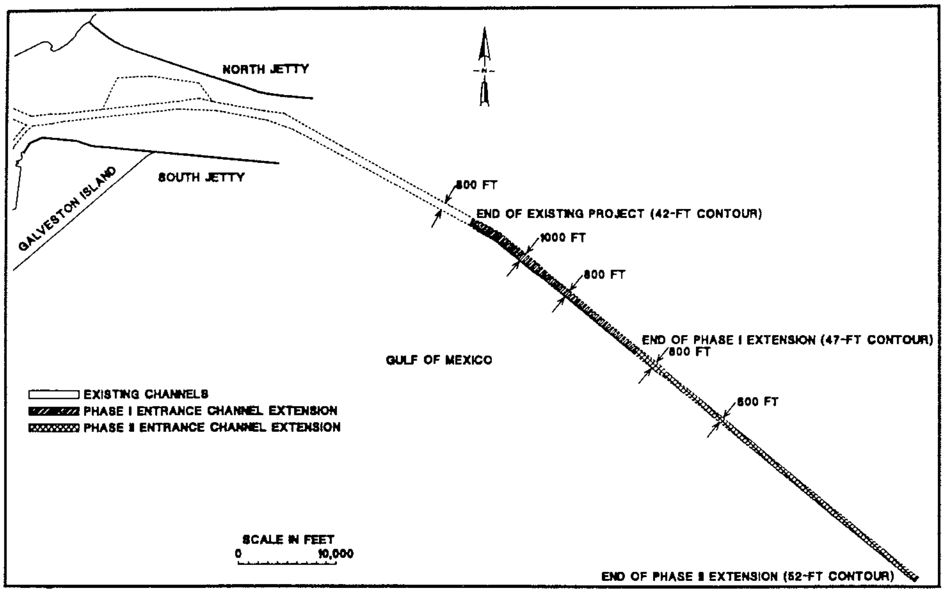

Figure 3. Entrance Channel extensions

The Phase II extension narrows to 600 ft. Bend wideners were installed for both phases of the proposed improvements for the Bar Channels.

Galveston Ship Channel

The Phase I Galveston Channel was proposed to be deepened to 45 ft and realigned to a 450-ft width (Figure 4). The Phase II channel was proposed to be 550 ft wide and 50 ft deep on the same alignment as the Phase I channel.

Outer Bar Channel

The Outer Bar Channel was widened 100 ft on the north side (Figure 5). This modification to the feasibility plan was in response to a pilot's request to allow an inbound vessel additional room to recover from the Gulf crosscurrents as it enters the jetty area.

Purpose and Scope of Investigation

The navigation study was conducted using the WES Hydraulic Laboratory's ship simulator facility. The objectives of the study were to:

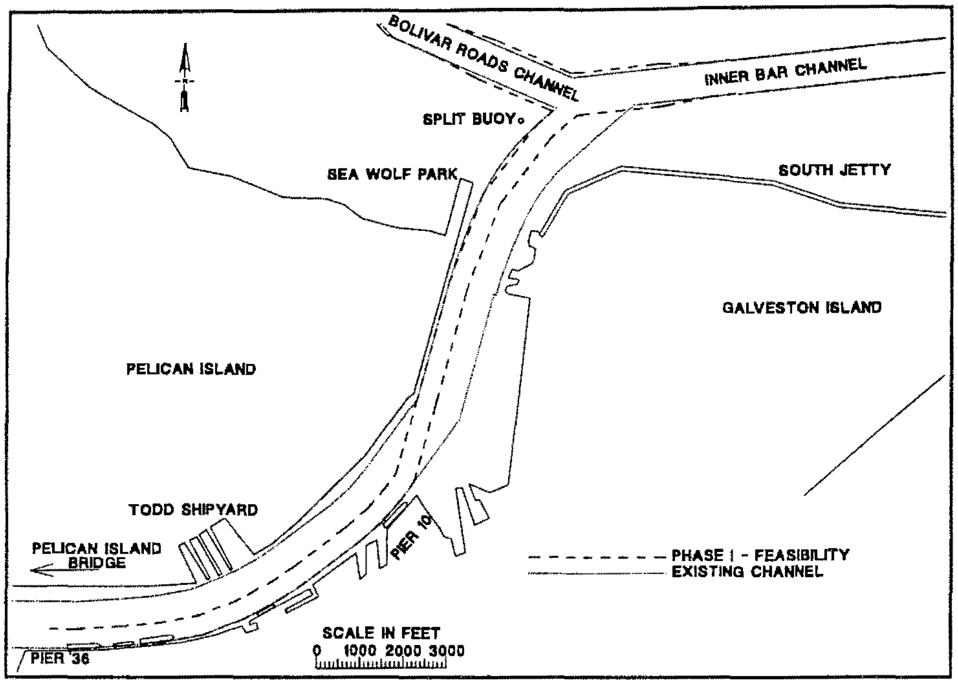

Figure 4. Phase I Galveston Ship Channel, feasibility report

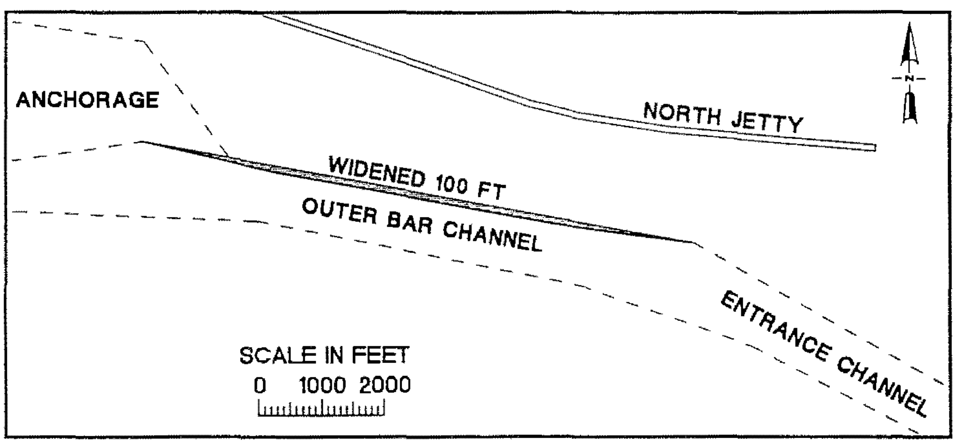

Figure 5. Outer Bar Channel widener

a. Test the adequacy of the Phase I and Phase II channels for two-way traffic.

b. Test the adequacy of the Phase I and Phase II Galveston Ship Channel for one-way traffic and turning manuevers.

c. Determine if loaded ships outbound from Houston can turn into the Galveston Ship Channel.

2 Data Development

Description of Simulator

It is beyond the scope of this report to describe in detail the WES ship simulator;[1] however, a brief explanation will be made. The purpose of the WES ship simulator is to provide the essential factors necessary in a controlled computer environment to allow the inclusion of the man-in-the-loop, i.e., local ship pilots in the navigation channel design process. The simulator is operated in real-time by a pilot at a ship's wheel placed in front of a screen upon which a computer generated visual scene is projected. The visual scene is updated as the hydrodynamic portion of the simulator program computes a new ship's position and heading resulting from manual input from the pilot (rudder, engine throttle, bow and stern thruster, and tug commands) and external forces. The external force capability of the simulator includes effects of wind, waves, currents, banks, shallow water, ship/ship interaction, and tug boats. In addition to the visual scene, pilots are provided simulated radar and other navigation information such as water depth, relative ground and water speed of the vessel, magnitude of lateral vessel motions, relative wind speed and direction, and ship's heading.

Required Data

Data required for the simulation study included channel geometry, bottom topography, channel currents for proposed as well as existing conditions, numerical models of test ships, and visual data of the physical scene in the study area. A reconnaissance trip was carried out for the purpose of observing actual shipping operations in the study area. Still photographs were taken during the reconnaissance transits to aid in the generation of the simulated visual scene. Discussions with pilots were also held during

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1 "Hydraulic design of deep draft navigation channels," PROSPECT (Proponent Sponsored Engineer Corps Training) course notes, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, 19-23 June 1989.

this trip so that WES engineers could become more familiar with concerns and problems experienced during channel operations.

Test File

The test file contains initial conditions (ship speed and heading, rudder angle, and engine setting) for the simulation and geographical coordinates for the channel alignment. The channel is defined in terms of cross sections located to coincide with changes in channel alignment and current direction and magnitude. The information used for the development of the Galveston Channel/Entrance Channels database was obtained from the District's project drawings. The Texas state plane coordinate grid was also plotted on these drawings and was used for the simulator database coordinate system. Also included in the test file is the steepness and overbank depth (water depth at the top of the side slope) adjacent to the channel. These data are used by the computer to calculate bank suction forces on the test vessels.

Water depths for the simulator were based on authorized project depths. For the simulated existing channel, the water depth represented the existing condition taken from the most recent dredging survey (May 1986) furnished by the District. Also, bank slopes and overbank depths were obtained from the District's dredging survey. These data are used in the calculation of ship hull bank forces. Briefly, bank forces occur when a ship travels close to a submerged bank (also wall or docked ship), and the resulting effect is characterized by a movement toward the bank and a bow-out rotation away from the bank.

Scene File

The scene database is comprised of several data files that contain geometrical information enabling the graphics computer to generate the simulated scene of the study area. The computer hardware and software used for visual scene generation is separate from the main computer of the ship simulator. The main computer provides motion and orientation information to a stand-alone graphics computer for correct vessel positioning in the scene that can be viewed by the pilot. Operators view the scene as if they are standing on the bridge of a ship looking toward the ship's bow in the foreground. View direction can be changed during simulation for the purpose of looking at objects outside of the relatively narrow straight-ahead view.

Aerial photographs, navigation charts, and dredging survey charts provided the basic data for generation of the visual scene. The simulation testing required low visual resolution beyond the immediate vicinity of the navigation channel. All land masses in the vicinity of the navigation channel were included in the scene. All aids to navigation in the vicinity of the study area were included. In addition to the man-made and topographical features in the vicinity, the visual scene included a perspective view of the bow of the ship from the pilot's viewpoint. Visual databases for all design ships were developed at WES for use in the simulation.

Radar File

The radar file contains coordinates defining the border between land and water and significant man-made objects, such as docked ships and aids to navigation. These data are used by another graphics computer which connects the coordinates with straight lines and displays them on a terminal. The objects viewed comprise visual information which simulates shipboard radar. The main information sources for this database were the project drawings and dredging survey sheets supplied by the District.

Ship Files

The ship files contain characteristics and hydrodynamic coefficients for the test vessels. These data are the computer's definition of the ship. The coefficients govern the reaction of the ship to external forces, such as wind, current, waves, banks, underkeel clearance, ship/ship interaction, and internal controls, such as rudder and engine rounds per minute (rpm) commands. The numerical ship models for the Galveston Channel/Entrance Channels simulations were developed by Tracor Hydronautics, Inc. of Laurel, Maryland (Ankudinov 1991). The test ships were chosen based on the District's economic analysis of future shipping business and operations and are shown in Table 1. The length of the ship is measured as the distance between perpendiculars. As in the simulations of the Bay and Bayou Segments, the design vessels were loaded to 1-ft underkeel clearance.

Table 1
Design Vessels for Simulation

Channel	Ship Type	Tonnage	Dimensions, ft
Existing	Tanker	132K	920 × 144 × 39
Existing	Bulk Carrier	93K	775 × 106 × 39
Phase I	Tanker	165K	990 × 156 × 44
Phase I	Bulk Carrier	100K	775 × 106 × 44
Phase II	Tanker	175K	1,013 × 173 × 49
Phase II	Bulk Carrier	155K	971 × 140 × 49

Current File

The current file contains current magnitude and direction and water depth for each of eight points across each of the cross sections defining the channel alignment. Current data for a ship simulation study are usually obtained from physical or numerical models. In this study, current data were available from a numerical model of Galveston Bay (Lin 1992). The model bathymetry was modified for generation of currents for the two proposed conditions.

Crosscurrents in the Gulf of Mexico and in the entrance channels were developed by Dr. Joannes J. Westerink, University of Notre Dame (Westerink 1993).

3 Navigation Study

Validation

The simulation was validated with the assistance of two pilots from the Galveston/Texas City Pilots Association. The following information was verified and fine tuned during validation:

a. Currents.

b. Bank conditions.

c. Ship/ship interaction.

d. Ship engine and rudder response.

e. The visual scene and radar image of the study area.

(1) Location of all aids to navigation.

(2) Location and orientation of the docks.

(3) Location of buildings visible from the vessel.

Validation began by the pilots maneuvering through the visual scene in a fast-time mode to quickly check building and buoy locations. After this, real-time simulation runs were undertaken with the vessel transiting the entire study area. Special attention was given by the pilot to the response of the ship to external forces. Problem areas were isolated, and the prototype data for these areas were examined. The model was adjusted and further simulation runs were undertaken through the problem areas, and if necessary, additional adjustment was made. This process was repeated until the pilot was satisfied that the simulated vessel response was similar to that of an actual vessel in the prototype.

Preliminary Testing

After the model was successfully validated, the validation pilots made preliminary test runs in the 450-ft-wide Phase I Galveston Channel. Tests of the bulk carrier outbound from Houston and turning into Galveston revealed that the ships were unable to make the turn during ebb or flood tide. None of the runs came close to making the turn, and the runs were aborted when the pilot lost control of his ship. Tests of the bulk carrier outbound from Galveston showed the pilots had problems keeping their vessels in the authorized channel for both ebb and flood tide conditions. Of additional concern to the pilots was the fact that the 450-ft-wide channel ran along side the docks between piers 10 and 36. Currents are strong in the Galveston Channel, and to maintain steerage when running with a fair tide (i.e., the vessel is heading in the same direction as the current, inbound flood and outbound ebb), the pilots must keep a headway of at least 4 knots. If the 450-ft channel runs alongside the docks, ships traveling at 4 knots or faster run a significant risk of sucking docked ships away from the docks, resulting in broken mooring lines and potential damage. Pilots also had a difficult time knowing their position in the curved, 450-ft-wide channel.

In response to concerns about the proposed Galveston Channel alignment, the 450-ft-wide Phase I channel was realigned (Figure 6). The 550-ft-wide Phase II channel was aligned identically to the Phase I channel. This alignment takes advantage of a naturally deep area just north of the Galveston Jetty and provides a funnel from the Inner Bar Channel and the Bolivar Roads Channel into the Galveston Channel. Additionally, the

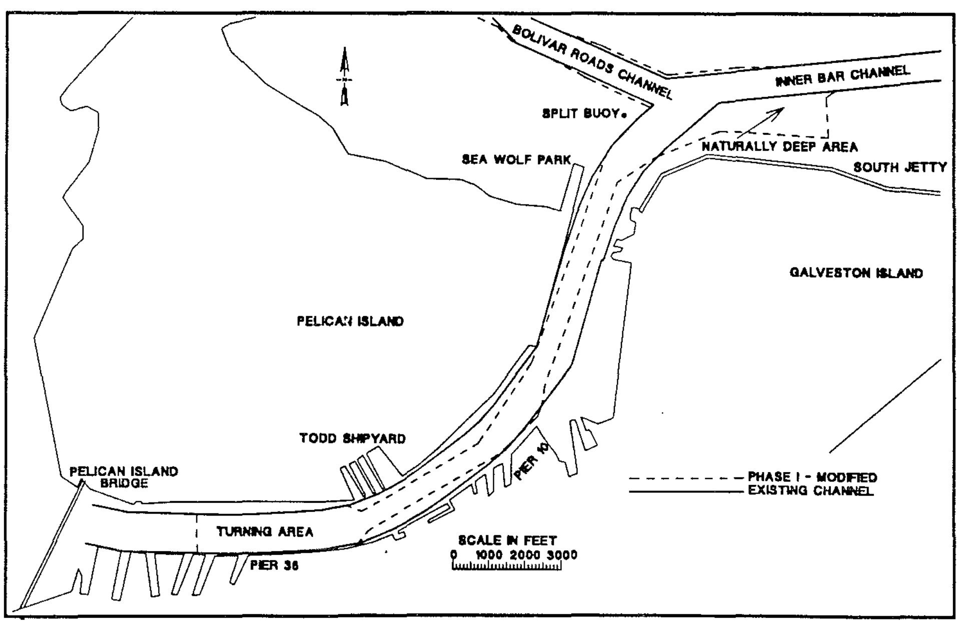

Figure 6. Phase I Galveston Channel, as tested

reach between Pier 10 and Seawolf Park was straightened so that outbound ranges could be positioned in Galveston Bay. These ranges could be used as rear ranges for inbound ships.

Preliminary tests were conducted on the realigned Galveston Channel with the validation pilots. Based on these runs, the modified alignment replaced the feasibility alignment in the navigation study.

The capability to test two simulations at once was not in place during the first week of validation. Therefore, portions of the project, including the crosscurrents in the Gulf of Mexico, were validated by the first pair of pilots to come to WES for testing and not by the original validation pilots. This reduced the number of actual test runs made by the first pair of pilots (Pilots 1 and 2).

Test Scenarios

Test conditions

The test scenarios, design vessels, and environmental conditions were selected to test the existing and proposed channels in the "maximum credible adverse situation." That is, the worst conditions under which the harbor would maintain normal operations. This approach provides a built in safety factor when analyzing the results. Three channel configurations, the existing channel, the Phase I channel, and the Phase II channel were tested during the simulations at WES. The existing channels were tested to provide a base with which to compare tests conducted in the proposed channels and to provide a basis of comparison of conditions to the pilots involved in the testing. The same bank conditions were used for the proposed channels as were used in the existing channel.

To test all channels with a variety of meeting and passing scenarios, the study area was divided into nine test reaches, A through I (Figures 7 through 15 at the end of this section). Testing of two way traffic was accomplished with two real-time piloted simulations conducted simultaneously. The pilots were in radio contact with each other and could see the other vessel on their visual scene and radar display.

Test reaches

a. *Reach A, inbound to Houston/outbound from Houston.* This test (Figure 7) was designed to test the meeting and passing of a loaded tanker (inbound to Houston) and a loaded bulk carrier (outbound from Houston), as well as to provide a track plot from the Gulf of Mexico through the Houston Ship Channel north of the Gulf Intercostal Waterway (GIWW). The meeting and passing was to occur in the Inner Bar Channel. This reach was tested for both the maximum ebb and maximum flood currents.

b. *Reach B, outbound from Galveston.* This test reach (Figure 8) was designed to test a loaded bulk carrier leaving the Port of Galveston and turning into the Inner Bar Channel. This reach is normally operated as one-way traffic. The primary concern of this test is the effect of crosscurrents on the vessel as it turns from the Galveston Channel into the Inner Bar Channel. This test was not run inbound since inbound vessels are typically light-loaded or in ballast and therefore are not restricted to the confines of the authorized deepened channel limits. This reach was tested for the maximum ebb and maximum flood currents.

c. *Reach C, outbound from Houston into Galveston.* This test (Figure 9) was designed to test a loaded bulk carrier outbound from Houston and turning into Galveston. This maneuver is done in the prototype as some grain ships leaving Houston will add to their load of grain in Galveston prior to going to sea. Test Reach C was tested for both the maximum ebb and maximum flood currents. Although the situation occurs in the prototype, tests were not conducted for vessels going from Galveston to Houston. These vessels are either in ballast or light-loaded.

d. *Reach D, passing in the Outer Bar Channel.* This test reach (Figure 10) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier inside of the jetties. This was a short test run that ended once the meeting and passing had been successfully completed. This reach was tested for both the maximum ebb and maximum flood currents.

e. *Reach E, passing in the Entrance Channel - northern portion.* This test reach (Figure 11) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier outside of the jetties. This was a short test run that ended once the inbound vessel had regained control inside of the jetties. This reach was tested for crosscurrents (both Freeport and Sabine sets) in the Gulf of Mexico. The ships were not affected by the crosscurrents while they were protected by the jetties.

f. *Reach F, passing in the Entrance Channel - southern portion.* This test reach (Figure 12) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier in the southern portion of the Entrance Channel. The area of passing was farther east of the jetties than the area tested in Test Reach E. This was a short test run that ended once the meeting and passing was successfully completed. This reach was tested for a Sabine set only.

g. *Reach G, passing in the Entrance Channel 1,000-ft widener.* This test reach (Figure 13) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier in the 1,000-ft widener at the beginning of the Phase I portion of the Entrance Channel. This was a short test run that ended once the meeting and passing had been successfully completed. This reach was tested for a Sabine set only. Testing was done only for Phase I and Phase II channels, since this is a new channel.

h. *Reach H, passing in the 800-ft-wide Entrance Channel.* This test reach (Figure 14) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier in the 800-ft-wide Phase I Entrance Channel. This was a short test run that ended once the meeting and passing had been successfully completed. This reach was tested for a Sabine set only. Testing was done only for Phase I and Phase II channels.

i. *Reach I, passing in the 600-ft-wide Entrance Channel.* This test reach (Figure 15) was designed to test the meeting and passing of a loaded tanker and a loaded bulk carrier in the 600-ft-wide Phase II Entrance Channel. This was a short test run that ended once the meeting and passing had been successfully completed. This reach was tested for a Sabine set only. Testing was done only for the Phase II channel.

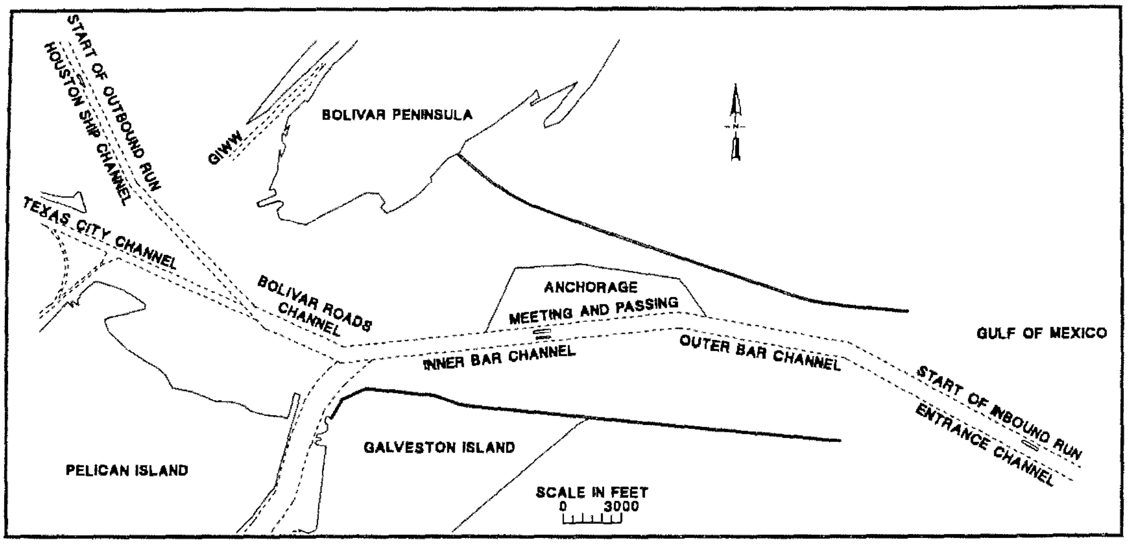

Figure 7. Test Reach A

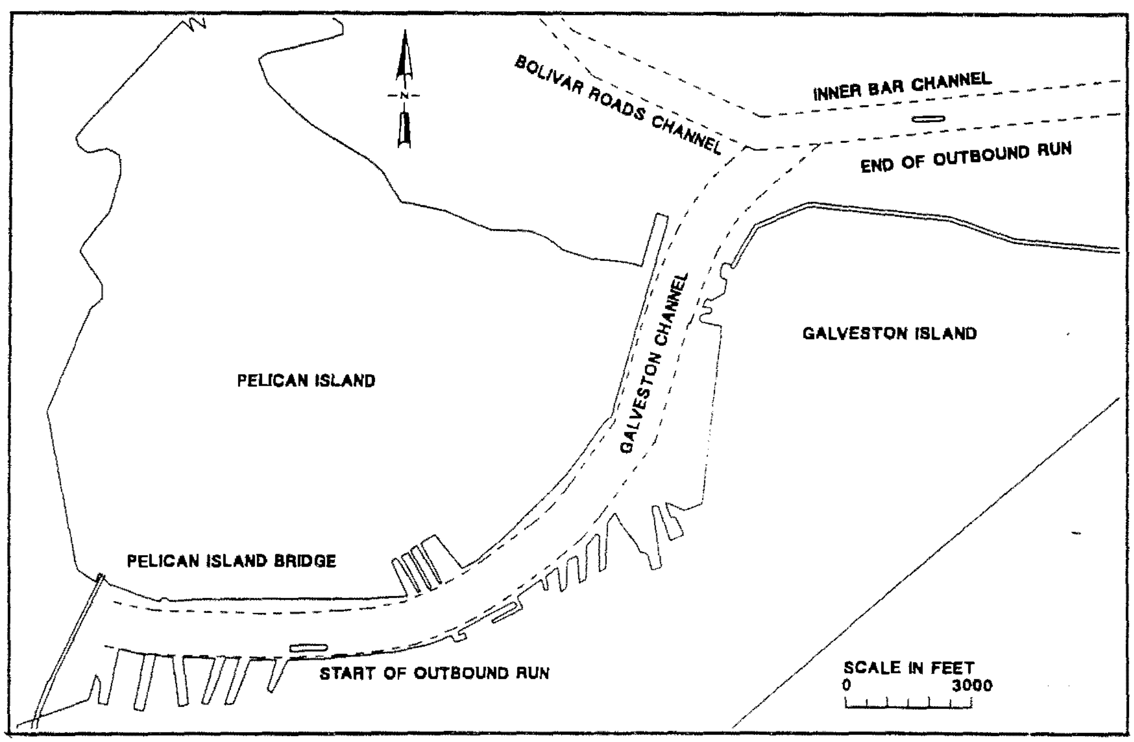

Figure 8. Test Reach B

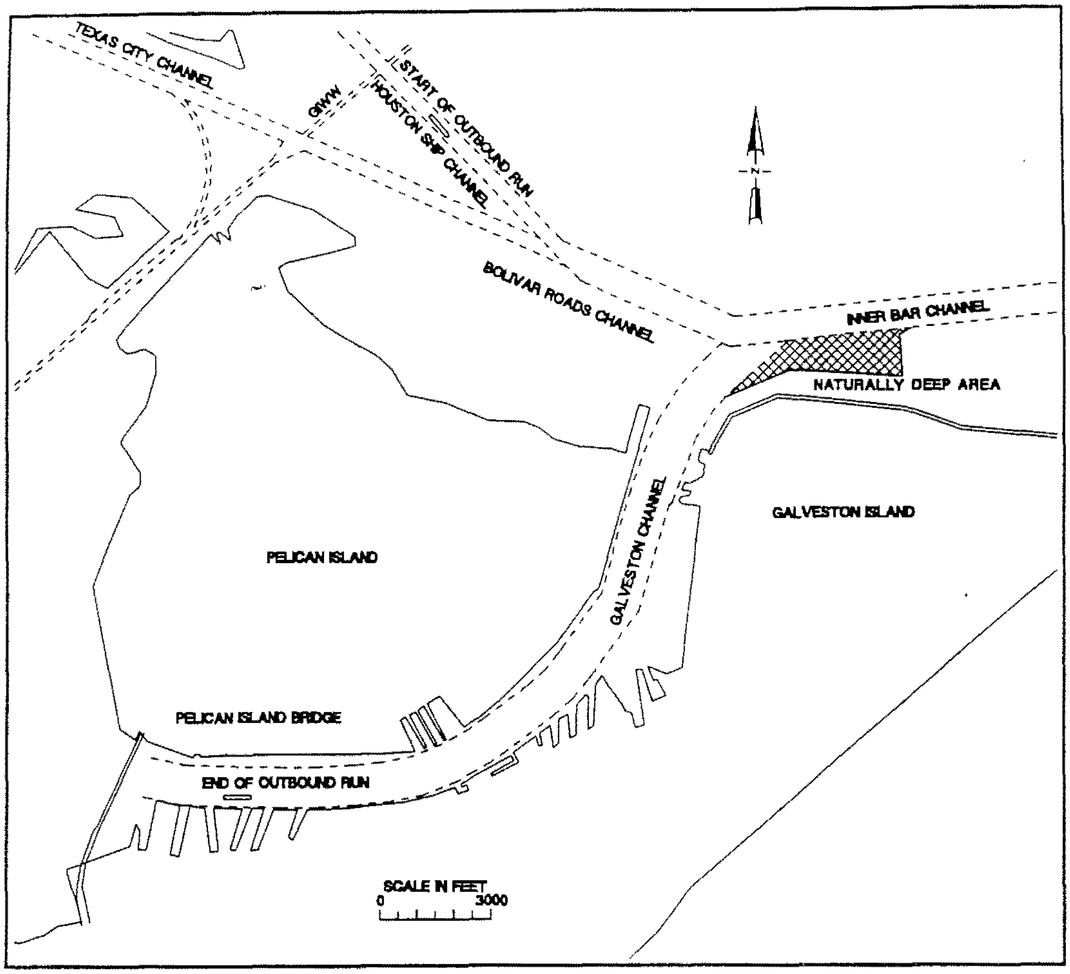

Figure 9. Test Reach C

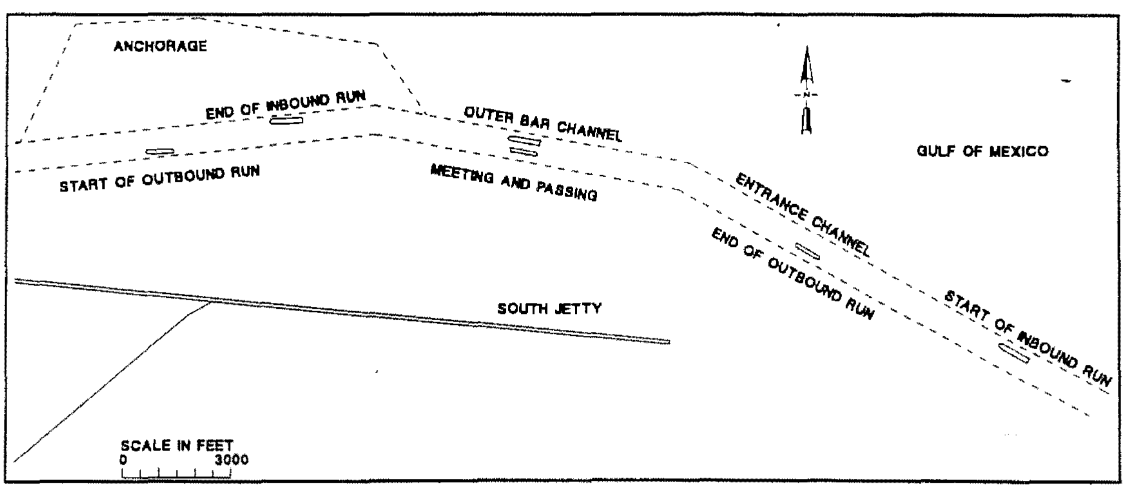

Figure 10. Test Reach D

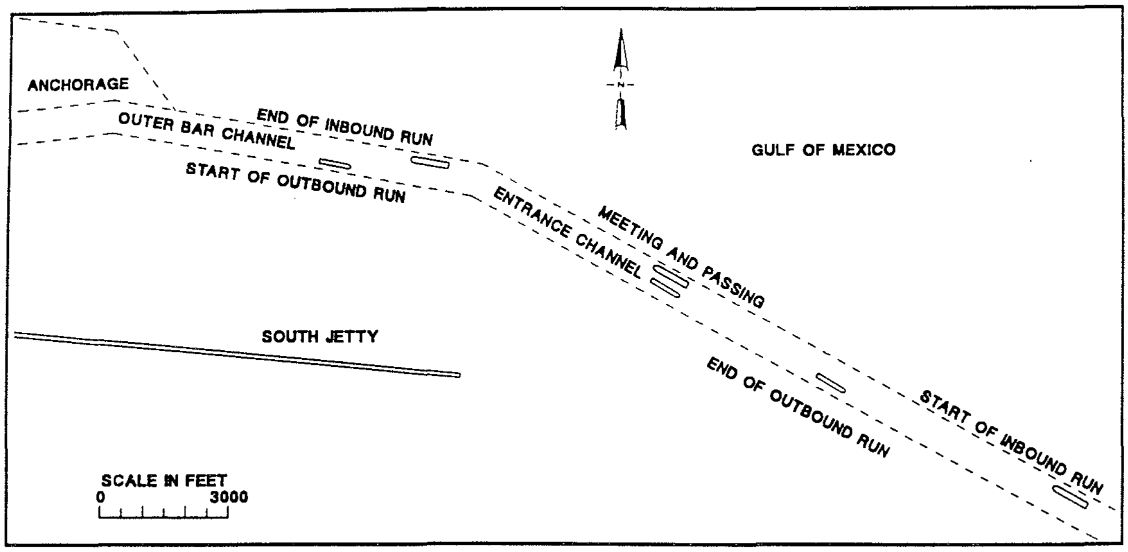

Figure 11. Test Reach E

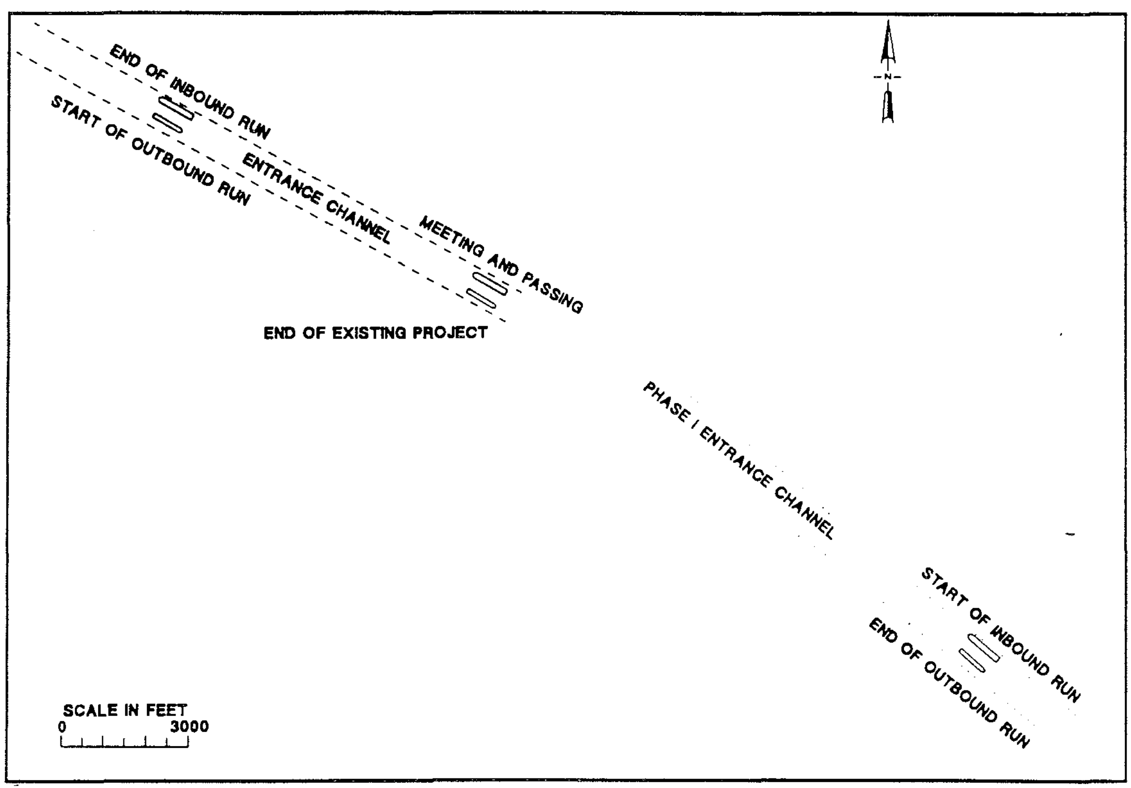

Figure 12. Test Reach F

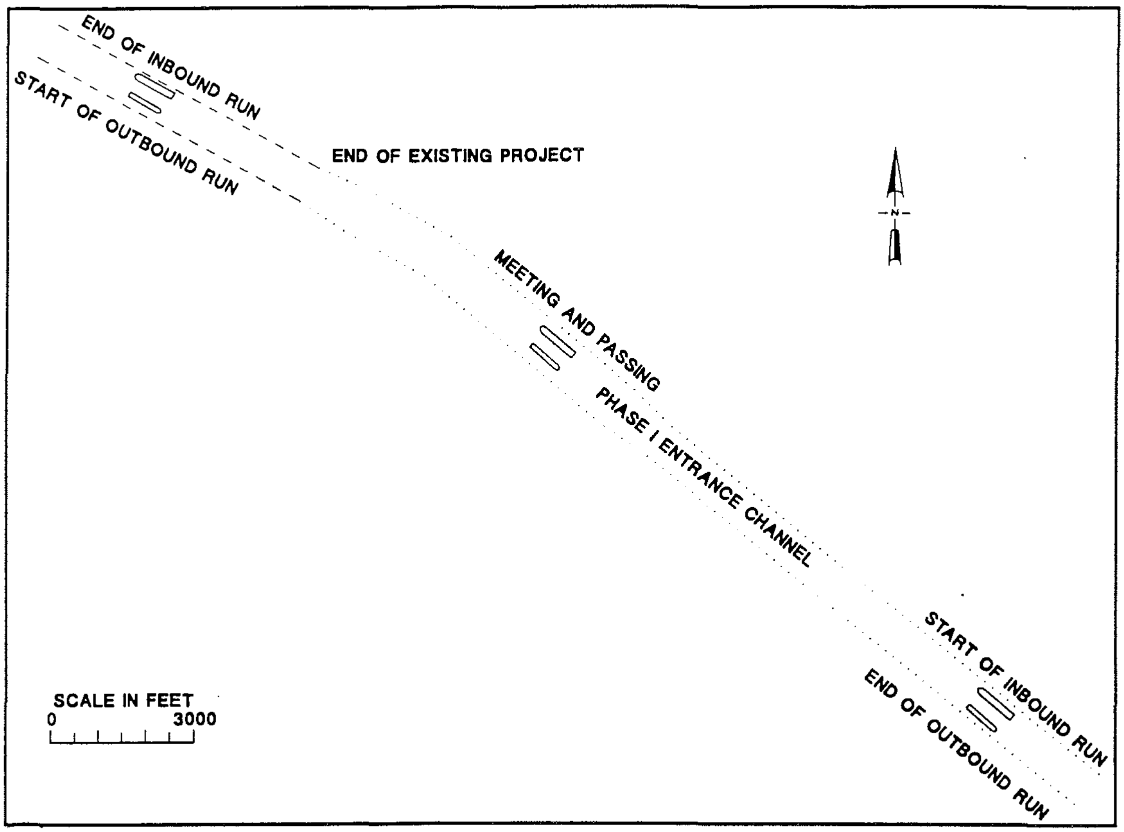

Figure 13. Tet Reach G

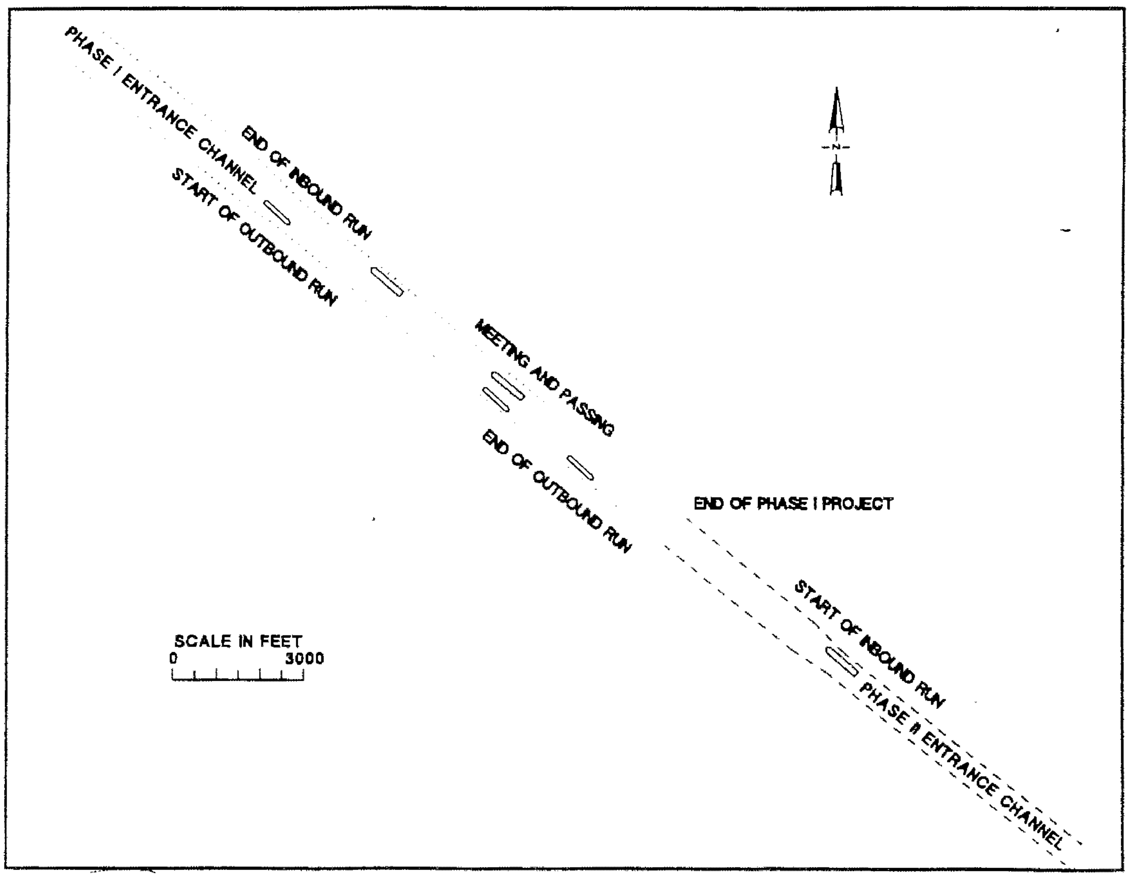

Figure 14. Test Reach H

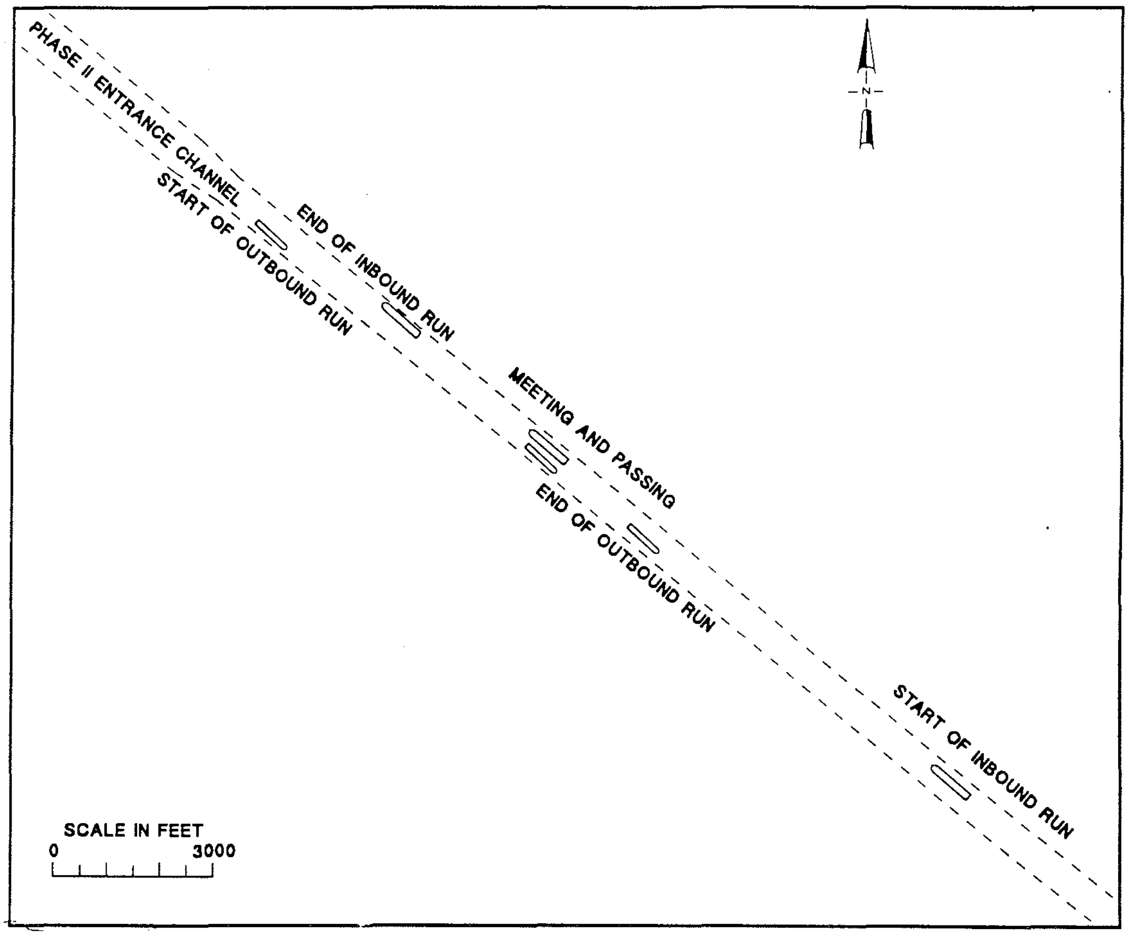

Figure 15. Test Reach I

4 Study Results

Six professional pilots from the Galveston/Texas City Pilots Association participated in the simulation testing of the Houston/Galveston Entrance Channels and the Galveston Channel. Tests were conducted in a random order. This was done to prevent prejudicing the results as would happen if, for example, all existing conditions were run prior to running the plans. The skill gained at operating the simulator could show the plans to be easier than they might really be. The primary method of analysis for these results are visual inspection of recorded track-lines and analysis of vessel control parameters.

During each run, the control, positioning, and orientation parameters of the ship were recorded every 5 seconds. These parameters included position, port and starboard clearances, ship speed, engine speed in propeller revolutions-per-minute (rpm), rudder angle, and rate of turn. These statistical parameters are plotted against distance along track. The distance along track is calculated by projecting the position of the ship's center of gravity perpendicular to the center line of the channel and is measured from the beginning of the center line. For reference purposes, the locations of important landmarks are identified.

Composite plots were used to analyze Test Reaches B and C. Individual plots were used to analyze the two-way traffic in the remainder of the test reaches. Composite plots were not done for tests of two-way traffic, since the plots become too "busy" and thus meaningless. Each of the individual track plots shows clearances during the meeting and passing situations for the particular run.

The composite plots of navigation parameters (Test Reaches B and C) present the statistical analysis as a mean of means within a sample channel section. A 500-ft channel section length was used. This means that for each individual run, each parameter was averaged over 500 ft, and these means were averaged over all runs under a given condition, thus a mean of the means. Individual control parameters are plotted for both vessels in the two-way test reaches and presented immediately after the track plot.

In evaluating the meeting and passing scenarios, it is important to remember that the Houston/Galveston Entrance channels do not provide many visual cues to keep the pilots informed of their location. The display of aids to navigation in a simulator visual scene is a problem with all simulators. Ranges in particular must be exaggerated in size to be seen. Pilots can take binoculars onto a real ship. They are not effective on a simulator. This is not a problem during the one-way portions of the tests because the Entrance Channels are designed for two-way traffic. Thus a single ship has about twice as much room as it needs, and therefore, the exact location of the ship is not as critical. The problem becomes more apparent during the simulation of the meeting and passing of two ships. Often during the meeting and passing one ship or the other will leave the authorized channel when it is obvious that is was not forced to do so in order to avoid a collision. Such cases, when it is clear that a large portion of the channel was not being used, do not necessarily imply a navigation problem. This hypothesis, that the visual representation is at least partially responsible for the results, is supported by the fact the best results for two-way traffic were obtained in the portions of the Phase I and Phase II that are presently open sea. Due to the length of the channel segments and the depth of the water where range structures would have to be built, ranges were deemed inappropriate as aids to navigation. A gated buoy system was used in the simulation of Test Reaches G, H, and I. Gauged buoys are easier to see in the simulator. The results seem to indicate that this improves the test results.

Test Reach A

A plot of the center line for Test Reach A and the distances from the beginning of the center line are shown in Plate 1. Individual plots of the vessel track-lines and control parameters for all runs conducted in Test Reach A are shown in Plates 2 through 64. Most of the runs were stopped upon completion of the meeting/passing. This was done to save time in an extremely full test schedule. Since this reach of the channel is designed for two-way traffic, there were few problems encountered in the one-way portion of the test.

Existing conditions, ebb tide

The ship track plots and the navigation parameter plots for runs in the existing channel with an ebb tide (Plates 2-13) show that the pilots of the outbound ship kepy the vessel on the southern edge of the Inner Bar Channel. The pilots stated that for this situation, they would keep an outbound ship along the channel edge. This is how the pilots navigate this reach in real life because there is deep water in that area. Since the outbound ship was on or out of the southern edge of the channel at the moment the two ships were abeam of each other, the ship/ship forces were reduced. The only significant ship/ship interaction in the navigation parameter plots is an increased rate of turn at the moment of passing.

Phase I conditions, ebb tide

The results of test runs in the Phase I channel with an ebb tide (Plates 14 through 22) show that the pilots of the outbound ship kept the vessel on the southern edge of the Inner Bar Channel as they did in the existing channel. For one run (Plate 20), the inbound pilot misjudged his turn from the Entrance Channel into the Outer Bar Channel. This was due to his misinterpretation of visual cues. He recovered and was able to complete his run. As in the existing conditions runs, the only navigation parameter showing ship/ship interaction is an increased rate of turn.

Phase II conditions, ebb tide

The results of runs in the Phase II channel with an ebb tide (Plates 23 through 34) show that the pilots of the outbound ship kept the vessel on the southern edge of the Inner Bar Channel as they did in the existing and Phase I channels. With the larger ships in the Phase II channel, the inbound pilot moved his ship closer to the northern channel edge and the passing tended to take place farther inbound of the turn. In all cases, the ships tended to have adequate clearance even though the outbound ship was often near or outside the southern channel edge at passing. The navigation parameter plots show that the Phase II ships did not increase their rate of turn at the moment of meeting as much as did the ships operating in the existing or Phase I channels.

Existing conditions, flood tide

The track plots for runs in the existing channel with a flood tide (Plates 35 through 43) show that the pilots of the outbound ship kept the vessel on the southern edge of the Inner Bar Channel. They did not stay on the southern edge for as long as they did in ebb tide runs because with a flood tide, the passing took place farther west. Once the meeting and passing was completed, the outbound ship moved to the center of the channel. The navigation parameter plots show little ship/ship interaction.

Phase I conditions, flood tide

The results of runs in the Phase I channel with a flood tide (Plates 44 through 55) show that, although the ships came near the channel edge in a few locations, they had enough room for a safe transit of the area. One run shows an extremely high rate of turn just after the meeting operation (Plate 45). However, this is not due entirely to ship/ship interaction. The pilot turned his ship to port to get back to the center of the channel before he grounded at the end of the naturally deep area. He did, however, leave the channel on the starboard side.

Phase II conditions, flood tide

The track plots for runs in the Phase II channel with a flood tide (Plates 56 through 64) show results similar to the runs in the Phase I channel except that all inbound ships had a problem turning into the Bolivar Roads Channel after the meeting/passing operation. This was probably because the passing took place so close to this turn and the ships did not have adequate time to completely recover. It would seem to be advisable to avoid passing in this area and pass farther east in the Inner Bar Channel. The channels are extra wide in this area and there is adequate clearance for passing. The navigation parameters plot shows high rates of turn due to both ship/ship interaction and making the turn between the Bolivar Roads Channel and the Inner Bar Channel.

Test Reach B

A plot of the center line for Test Reach B and the distances from the beginning of the center line are shown in Plate 65. Composite plots of the vessel track-lines and control parameters for all runs conducted in Test Reach B are shown in Plates 66 through 75.

Existing conditions, ebb tide

The composite track plot for runs in the existing channel with an ebb tide (Plate 66) indicates that there could be a problem area near the split buoy. This is because during ebb tide, the pilots purposely head outbound ships toward the split buoy in preparation for the set they know they will experience with the ebb tide. The split buoy is in deep water and is called a split buoy because vessels drafting 20 ft or less can pass on the western side of the split buoy, thus splitting the traffic. The only other time a vessel approached the channel's edge was north of Pier 10. However, this ship did not leave the channel.

Phase I conditions, ebb tide

The composite track plot for runs in the Phase I channel with an ebb tide (Plate 67) shows three of the six ships leaving the channel north of Pier 10. This occurred because several of the pilots had a difficult time judging their position in the channel and when to begin the turn. This is a problem, because any buoys placed in the channel to mark this turn would restrict navigation for shallow draft vessels. This turn was not difficult for the ships to navigate, just difficult to determine the ship's position.

Ships also left the channel to the southwest of Pier 10. This was also caused by the difficulty of determining the ship's position. However, none of these vessels would have grounded, assuming that the area will be deepened to allow access to the docks. One ship left the channel south of Seawolf Park. This was caused by his making the turn at Pier 10 too late. As in the existing channel, ships left the channel near the split buoy.

Phase II conditions, ebb tide

The composite track plot for runs in the Phase II channel with an ebb tide (Plate 68) shows test results nearly identical to results from the Phase I runs. Ships left the channel southwest of Pier 10, north of Pier 10, and near the split buoy. This was caused by the same situation as the Phase I test channel.

Navigation parameters, ebb tide

The navigation parameter plots for runs conducted with an ebb tide are presented in Plates 69 and 70. Analysis of the port and starboard clearance plots shows that for most of the reach, the wider existing channel averaged a higher clearance. This is to be expected, given the existing channel's 1,100-ft width as opposed to the Phase I 450-ft and the Phase II 550-ft width. However, port clearance at the split buoy was negative for the existing channel and positive for both Phase I and II channels. This is because the realigned channels did not allow the vessels to turn north as early as does the existing channel. The average port clearance for both Phase I and II channels is nearly identical throughout the length of the Galveston Channel. The increased width for the Phase II channel accounts for the fact the while the average starboard clearance for Phase I approached zero near Todd Shipyard and became negative past Pier 10, starboard clearances for Phase II remain positive.

The plot of the vessels' average rate of turn shows that at the split buoy, the Phase II vessels did not turn as fast as the vessels operating in the existing or Phase I channels. This is probably due to the increased size and bulk of the Phase II design vessel.

The plot of the vessels' average engine speed shows that the vessels in the existing channel used considerably less rpm than Phases I or II. The plot of the average rudder angle shows the existing channel requiring less rudder angle than either proposed channel in the reach from Pier 10 to Sea Wolf Park. Both the reduced engine speed and rudder angle required are indicative of the additional width available for the existing channel.

Plots of the average ship speed correspond to the engine speed used for the reach and the fact that the Phase II ship was larger and slower than the existing or Phase I vessels.

Existing conditions, flood tide

The composite track plot for runs in the existing channel with a flood tide (Plate 71) shows the only problem area to be near the split buoy. The strong flood tide pushes the vessels west at the point as they attempt to make the turn to the east in the Inner Bar Channel. One ship did come close to another ship docked across the channel from Todd's Shipyard. This occurred because the pilot was distracted early in the run. He recovered and completed the run successfully.

Phase I conditions, flood tide

The composite track plot for runs in the Phase I channel with a flood tide (Plate 72) shows that with the exception of one run (which left the channel by more than the ship's beam width), the pilots were better able to make the turn at Pier 10. This is because with the ships moving against the flood tide, they are able to go slower and still maintain steerage. As stated in the analysis of the ebb tide tests, runs leaving the channel southwest of Pier 10 were in no danger of grounding. The ships were pushed out of the channel near the split buoy just as they were in the existing condition.

Phase II conditions, flood tide

The composite track plot for runs in the Phase II channel (Plate 73) shows one ship leaving the channel southwest of Pier 10 and one ship leaving the channel after making the turn near Pier 10. The flood tide pushed several ships out of the channel near the split buoy. These results are similar to those in the Phase I channel.

Navigation parameters, flood tide

The navigation parameter plots for runs conducted with a flood tide are presented in Plates 74 and 75. Analysis of the port and starboard clearance plots show that for most of the reach, the 1,100-ft-wide existing channel averaged a higher clearance. However, port clearance at the split buoy was negative for the existing and Phase I channels and positive for both Phase II channels. None of the channels averaged negative starboard clearance at any point in the reach.

The plot of the vessels' average rate of turn shows that at the split buoy, the Phase II vessels did not turn as fast as the vessels operating in the existing or Phase I channels due to the increased size and bulk of the Phase II design vessel.

The plot of the vessels' average engine speed shows that the vessels in the existing channel used considerably less rpm than in Phases I or II.

The Phase I rpm plot follows the existing rpm plot until the turn at Pier 10, where it increases to match the Phase II plot. The plot of the average rudder angle shows the existing channel requiring less rudder angle than either proposed channel in the reach from Pier 10 to Sea Wolf Park. Both the reduced engine speed and rudder angle required are indicative of the additional width available for the existing channel.

Plots of the average ship speed correspond to the engine speed used for the reach and the fact that the Phase II ship was larger and slower than the existing or Phase I vessels.

Test Reach C

A plot of the center line for Test Reach C and the distances from the beginning of the center line is shown in Plate 76. Composite plots of the vessel track-lines and control parameters for all runs conducted in Test Reach C are shown in Plates 77 through 86. The areas of significance in Test Reach C are the two turns. The first turn is from the Inner Bar Channel into the Galveston Channel. Some of the test run plots of this turn showed the vessel out of the authorized channel. Often, after completion of the test, the pilot was surprised to see the true position of his ship on the track plot. There are few visual aids in this area, and due to the limitations of depth perception, the pilots were mistaken about the ship's location. The second turn is in the Galveston Channel prior to docking. Turning the ship in the Galveston Channel on the simulator was fairly difficult due to the visual limitations of simulators. In real life, the pilots can position an additional pilot on the bow of the ship. The second pilot, with a radio, can keep the pilot on the bridge informed of the distance from his bow to land. In addition, there are other visual ques, missing from simulators, that pilots rely upon to know their position and headway. In evaluating the results of these two turns, it is important to consider not only if the ship left the channel but how much area was required for the maneuver. Often, the channels provided enough room, but the pilot did not have his ship in the proper position before beginning the turn. Typically, the amount of room required to turn a ship is defined by a circle. However, both of these turns were done in 3 to 4 knots of current. Therefore, the area of the turn would be better circumscribed by an ellipse, with the long axis of the ellipse being the critical parameter. Accordingly, the distances from the initiation of the turn to the completion of the turn is shown in Table 2.

Existing conditions, ebb tide

The composite track plot for runs in the existing channel with an ebb tide (Plate 77) shows that both runs required the naturally deep area north of the Galveston Island Jetty to turn the vessels prior to entering the Galveston Channel. One pilot came to a stop, turned his ship 180 deg and

Table 2
Distances Required for Turning

Channel	Tide	Pilot	Turn 1, ft	Turn 2, ft
Existing	Ebb	5	4,130	1,000
Existing	Ebb	6	2,860	1,320
Existing	Flood	5	960	2,980
Phase 1	Ebb	1	2,420	1,200
Phase 1	Ebb	2	3,700	1,420
Phase 1	Ebb	5	3,820	1,410
Phase 1	Flood	1	2,950	2,330
Phase 1	Flood	2	3,330	2,580
Phase 1	Flood	4	1,900	1,850
Phase 1	Flood	3	2,220	2,830
Phase 2	Ebb	4	4,740	1,840
Phase 2	Ebb	3	3,370	1,930
Phase 2	Ebb	5	4,180	1,880
Phse 2	Ebb	6	4,290	1,700
Phase 2	Flood	4	2,020	2,970
Phase 2	Flood	3	2,870	2,900
Phase 2	Flood	5	1,670	3,520
Phase 2	Flood	6	2,520	3,380

then maneuvered into the Galveston Channel. The other pilot attempted to drive the ship from Bolivar Roads into the Galveston Channel. This run left the Inner Bar Channel on the north side. Both ships turned in the Galveston Channel near the Todd Shipyard. The pilots stated that the water in the Galveston Channel is deep from bank to bank. Therefore, leaving the authorized channel is not a problem, particularly for ships that are lighter then the authorized channel depth. One ship did touch the land boundary west of Todd Shipyard.

Phase I conditions, ebb tide

The composite track plot for tests conducted in the Phase I channel is shown in Plate 78. Results from the first turn show two of the three runs leaving the authorized channel. Two of the runs had difficulty entering the 450-ft portion of the channel near Seawolf Park. One ship came to the channel edge on the west side of the channel, the other came near the edge on the east side. All turns prior to docking were successful.

Phase II conditions, ebb tide

The composite track plot of runs in the Phase II channel is shown in Plate 79. Both turns were more difficult because the Phase II design bulk carrier is nearly 200 ft longer than the Phase I bulk carrier. The additional length greatly increases the effects of currents striking the vessel broadside. As in the existing and Phase I channels, the most successful turn from the Inner Bar Channel into the Galveston Channel was accomplished by bringing the ship to a stop in the area north of the jetty and turning the ship dead in the water. Two of the four runs performed successful turns prior to docking, while the other two runs grounded while turning.

Navigation parameters, ebb tide

The navigation parameter plots for runs conducted with an ebb tide are presented in Plates 80 and 81. Average parameters are not plotted for the portion of the reach used to turn the vessel into the Galveston Channel and were ended at the Todd Shipyard prior to the vessel's turning in the Galveston Ship Channel. Navigation parameters are projected from the vessels center of gravity perpendicular to the channel edge. Because the vessels are sideways in the channel for a long period of time, the parameter plots for that portion of the run are impossible to interpret.

Analysis of the port and starboard clearance plots shows that vessels operating in all three channels had a low average port clearance for the turn from the HSC into Bolivar Roads.

The plot of the vessels' average rate of turn shows that due to the bulk of the Phase II design vessels, the Phase II vessels did not turn as fast at Sea Wolf Park as the vessels operating in the existing or Phase I channels.

The plot of the vessels' average engine speed, average rudder angle, and average ship speed (Plate 81) show relatively little difference between the three channels.

Existing conditions, flood tide

Turning from the Inner Bar Channel into the Galveston Channel is easier with a flood tide than with an ebb tide because the tidal currents help slow the ship's speed. This was true for all channels tested. Only one run was conducted with the existing channel and flood tide (Plate 82). This plot shows the ship being pushed into the area near the split buoy by the currents. The turn in Galveston Ship Channel prior to docking was also successful.

Phase I conditions, flood tide

The composite track plot of the runs conducted in the Phase I channel with flood tide (Plate 83) shows that all ships were able to turn in the authorized area north of the jetty. One pilot left the west side of the 450-ft channel near Seawolf Park, and two runs left the west side of the channel near Pier 10. One ship hit land turning prior to docking.

Phase II conditions, flood tide

The composite track plot of the runs conducted in the Phase II channel with flood tide (Plate 84) shows all ships were able to turn in the authorized area north of the jetty but were also pushed out of the channel near the split buoy. Two of these runs hit the split buoy. This is because the large Phase II vessel drafting 49 ft is more susceptible to currents than the Phase I ship drafting 44 ft. It appears that there is adequate room to the east so that the pilots could wait until later to begin the turn and allow more room for the ship to drift to the west One run grounded while making the turn prior to docking. The remainder of the ships were able to turn successfully.

Navigation parameters, flood tide

The navigation parameter plots for runs conducted with a flood tide are presented in Plates 85 and 86. Average parameters are not plotted for the portion of the reach used to turn the vessel into the Galveston Channel and were ended at the Todd Shipyard prior to the vessel's turning in the Galveston Ship Channel for the same reasons as stated in the discussion of the ebb tide navigation parameters.

Analysis of the port and starboard clearance plots shows that vessels operating in all existing and Phase II channels averages a negative clearance between the split buoy and Sea Wolf Park.

The plot of the vessels' average rate of turn shows little difference for the three channels.

The plots of the vessels' average engine speed, average rudder angle, and average ship speed (Plate 86) show the vessels operating in the existing channel used more engine speed (and therefore an increased ship speed) in the reach near Sea Wolf Park. The ships in the existing channel used port rudder in the reach from Pier 10 to Todd Shipyard, while vessels in the proposed channels used starboard rudder in the same reach.

Test Reach D

A plot of the center line for Test Reach D and the distances from the beginning of the center line is shown in Plate 87. Individual track plots of all runs conducted in Test Reach D are shown in Plates 88 through 107.

Existing conditions, ebb tide

The track plot of the run conducted with the existing channel and ebb tide (Plate 88) shows adequate channel width for the meeting and passing of the two ships. The navigation parameters plot (Plate 89) shows that the inbound pilot used about twice the rudder angle as did the outbound pilot. This is because the inbound vessel is still recovering from the turn from the Entrance Channel into the Outer Bar Channel. The outbound ship is somewhat smaller than the inbound ship and requires ruder to turn from the Inner Bar Channel into the Outer Bar Channel.

Phase I conditions, ebb tide

The track plot of the run conducted in the Phase I channel with ebb tide (Plate 90) shows that while the inbound ship did come within 27 ft of the channel edge, there was adequate channel width for the maneuver. The outbound vessel was able to stay 125 ft from the southern channel edge while remaining 370 ft away from the inbound ship. The navigation parameters plot (Plate 91) shows that (for the same reasons as in the existing channel) the inbound pilot used about twice the rudder angle as the outbound pilot as the vessels approached and met each other.

Phase II conditions, ebb tide

Individual track plots and navigation parameters of the runs in the Phase II channel with ebb tide are shown in Plates 92 through 95. The track plots show one run (Plate 92) with adequate clearances for both vessels. Plate 94 shows a 56-ft clearance between vessels, with the outbound ship heading toward the north edge of the channel at the end of the run. The outbound ship had 220-ft clearance to the south edge of the channel at the meeting location and would have had a better run if he had made his turn sooner. It is not clear why he waited so late to turn. Plate 93 shows the inbound pilot using more rudder than the outbound pilot, but the difference is not as great as in the existing and Phase I channel. This is because both vessels are large and bulky. However, as in all scenarios, the inbound tanker is larger than the outbound bulk carrier. Plate 95 shows the outbound vessel using more rudder angle than the inbound because outbound pilot had to make a port turn quickly to avoid grounding on the southern side of the channel.

Existing conditions, flood tide

The track plot of the run conducted with the existing channel and flood tide is shown in Plate 96 with adequate channel width for the meeting and passing of the two ships. The navigation parameters plot (Plate 97) shows that the inbound pilot used more rudder angle than the outbound pilot. However, the rudder angle required of the inbound vessel with flood tide is not as much as that required for the inbound ship with ebb tide.

Phase I conditions, flood tide

Individual track plots and navigation parameters of the runs in the Phase I channel with flood tide are shown in Plates 98 through 101. Plate 98 shows the inbound ship leaving the channel by 54 ft on the north side. After the run, the pilot stated that he did not realize he was out of the channel and there was adequate channel width for the maneuver. The other run (Plate 100) reveals that the outbound pilot did not move over to allow the inbound ship to remain in the authorized channel. Plots of the navigation parameters (Plates 99 and 101) reveal that one outbound vessel (Plate 99) used less rudder at the point of meeting/passing while the other (Plate 101) used more. This shows the outbound pilot attempting (successfully) to swing the ship's stern out of the way of the inbound vessel.

Phase II conditions, flood tide

Individual track plots and navigation parameters of the runs in the Phase II channel with flood tide are shown in Plates 102 through 107. These plots show none of the ships leaving the channel, although during one run (Plate 104) the outbound ship made a very erratic maneuver at the meeting and passing situation. This is due to the fact that the outbound ship was on the north side of the channel and had to move quickly to the southern side to avoid the inbound ship. The inbound pilot waited too late to turn west and entered the anchorage area. One vessel parameter plot (Plate 102) shows that the pilots had maneuvered their vessels near the edge of their half of the channel and had placed their ships rudder at midships for the meeting/passing.

Test Reach E

A plot of the center line for Test Reach E and the distances from the beginning of the center line is shown in Plate 108. Individual track plots of all runs conducted in Test Reach E are shown in Plates 109 through 148.

Existing conditions, Freeport set

Individual track plots and navigation parameters of the runs in the existing channel with a Freeport set are shown in Plates 109 through 116. These track plots show that for all runs both vessels suffered a severe set to the south and the outbound ship left the channel. It should be noted that the parameter plots (Plates 110, 112, 114, and 116) show that although they used some starboard rudder, none of the pilots on the inbound vessels used all the rudder available to maneuver their vessel to the north side of the channel. Only one inbound vessel (Plate 111) approached the outbound ship on the north side of the channel. Therefore, not only did the outbound ship have strong crosscurrents to contend with, it was meeting a vessel that was in the middle of the channel. This explains that fact that for three runs, the outbound vessels used starboard rudder even though they were being set to the starboard side of the channel by the crosscurrents. The outbound vessel in the remaining run (Plates 111 and 112) used starboard rudder to recover from the meeting/passing.

Phase I conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase I channel with a Freeport set are shown in Plates 117 through 124. These runs show the same problem as in the existing channel. One run (Plate 119) was somewhat successful with the outbound ship only clipping the channel edge.

Phase II conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase II channel with a Freeport set are shown in Plates 125 through 130. These runs show the larger ships being more affected by the crosscurrents. Although two of the runs (Plates 127 and 129) show that the inbound ship was able to stay on the north side of the channel, the outbound ship was still pushed out of the channel by the crosscurrents.

Crosscurrent magnitude

As discussed earlier, the current magnitude and direction was calculated by Dr. Westerink's model. There is a lack of prototype data in this area, and the magnitude of the crosscurrents for the Freeport set was validated by the pilots to setup a "worst case scenario." Perhaps, now that the results can be examined with perfect hindsight, the magnitude of the crosscurrents, particularly for the Freeport set, was too severe. Runs conducted in the other test reaches in the Gulf of Mexico were acceptable because the magnitude of the currents decreases the farther the ships get from the jetties.

Existing conditions, Sabine set

The magnitude of the crosscurrents is less for a Sabine set than for a Freeport set, therefore the vessels had less difficulty staying in the channel. Individual track plots and navigation parameters of the runs in the existing channel with a Sabine set are shown in Plates 131 through 136. These plots show one successful run (Plate 133), one run where the inbound vessel clipped the north edge of the channel (Plate 131), and one run where the inbound vessel ran slightly out of the channel for nearly 1/2 mile (Plate 135). Plots of the navigation parameters (Plates 132, 134, and 136) show that the pilots used both port and starboard rudder for both inbound and outbound ships.

Phase I conditions, Sabine set

Individual track plots and navigation parameters of the runs in the Phase I channel with a Sabine set are shown in Plates 137 through 142. These track plots show two successful runs (Plates 137 and 139) and one run where the inbound vessel clipped the north edge of the channel (Plate 141). These track plots also show that for all three runs, the stern of the smaller outbound vessel was pulled toward the inbound ship. Plots of the navigation parameters (Plates 138, 140, and 142) show that the ship/ship interaction cause both vessels to have an abrupt drop in speed at the moment of meeting/passing.

Phase II conditions, Sabine set

Individual track plots and navigation parameters of the runs in the Phase II channel with a Sabine set are shown in Plates 143 through 148. The track plots show two runs (Plates 143 and 145) in which the inbound ship left the north edge of the channel. One run (Plate 147) shows the inbound vessel more than 100 ft out of the channel. Two of the navigation parameters plots (Plates 144 and 146) show that the ship/ship interaction caused both vessels to have an abrupt drop in speed at the moment of meeting/passing. The other navigation parameter plot (Plate 148) does not show as abrupt a loss in speed, because the vessels were farther apart.

Test Reach F

A plot of the center line for Test Reach F and the distances from the beginning of the center line is shown in Plate 149. Individual track plots of all runs conducted in Test Reach F are shown in Plates 150 through 173. All runs in Test Reach F were conducted with a Freeport set.

Existing conditions, Freeport set

Individual track plots and navigation parameters of the runs in the existing channel with a Freeport set are shown in Plates 150 through 157. The track plots (Plates 150, 152, 154, 156) show at least one of the ships leaving the authorized channel for each test conducted. However, for existing conditions, the water is deep in this area and none of the vessels would have grounded. The pilots were following their current operating procedure by keeping the meeting vessels as far apart as possible in this reach. The navigation parameter plots (Plates 151, 153, 155, 157) show that none of the pilots used maximum rudder for a length of time greater than that required to start the ship turning.

Phase I conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase I channel with a Freeport set are shown in Plates 158 through 165. The individual track plots (Plates 158, 160, 162, 164) show successful runs with the exception of one inbound ship (Plate 160) that left the authorized channel. There appears to be no reason to do this unless he was having difficulty knowing where he was in the channel. The navigation parameter plots (Plates 159, 161, 163, 165) show that none of the pilots used maximum rudder for a length of time greater than that required to start the ship turning.

Phase II conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase II channel with a Freeport set are shown in Plates 166 through 173. The track plots (Plates 166, 168, 170, 172) show two successful runs (Plates 168 and 172) and two runs (Plates 166 and 170) where one of the ships slightly left the authorized channel. The navigation parameter plots (Plates 167, 169, 171, 173) show that none of the pilots used maximum rudder for a length of time greater than that required to start the ship turning.

Test Reach G

A plot of the center line for Test Reach G and the distances from the beginning of the center line is shown in Plate 174. Individual track plots of all runs conducted in Test Reach G are shown in Plates 175 through 190. No test runs in the existing channel were conducted since there is presently no authorized channel in this area, because the water is naturally deeper than 40 ft. All runs in Test Reach G were conducted with a Freeport set.

Phase I conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase I channel with a Freeport set are shown in Plates 175 through 182. The individual track plots of runs conducted in the Phase I channel (Plates 175, 177, 179, 181) show successful runs with the exception of one inbound ship (Plate 177) that clipped the edge of the authorized channel. The navigation parameter plots (Plates 176, 178, 180, 182) show the pilots using more rudder during the meeting/passing but not using hard rudder for an extended period of time. The pilots did not use maximum rudder for a length of time greater than that required to start the ship turning during the other portions of the run.

Phase II conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase II channel with a Freeport set are shown in Plates 183 through 190. The individual track plots of runs conducted in the Phase II channel (Plates 183, 185, 187, 189) show two successful runs (Plates 183 and 187), one run (Plate 185) where the inbound ship clipped the channel edge prior to the meeting/passing, and one run (Plate 189) where both of the ships left the authorized channel after the meeting/passing due to the strong ship/ship interaction. The navigation parameter plots (Plates 184, 186, 188, 190) show the pilots used more rudder during the meeting/passing. Two of the plots (Plates 188 and 190) show the pilots held maximum rudder on the ship to counter the ship/ship interaction. The pilots did not use maximum rudder for a length of time greater than that required to start the ship turning during the other portions of the run.

Test Reach H

A plot of the center line for Test Reach H and the distances from the beginning of the center line are shown in Plate 191. Individual track plots of all runs conducted in Test Reach H are shown in Plates 192 through 207. No test runs in the existing channel were conducted since there is presently no authorized channel in this area, because the water is naturally deeper than 40 ft. All runs in Test Reach H were conducted with a Freeport set.

Phase I conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase I channel with a Freeport set are shown in Plates 192 through 199. The individual track plots of runs conducted in the Phase I channel (Plates 192, 194, 196, 198) show two successful runs (Plates 194 and 198) and two runs (Plates 192 and 196) where the outbound ship clipped the edge of the authorized channel. The navigation parameter plots (Plates 193, 195, 197, 199) show the pilots using rudder during the meeting/passing. However, the pilots did not use hard rudder for an extended period of time. The pilots did not use maximum rudder for a length of time greater than that required to start the ship turning during the other portions of the run.

Phase II conditions, Freeport set

Individual track plots and navigation parameters of the runs in the Phase II channel with a Freeport set are shown in Plates 200 through 207. The individual track plots (Plates 200, 202, 204, 206) show one run (Plate 206) where the vessels passed close (140 ft) to each other and the ship/ship interaction forced both ships out of channel after passing. The remainder of the runs in the Phase II channel were successful. The navigation parameter plots (Plates 193, 195, 197, and 199) show the pilots used rudder during the meeting/passing. The pilots did not use hard rudder for an extended period of time, with the exception of one run (Plate 207) where both pilots used hard rudder to offset the ship/ship interaction. The pilots did not use maximum rudder for a length of time greater than that required to start the ship turning during the other portions of the run.

Test Reach I

A plot of the center line for Test Reach I and the distances from the beginning of the center line is shown in Plate 208. Individual track plots of all runs conducted in Test Reach I are shown in Plates 209 through 216. No test runs in the existing or Phase I channel were conducted since there is presently no authorized channel in this area. There will be no Phase I channel, because the water is naturally deeper than 45 ft. All runs in Test Reach I were conducted with a Freeport set.

Individual track plots and navigation parameters of the runs in the Phase II channel with a Freeport set are shown in Plates 209 through 216. These track plots (Plates 209 211, 213, and 215) show the ships were out of the 600-ft channel at the time of meeting/passing or, if they did not get out of the channel, the ship/ship interaction pushed them out after the meeting. This is similar to what would occur in Galveston Bay if the bank effects did not push the ships back into the channel. The pilots stated that if anyway possible, they would avoid meeting and passing two ships of these sizes in the 600-ft Phase II entrance channel. The navigation parameter plots (Plates 210, 212, 214, and 216) show the pilots used an extreme amount rudder during the meeting/passing. This was in attempt to control the vessel during the ship/ship interaction.

Pilot's Evaluations

After completing the week's testing, each pilot was given a questionnaire to complete. Included in this report are the pilot's responses to the questionnaire.

a. How will deepening the channel affect ship maneuverability and safety?

Deepening of the channel along (Entrance & Bar), will enhance ship maneuverability and improve safety for those vessels which presently use the channel. It is to be expected, however, that an improved channel will attract larger & deeper ships, which will test the limits of the improvements. I would, therefore, expect that bank effect and interaction between vessels of the larger, deeper type would be more pronounced and have a detrimental effect upon ship maneuverability and channel safety.

Deepening the channel will be a great help in maneuvering the ships that we handle now. But a larger and deeper channel will also increase the size of the ships that we work with and make it harder to maneuver and possibly reducing the safety factor.

Deepening the channel should increase the maneuverability and safety for the size of ships we are handling today at 40 feet of draft and less. However, a deeper channel will also bring larger ships and deeper drafts which will be slower to maneuver, thereby reducing safety.

Yes, I feel the deepening of the channel should increase the maneuverability and safety of the ships. However, like [the Capt. in the previous paragraph] points out, a deeper channel will bring larger ships and deeper drafts, thereby reducing safety.

It should increase maneuverability if the ships don't outgrow the channel as they have now.

Based on the Simulator runs the maneuverability and safety aspects would not be altered much. On the other hand, not having personally piloted ships of this size (150,000 + dwt) or draft (49 foot +) on a regular basis, it is difficult to determine accurately. The main concern that I have is whether at Phase I 45 foot deep channel and 44 foot draft in narrow congested channels, is one foot clearance enough? I have the same concern for Phase II 50' channel + 49' draft ships. My impression is that bottom suction would be substantially increased (greater) than the simulated runs.

b. On a scale of 1 to 10, please rate the safety of the channels.

Existing: *8-9*

Phase I: 6-*7 Two way traffic deep draft*
8 One way traffic deep draft

Phase II: *1-2 Two way deep draft, large size*
7-8 One way deep draft, large size

Existing: *8 at 40 feet*
Phase I: *6 at 45 feet*
Phase II: *8 at 50 feet*

Existing: *9 at 40 foot draft*
Phase I: *5 at 45 foot draft*
Phase II: *7 at 50 foot draft*

Existing: *8 at 40 foot draft*
Phase I: *6 at 45 foot draft*
Phase II: *5 at 50 foot draft*

Existing: *8*
Phase I: *6*
Phase II: *6*

Existing: *9*
Phase I: *6*
Phase II: *8*

c. Are the proposed channels wide enough for safe navigation? If not, state where they are not wide enough.

The proposed improvements for the Entrance & Bar channels does not address any widening, except for easing the turns at #s 7&8 and 9&10 buoys. These changes alone would significantly improve navigation safety for existing traffic.

For the reasons stated above in Q#1, however, they would do little to enhance the safe navigation of large deep draft vessels attempting to pass each other in these channels. The proposed improvements in conjunction with a "one way" (NO PASSING) restriction on vessels over a certain size and draft would, if not enhance, at least maintain the safe navigation of these channels.

The channels are not wide enough for safety from Galveston #1 to proposed turning basin. The proposed channel should be around 1,200 feet. We need as much space between docked ships as we can get.

The proposed channels are not wide enough for safe navigation from Galveston #1 buoy to the proposed turning basin. From Grasso Fuel Dock to the proposed turning basin should be a minimum of 1050 feet wide to safely navigate that part of the channel including the turns. Also, this would allow more distance between docked ships and moving ships, which would lessen the effects of cushion and suction as the ships passed.

The proposed channels I do not feel are wide enough for safe navigation from Galveston "GB" buoy to Galveston Buoy 16. I feel that these channels should be no less than 1000 feet in width (that is, from the Seabuoy to Galveston Channel Buoy 16) if we are going to be handling vessels 900 feet and longer with beams exceeding 150 feet with 50 foot draft. I also feel, like [the Capt. in the previous paragraph] that the proposed channel in Galveston Harbor itself from Galveston Buoy #1 to the new proposed turning basin will not be wide enough for safe navigation for these large size vessels. I feel we should maintain a minimum 1000 foot wide channel.

I think the channel should be 800 to 1000 feet from the seabuoy to the 1050 foot turning basin.

The area I had the most problems with was from the west end of Pier 10 to about Pier 27. This area is a continuous turn and is hard to position the whole ship in the center of the channel. The effects of strong currents either way makes this area even more difficult. Ranges for this area do help (as tested in the simulator), but I strongly feel this area should be wider than proposed in either Phase I or II.

d. What is your opinion of the realignment of the Galveston Channel?

The realignment will probably work. The inclusion of the naturally deep water in the approach to Galveston into the maintained channel improvements is good idea. The slight turn and point occurring off Pier #16 area could cause a problem, but better familiarity will eliminate this concern.

The reach from Seawolf Park to Pier #10 could encounter a shoaling problem off the U.S. Coast Guard Base Galveston. The naturally deep water occurs closer to Seawolf Park and builds significantly off the Coast Guard Base.

The realignment of the Galveston Channel is a very good idea especially the widening of the channel at Buoys 7 & 8 and 9 & 10. This will be a great help to all the pilots.

I like the idea of widening the turns at #7 and #8 buoys and #9 and #10 buoys. This would correct a present problem. The realignment *in Galveston Harbor from Galveston #1 buoy to Pelican Island Bridge needs to be adjusted as described in question #3 to be safely navigated.*

Once again I agree with [the Capt. in the previous paragraph] of widening the turns at #7 and #8 buoys and #9 and #10 buoys. As for the realignment of the channel in Galveston Harbor from buoy #1 to Pelican Island Bridge is already addressed in the above paragraph.

The idea of widening the channel at #7 and #8 buoys and #9 and #10 buoys as in Phase #3 should be a must to safely meet in these turns.

The proposal to make the turns at buoys 7-8 and 9-10 are very good ideas. It enables us to initiate and complete these known problem areas with more confidence. In Galveston Harbor deepening the channel on the center line is safer than the south side, enabling Pilots to navigate further away from moored ships in the harbor.

e. Are there any places the channel may not need to be widened as much as proposed?

I do not support any reduction in the width of any part of the channel or improvements unless a one-way traffic restriction is applied.

NO.

Definitely no.

f. Do you have any suggestions or changes to the aids to navigation?

Existing "Ranges" must be significantly improved by increasing their height, size and horizontal and vertical separation.

The use of "GAGED" buoys alone to mark the offshore approach in Phase I&II is inadequate. A fixed system to indicate centerline is necessary. An electronic system, capable of indicating channel centerline, of a portable receiver type or interfacing with onboard equipment should also be installed.

I feel that passing ranges would be a tremendous help and also any type of electronic ranges or aids that could be used while transiting the channels.

(1) The ranges for the entrance channel could be brighter.

(2) The ranges for the outer bar channel need to be raised so that they may be seen over the anchored ships.

(3) Depending on the final configuration of the Galveston harbor channel, ranges will have to be established for guidance in the deeper part of the channel.

g. Do you feel your ability, on the simulator, to turn a vessel in Galveston Channel was limited because you could not position an additional pilot on the bow of the ship?

NO. The close in display was as good an alternative. The greatest problem encountered while turning around was the inability to accurately determine vessel headway or sternway. Information such as tug wakes, propeller wash and Seaman's Eye are all useful during this maneuver.

The inability of the simulation to produce three (3) dimensional images will always be a limitation of these systems.

Somewhat, in the real world, we would have a pilot on the bow, but in simulation I don't know if the distance off the bank could be judged accurately enough to make any difference.

Yes.

h. Any additional comments of suggestions.

I would like to comment on the proposed phase 3 pertaining to the 600 foot deep draft channel from the "GA" buoy to the "GB" buoy, I definitely feel due to currents, strong winds and seas in this area that one way traffic which means no passing or meeting is a must for safety.

5 Recommendations

Based on the real-time ship simulator study conducted by WES, the following recommendations are made for the Houston/Galveston Entrance Channels and the Galveston Channel.

a. Based on the simulation results, the Bolivar Roads Channel, the Inner Bar Channel, the Outer Bar Channel, and the Entrance Channel should be built as tested (Figure 3) for the Phase I channels. The U.S. Coast Guard should be contacted to investigate the possibility of using passing ranges, rather than center-line ranges, in this area.

b. Based on the simulation results, the Bolivar Roads Channel, the Inner Bar Channel, and the Outer Bar Channel should be built as tested (Figure 3) for the Phase II channels. The Phase II Entrance Channel may be built as tested with the stipulation that two vessels as large as those tested not meet in the 600-ft-wide portion (Test Reach I) of this channel. However, it is recommended that this portion of the channel be widened to 800 ft to maintain two-way traffic through the entrance.

c. The Phase I Galveston Channel should be built to a width of 550 ft and realigned near the split buoy (Figure 16). The turning area in Galveston Channel should be extended past Pier 36 to a length of 4,500 ft. Although this is longer than any of the distances required to turn a ship in the simulation of the Galveston Channel, the extra length is required to:

(1) Allow pilots a certain amount of choice in where they turn a vessel to account for variable factors such as the position of docked ships.

(2) Add a factor of safety to compensate for the fact that vessels in simulators do not affect the currents. Obviously, a vessel turned sideways in an 1,100-ft-wide channel will increase the magnitude of the current velocities.

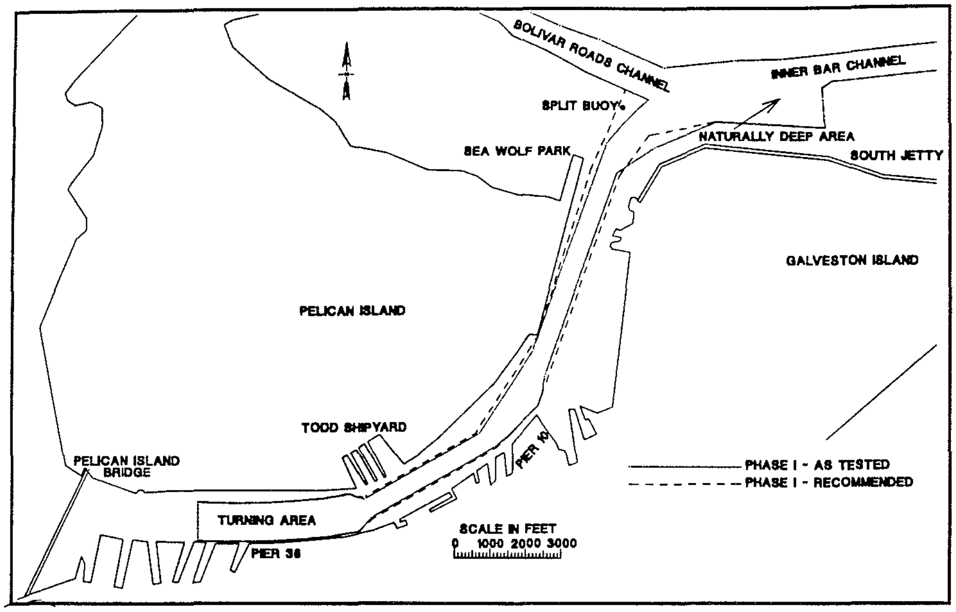

Figure 16. Phase I Galveston Channel, recommended

d. The Phase II Galveston Channel should be built to the same channel alignment as the Phase I channel.

e. The turning area north of the jetty (Figure 6) and used by loaded ships leaving Houston and going into Galveston should be built. The turning length provided by this area is 5,500 ft. The Coast Guard should be contacted regarding possible aids to navigation that might better mark the area.

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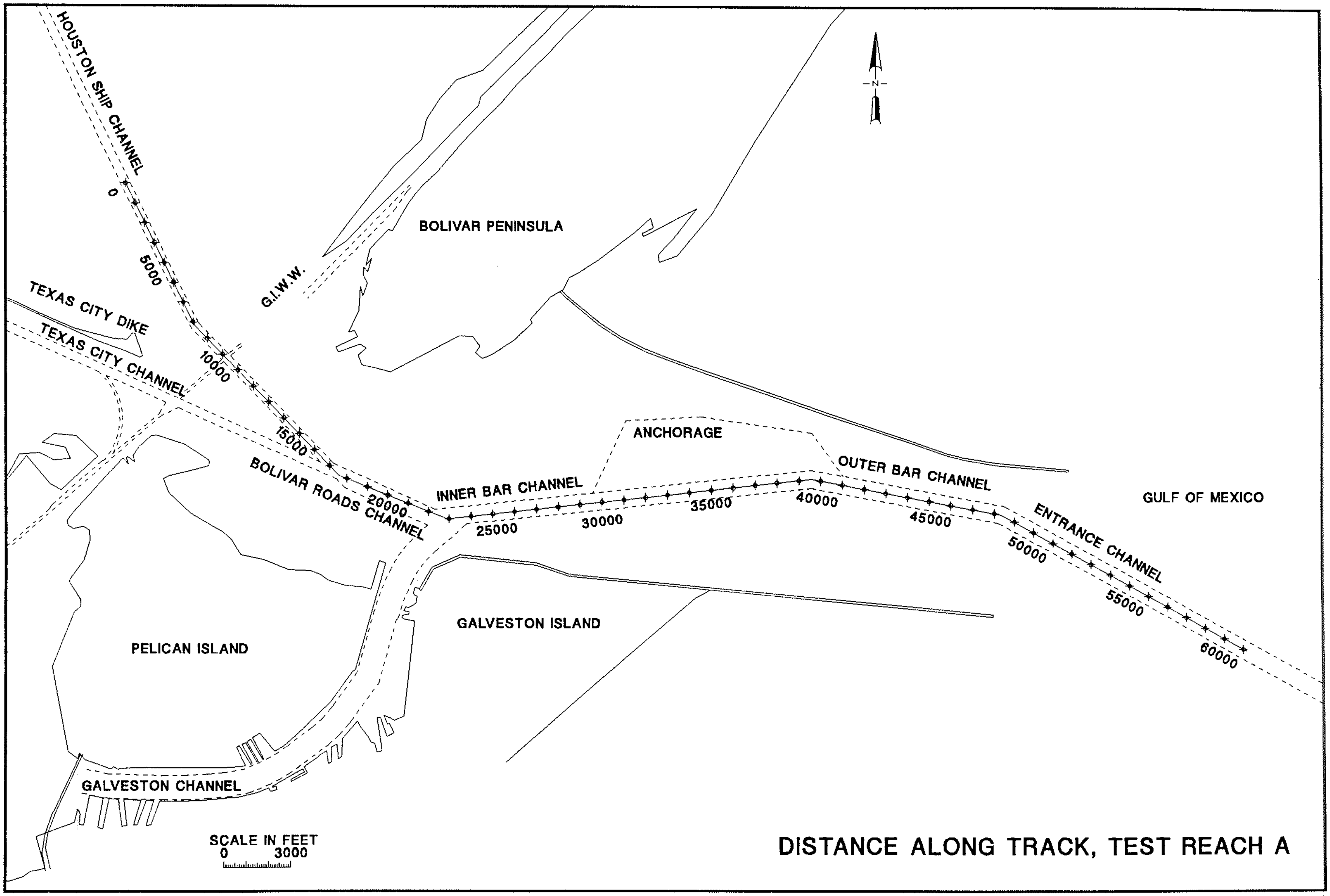
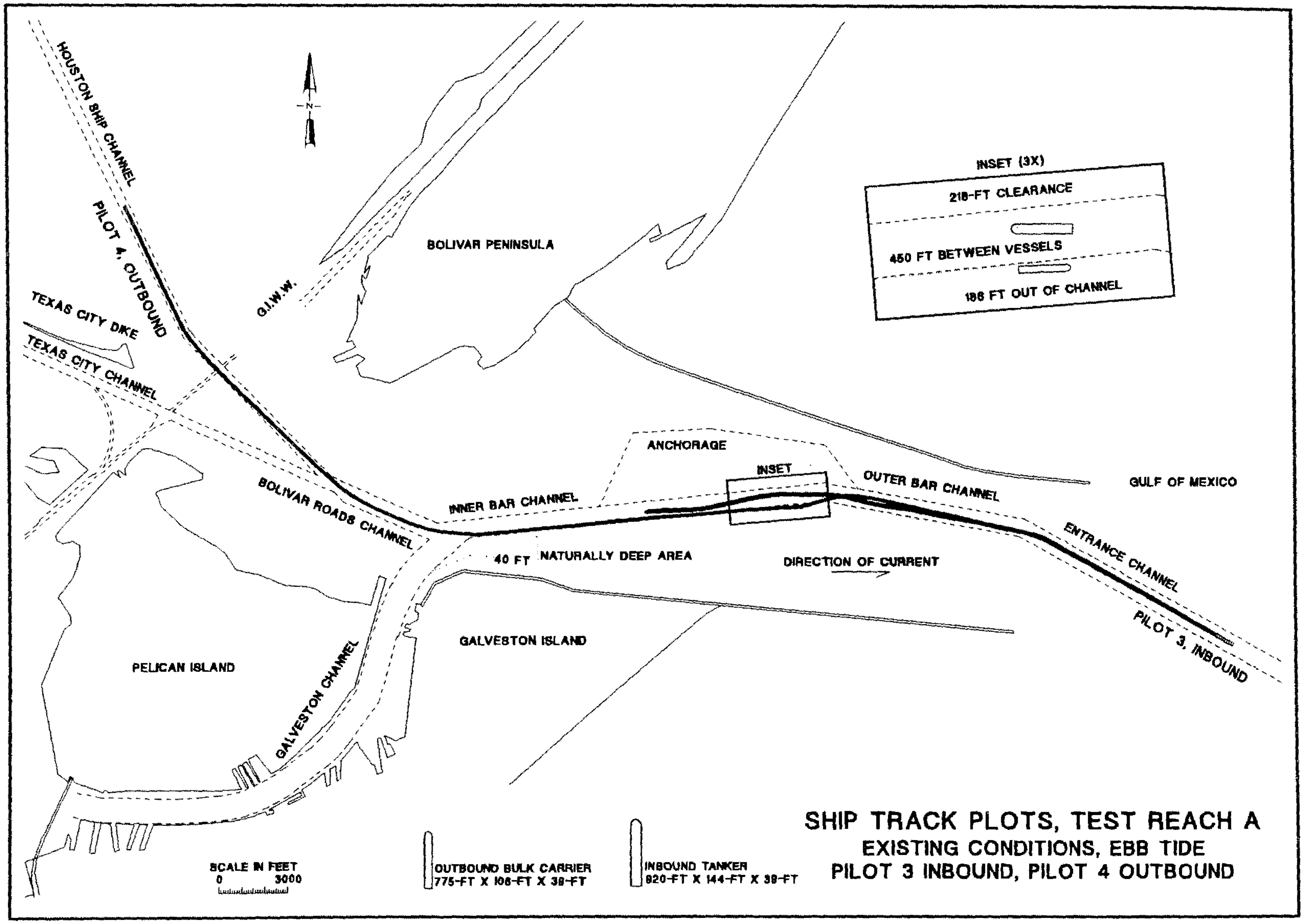
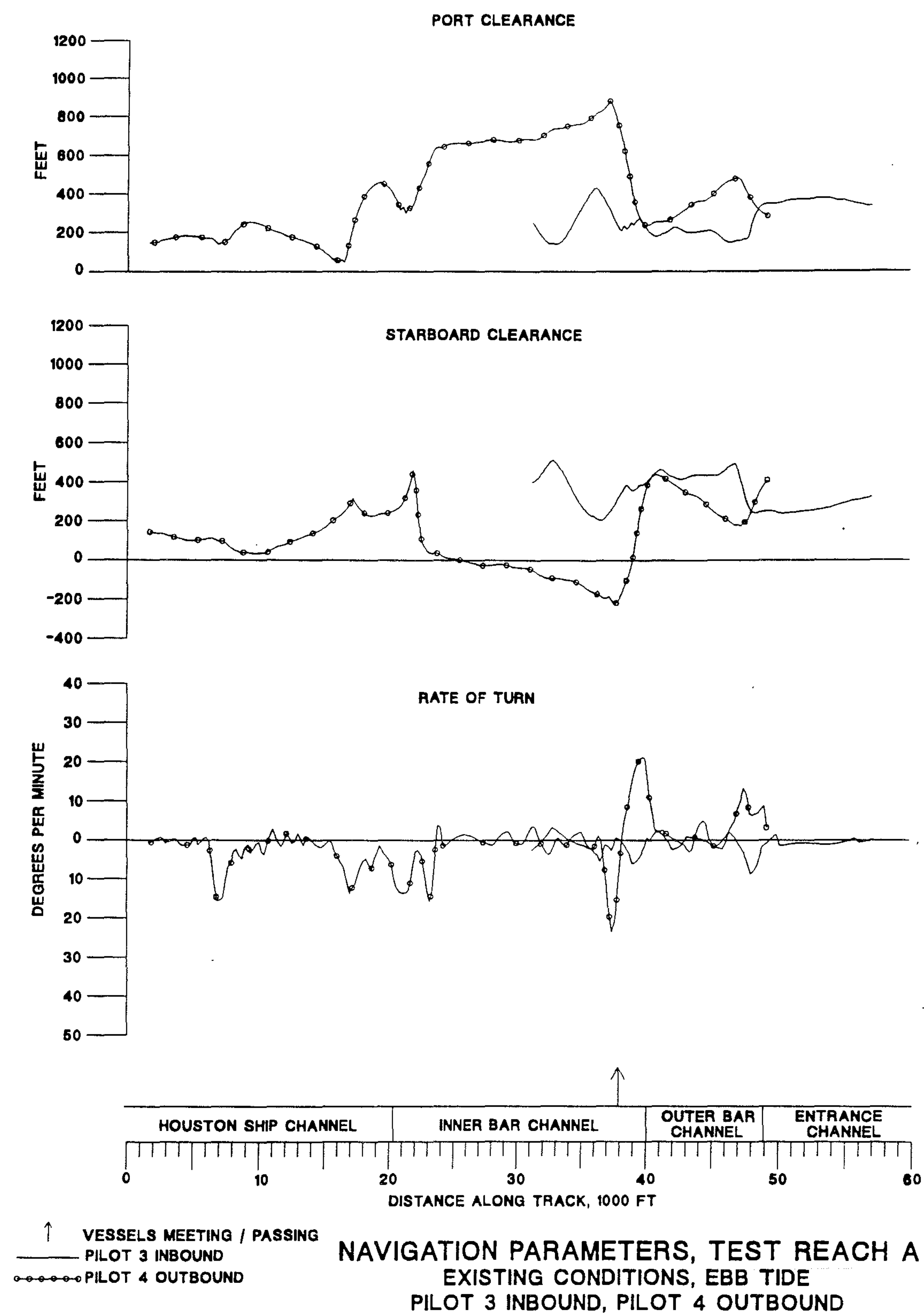

HOUSTON SHIP CHANNEL
G.I.W.W.
BOLIVAR PENINSULA
TEXAS CITY DIKE
TEXAS CITY CHANNEL
BOLIVAR ROADS CHANNEL
ANCHORAGE
INNER BAR CHANNEL
OUTER BAR CHANNEL
ENTRANCE CHANNEL
GULF OF MEXICO
GALVESTON ISLAND
PELICAN ISLAND
GALVESTON CHANNEL
0
5000
10000
15000
20000
25000
30000
35000
40000
45000
50000
55000
60000
N
SCALE IN FEET
0 3000
DISTANCE ALONG TRACK, TEST REACH A

Plate 1

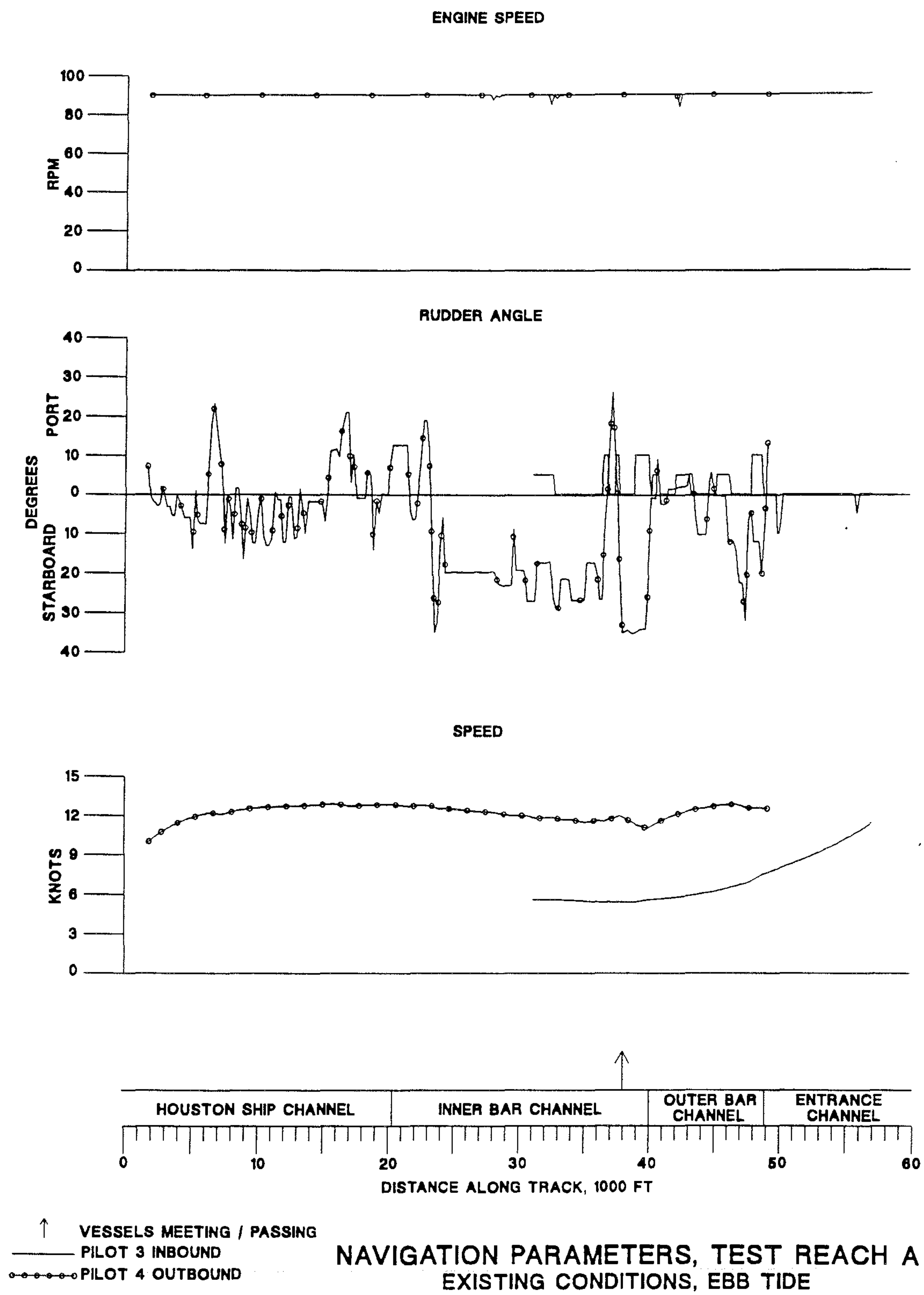
Plate 2



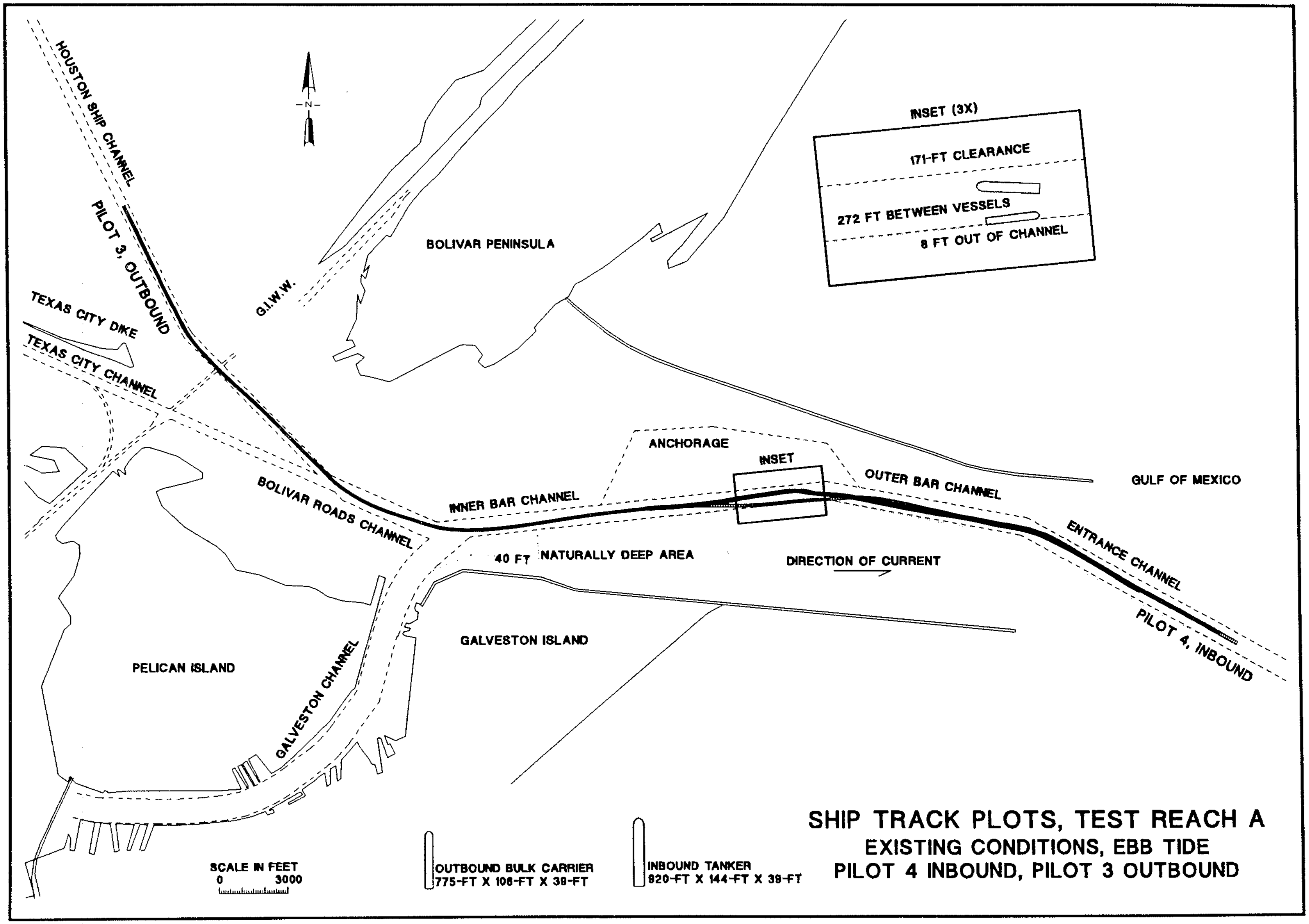
SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

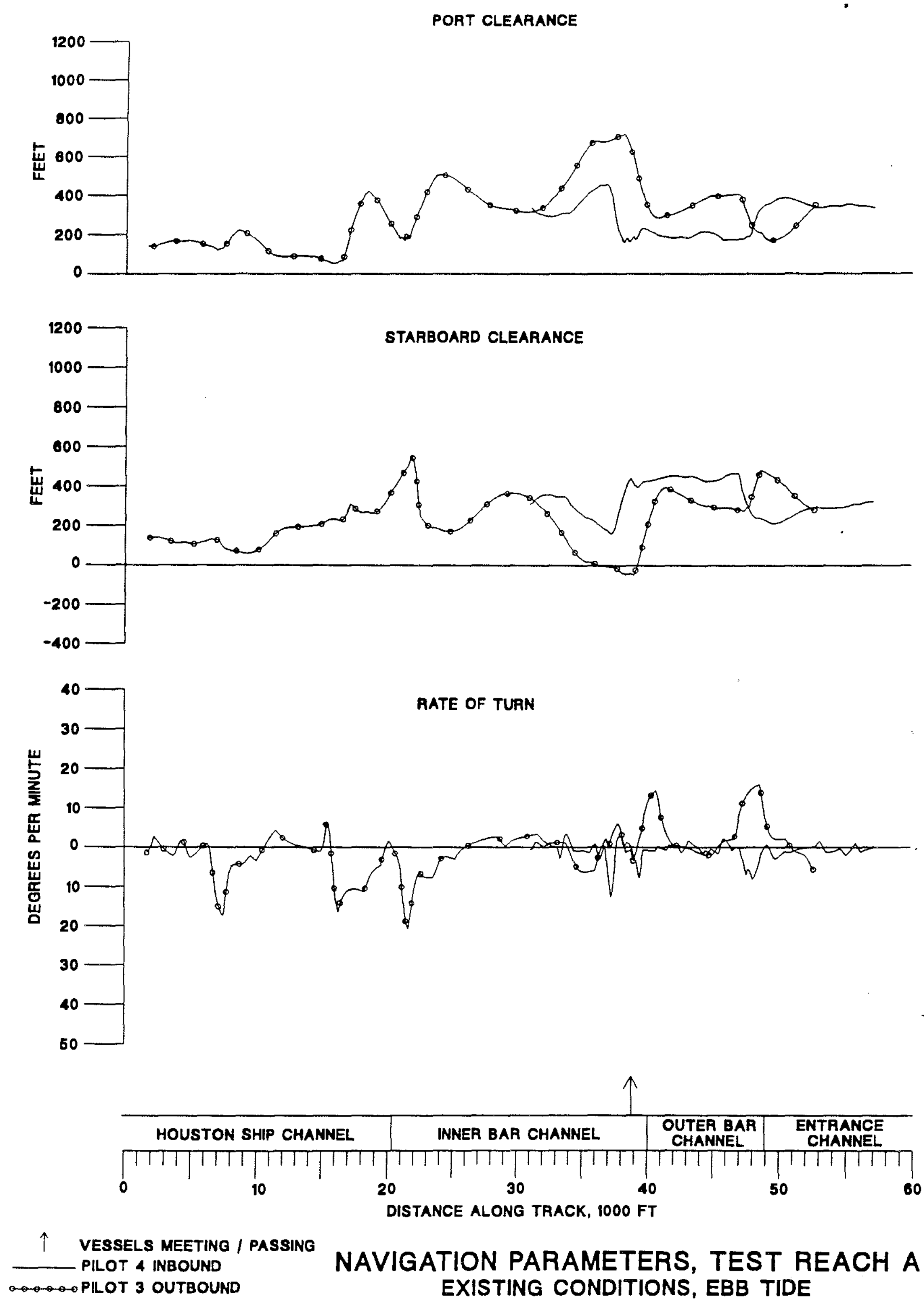


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

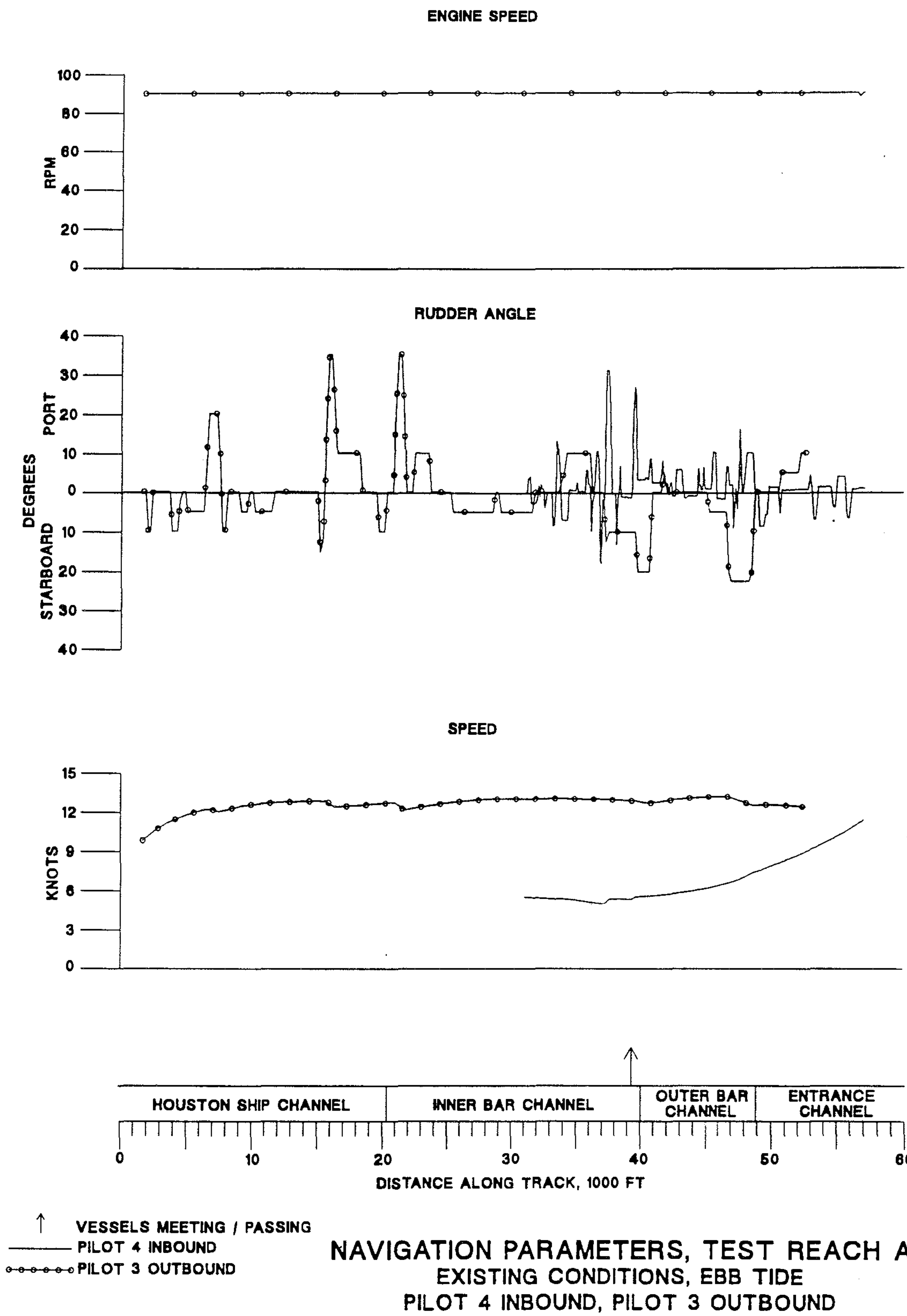


SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 5

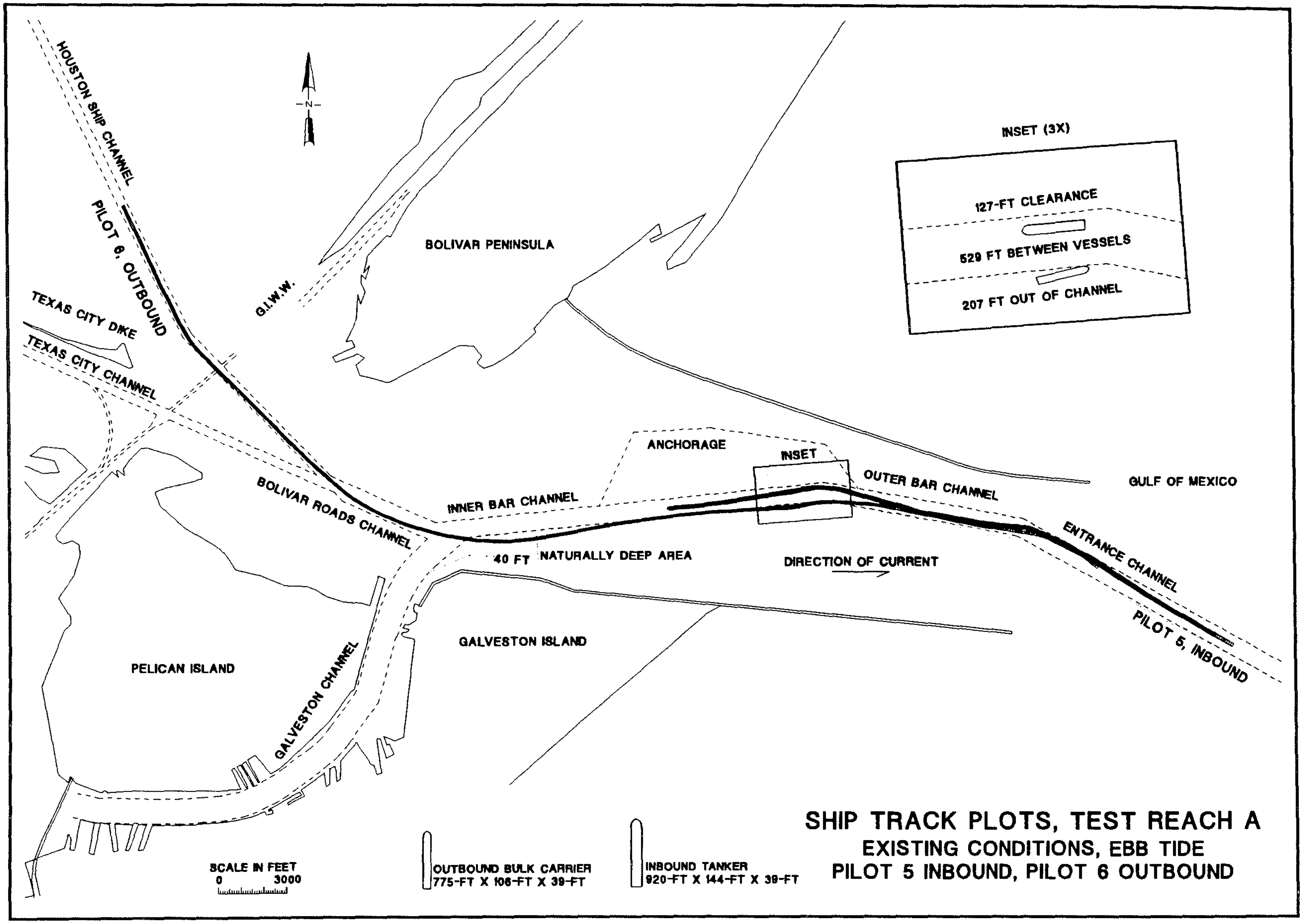


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

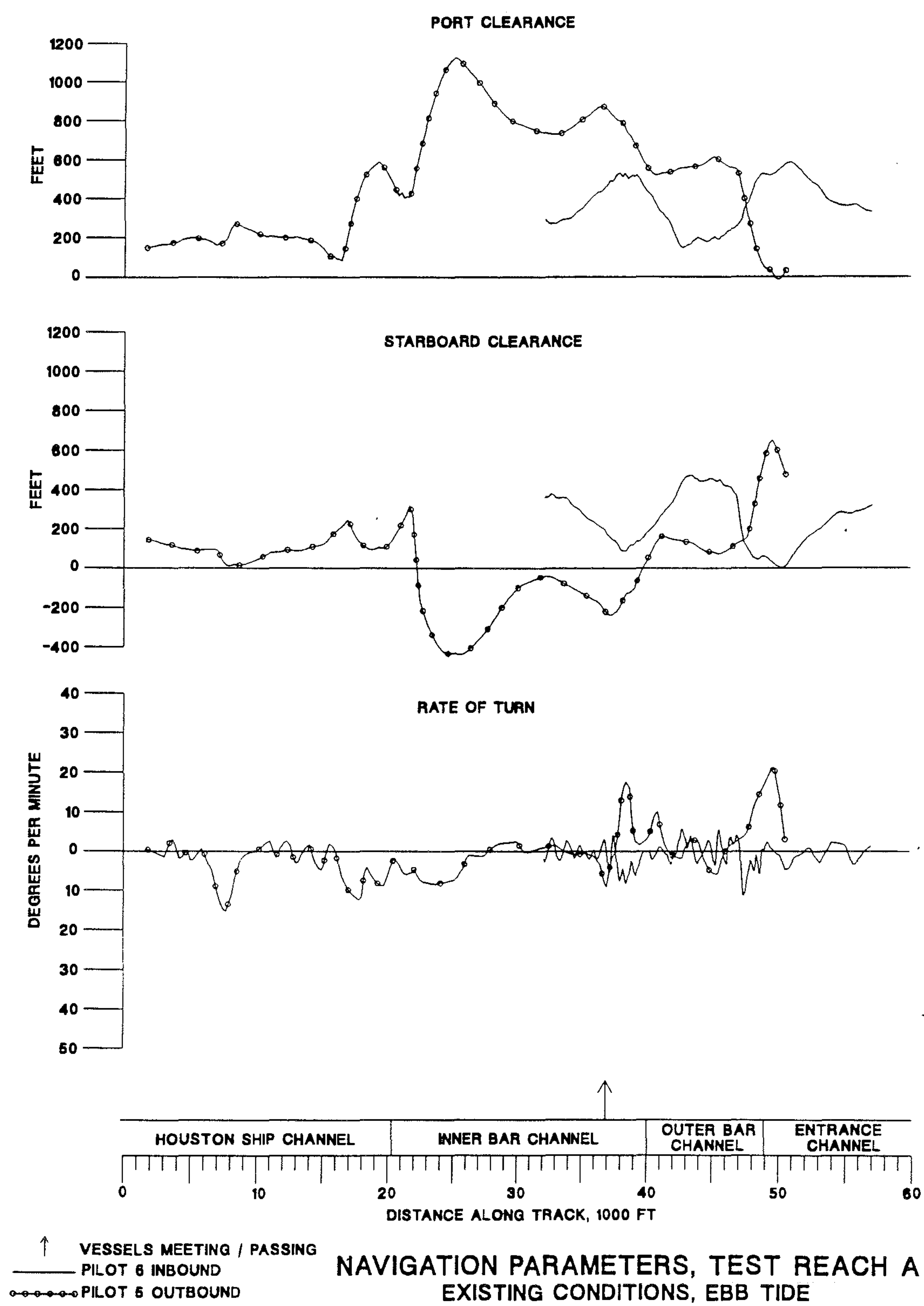


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

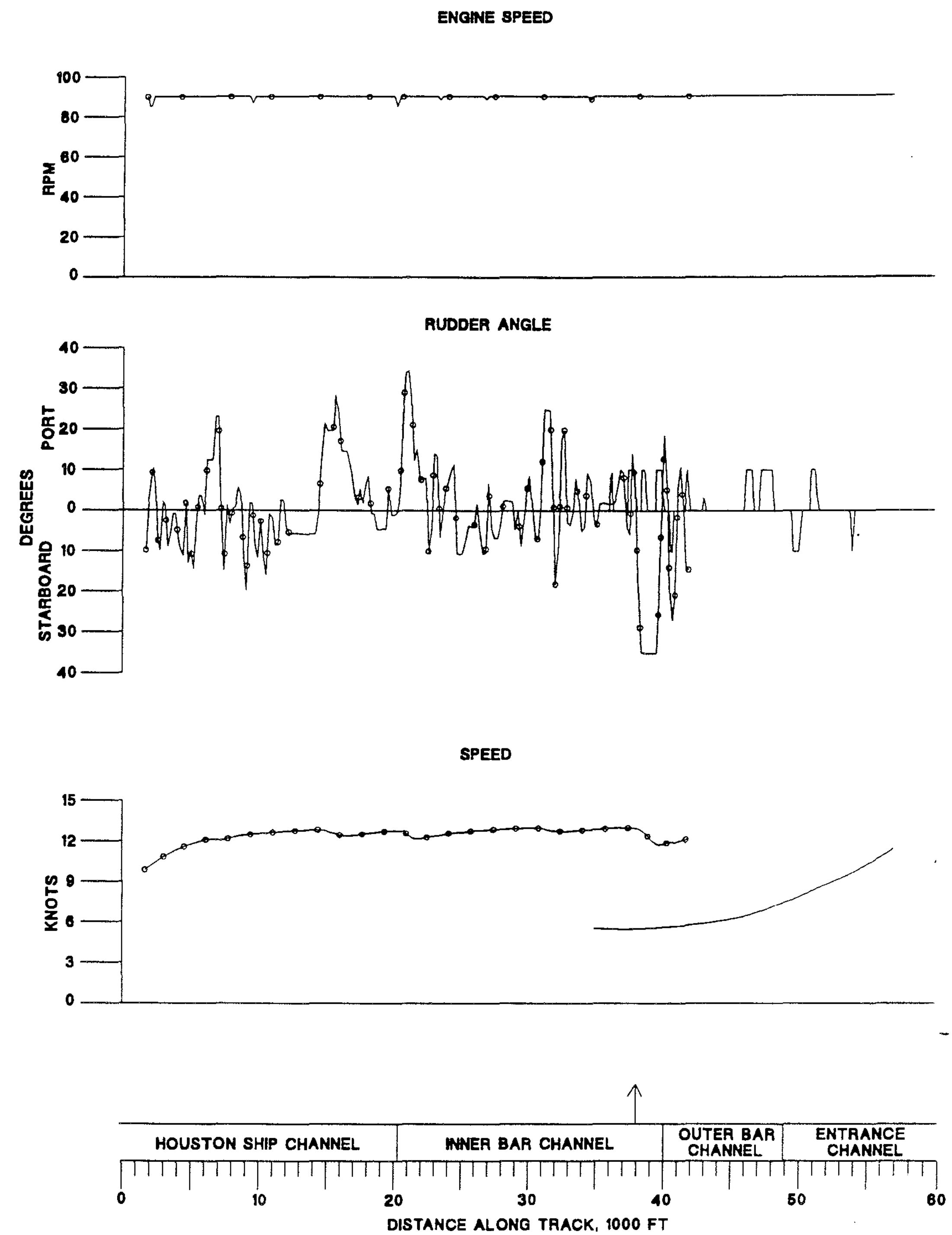
Plate 8



SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

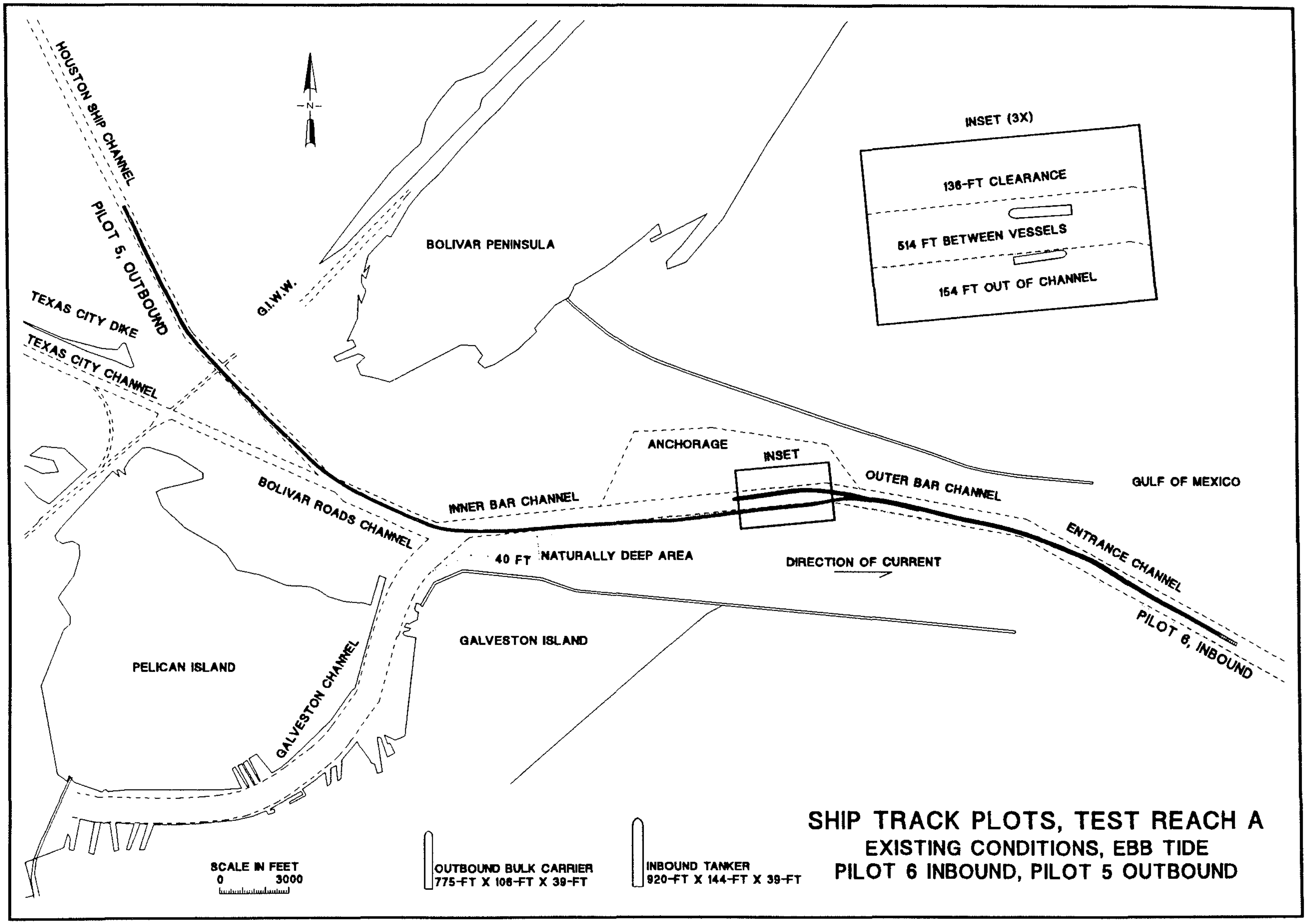


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

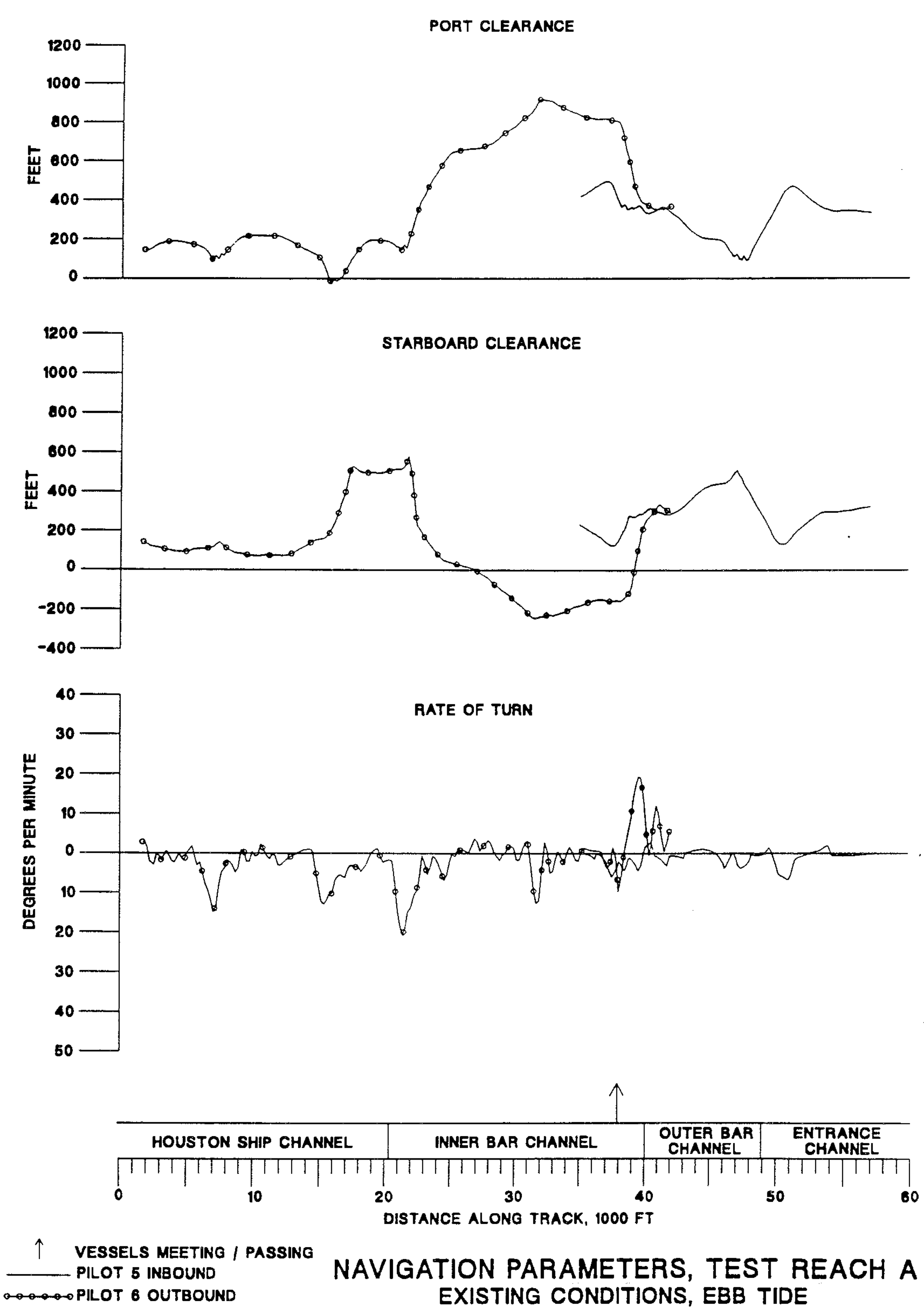


↑ VESSELS MEETING / PASSING
——— PILOT 5 INBOUND
-o-o-o- PILOT 6 OUTBOUND

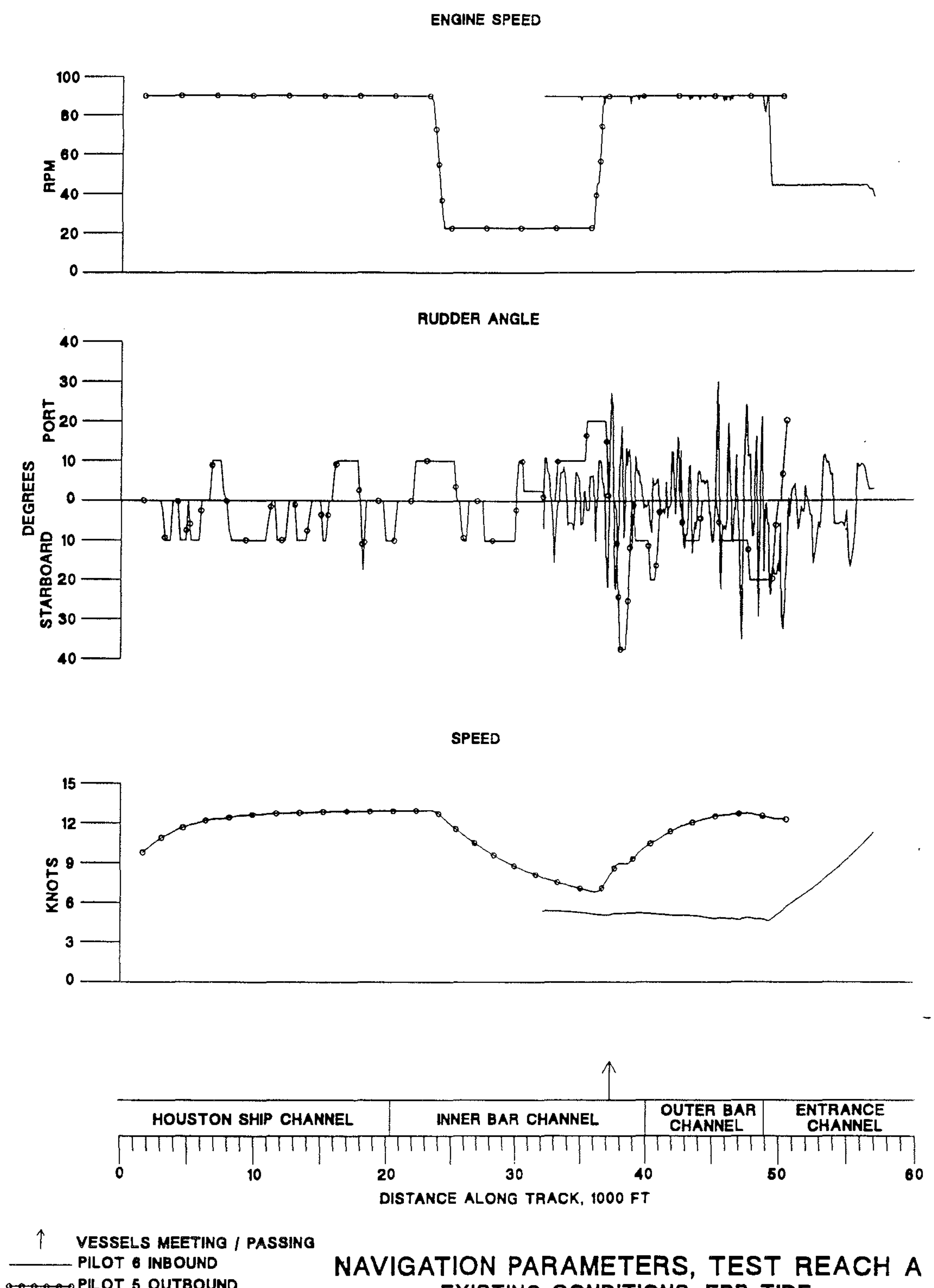
NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

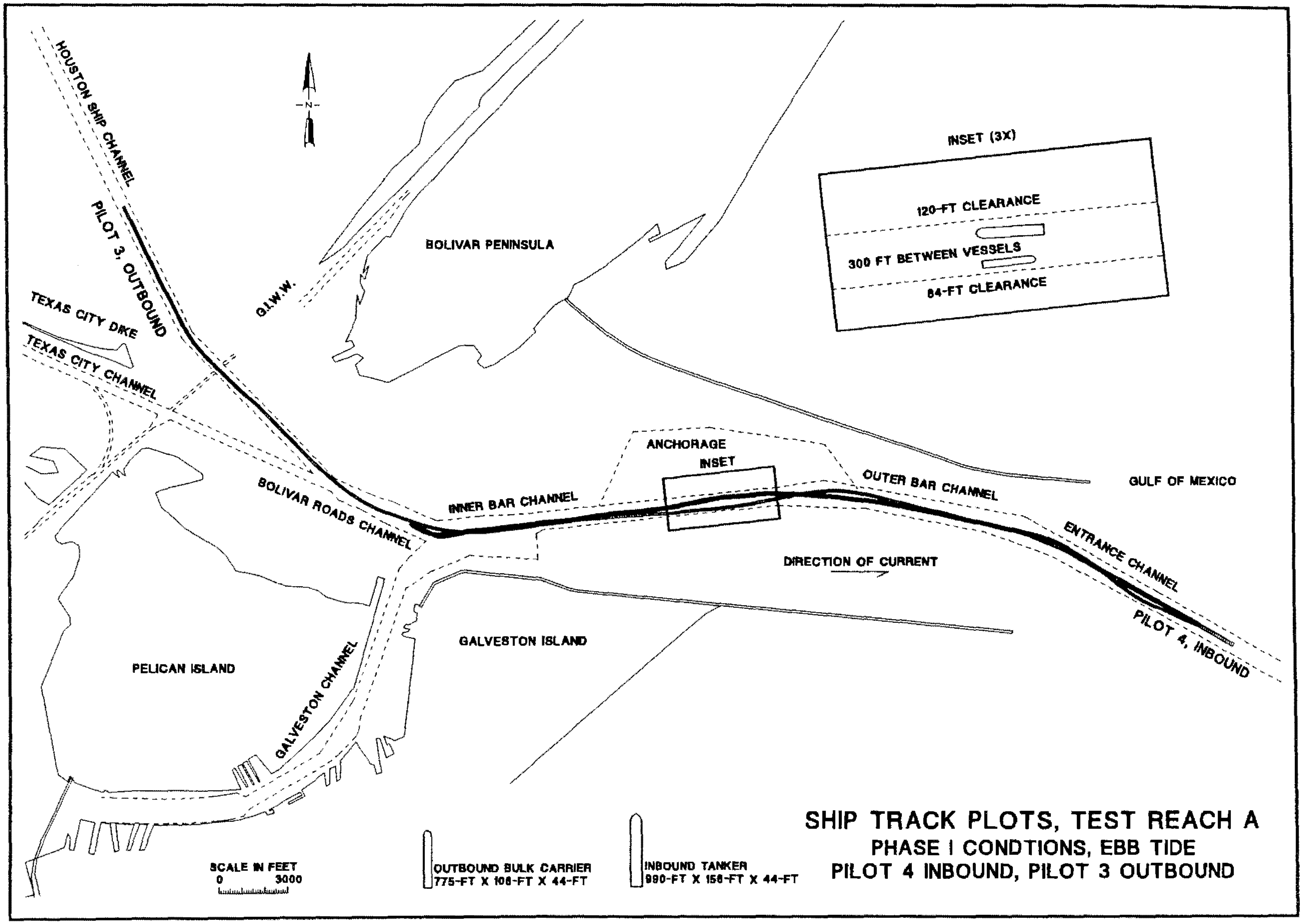


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

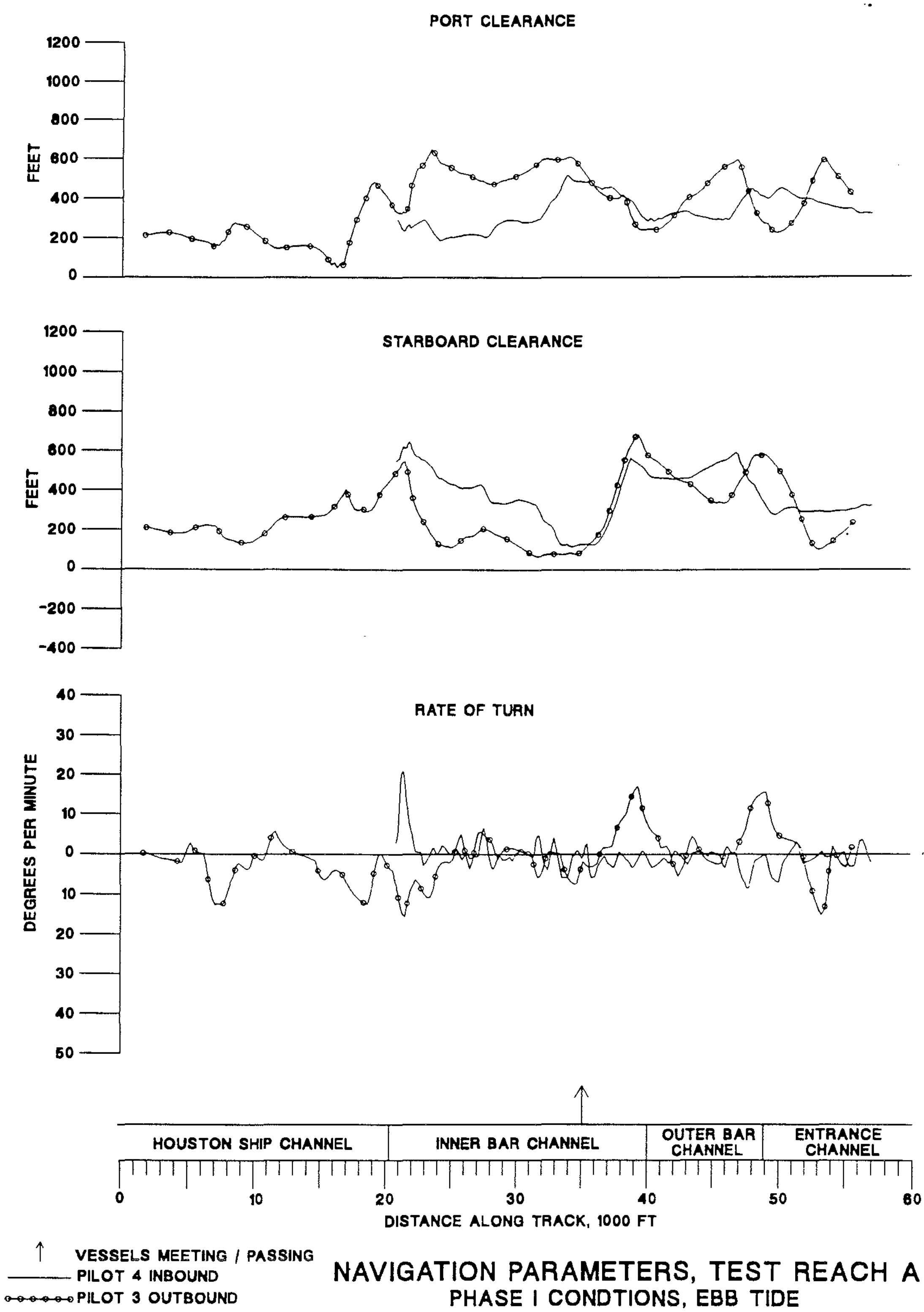


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

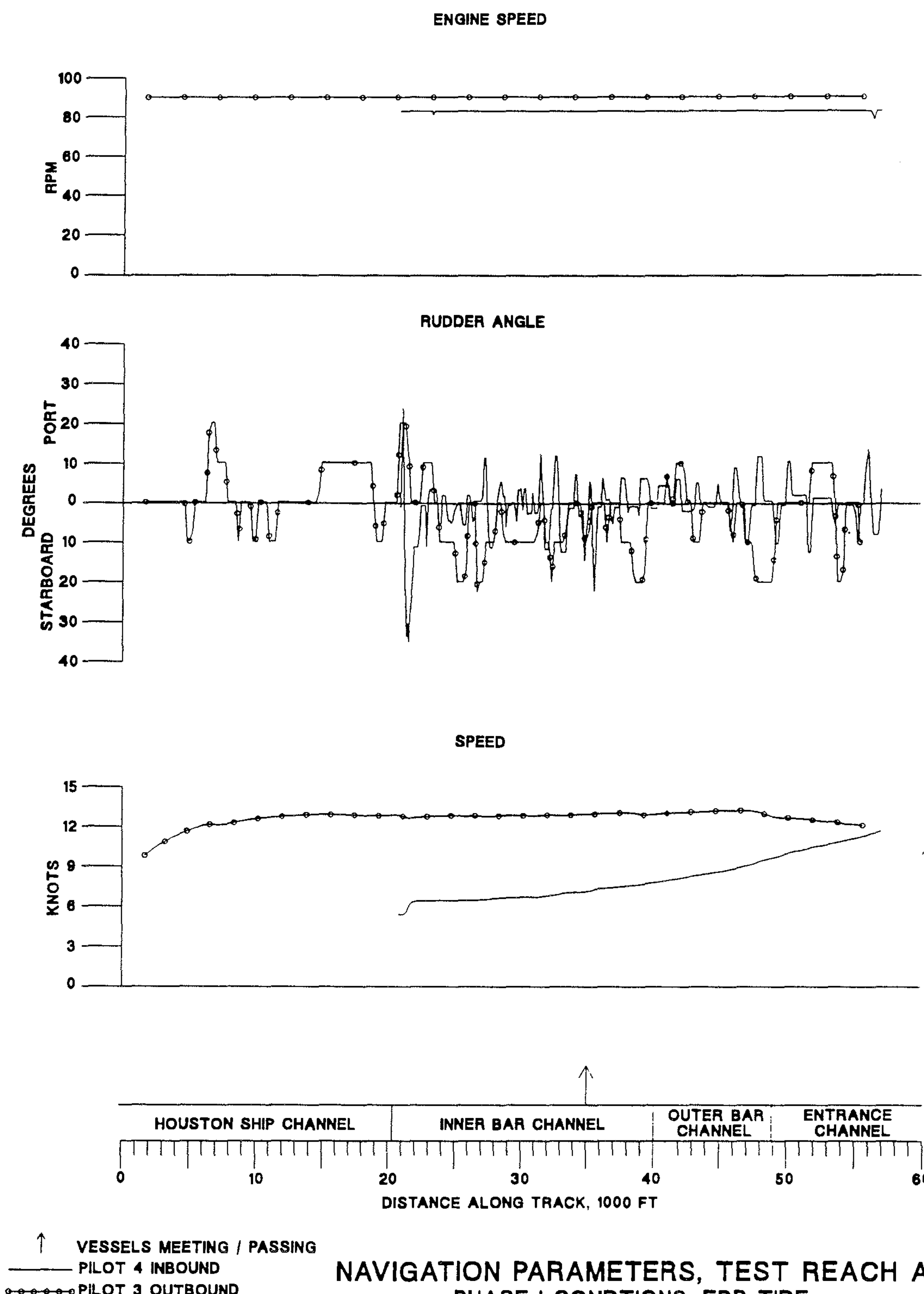
Plate 14



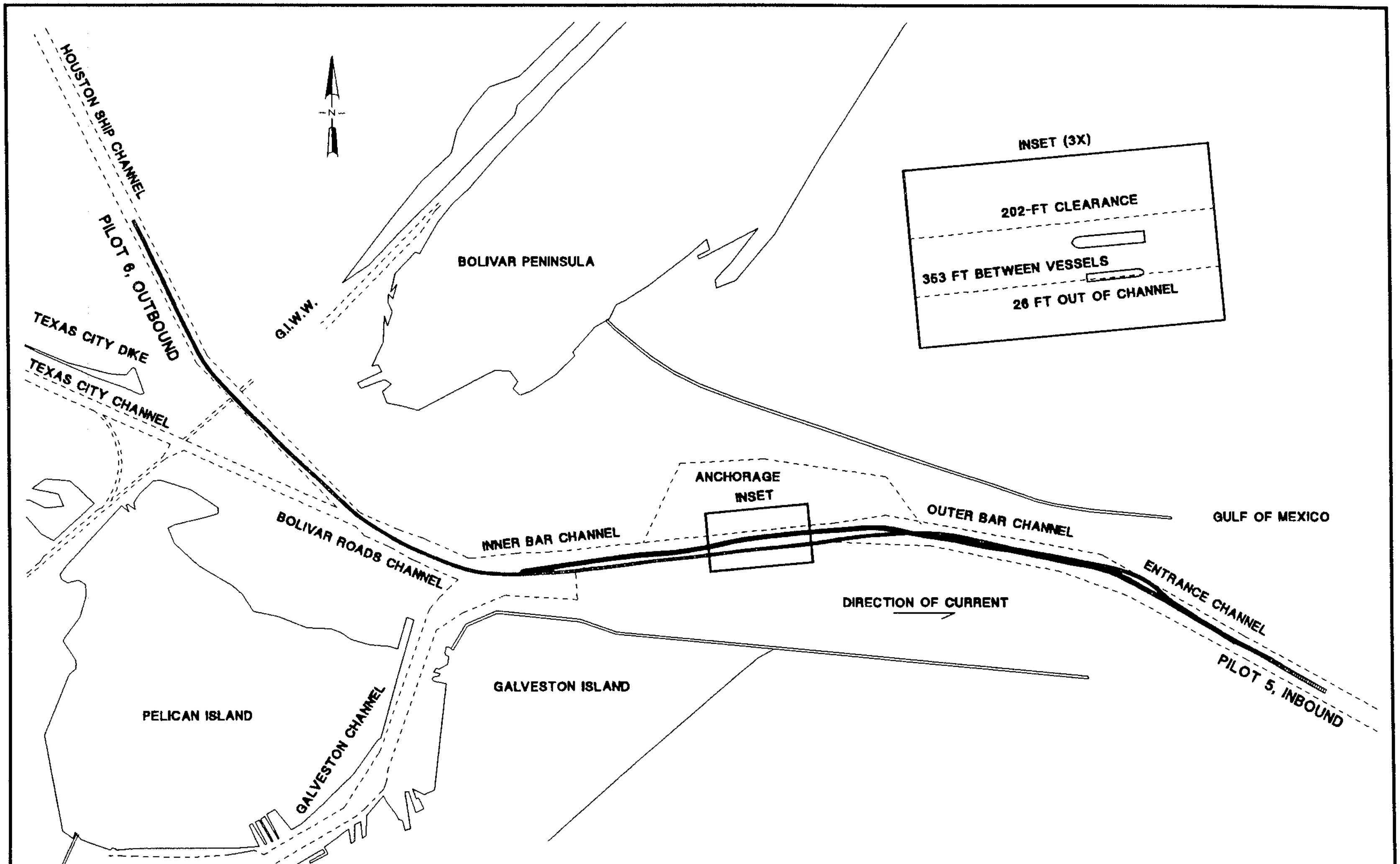
SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

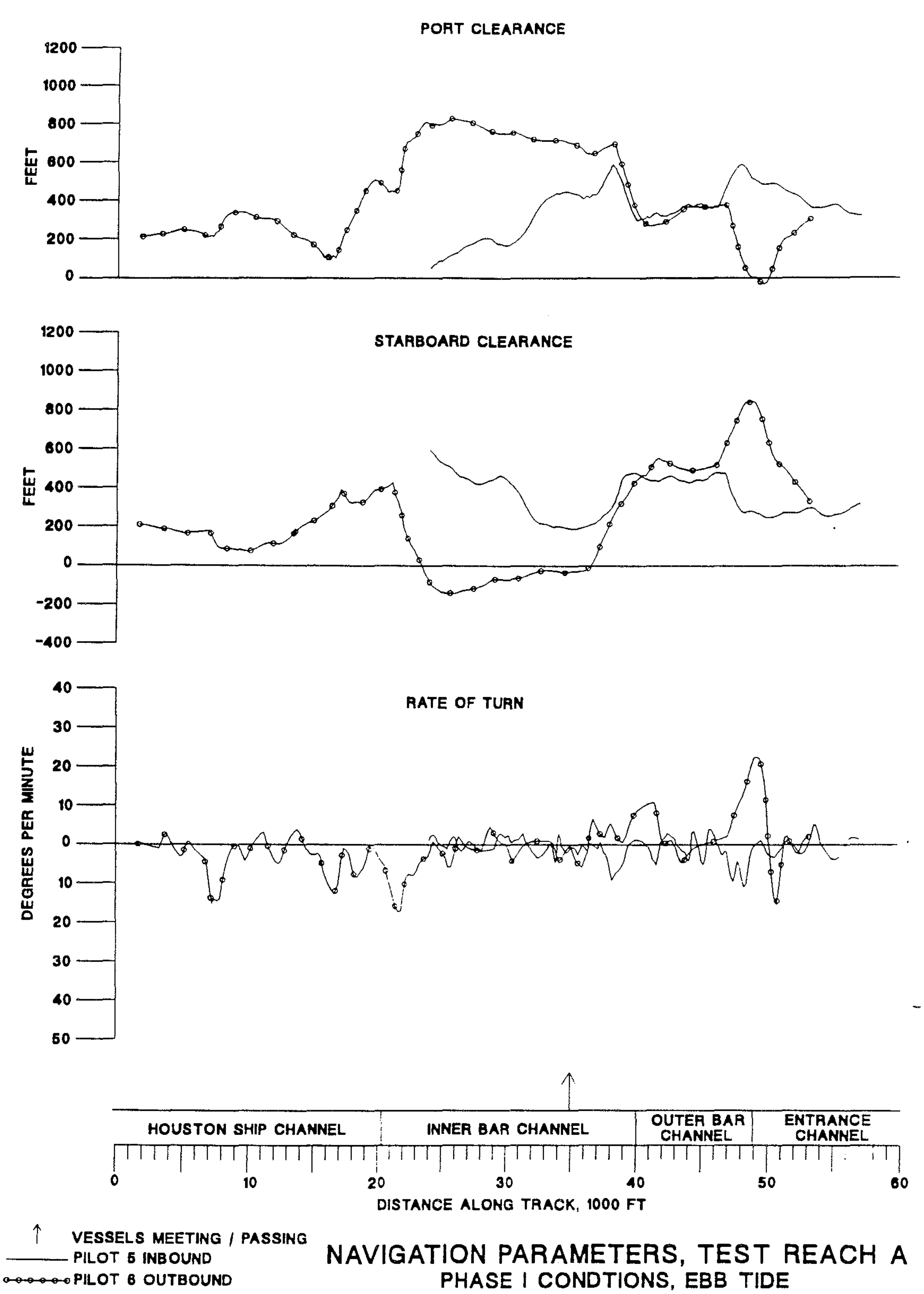


NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

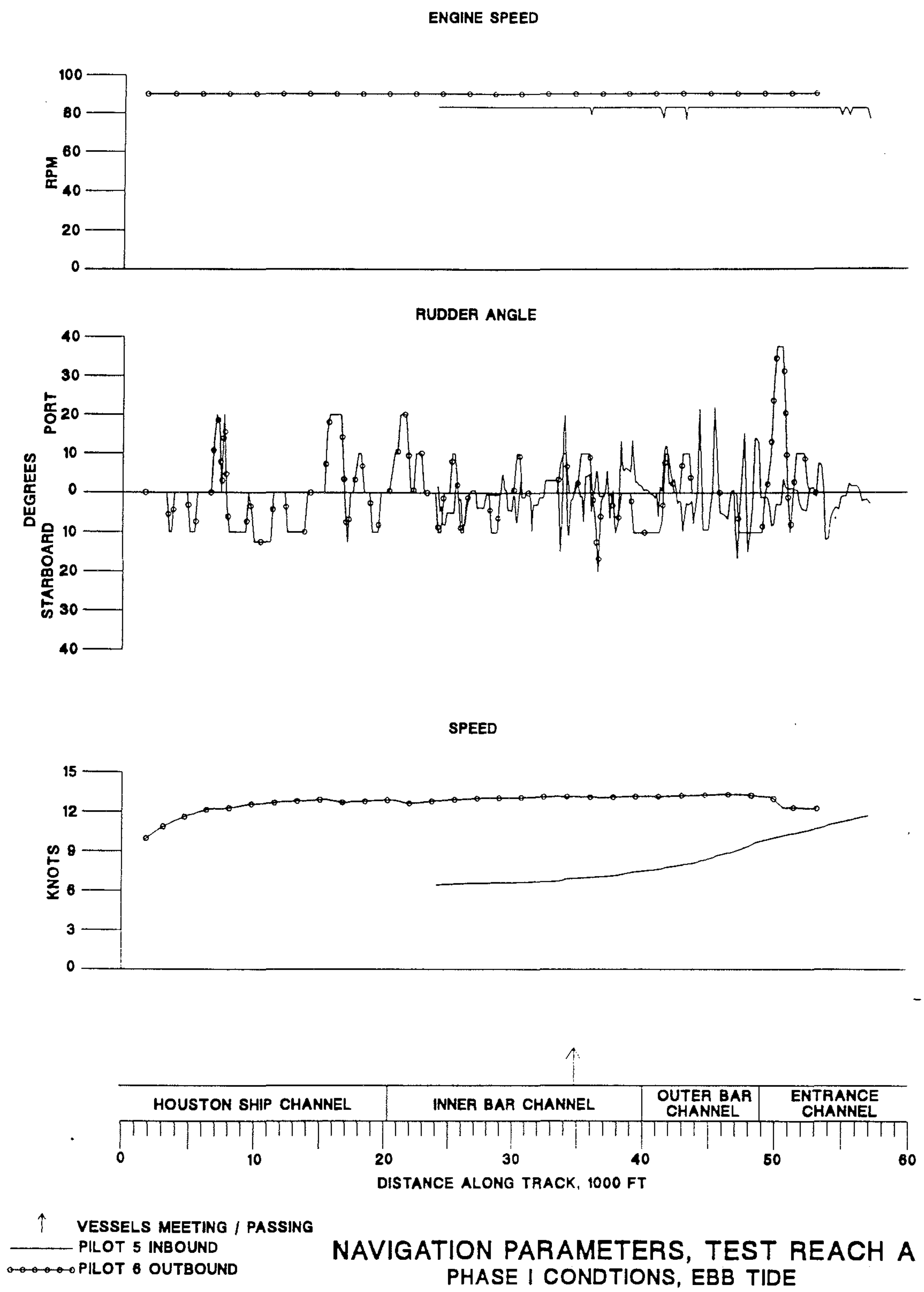


SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 17

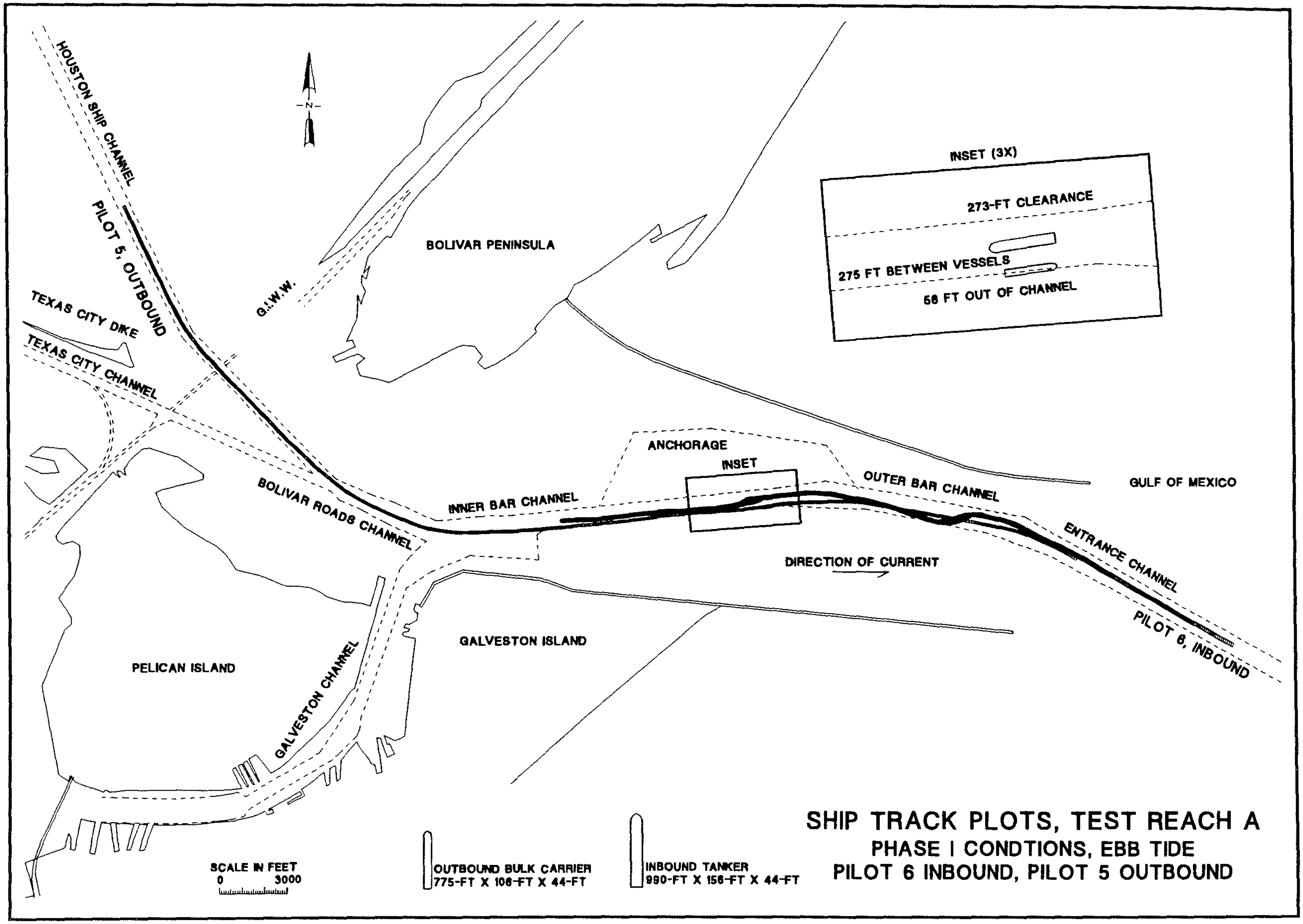


NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

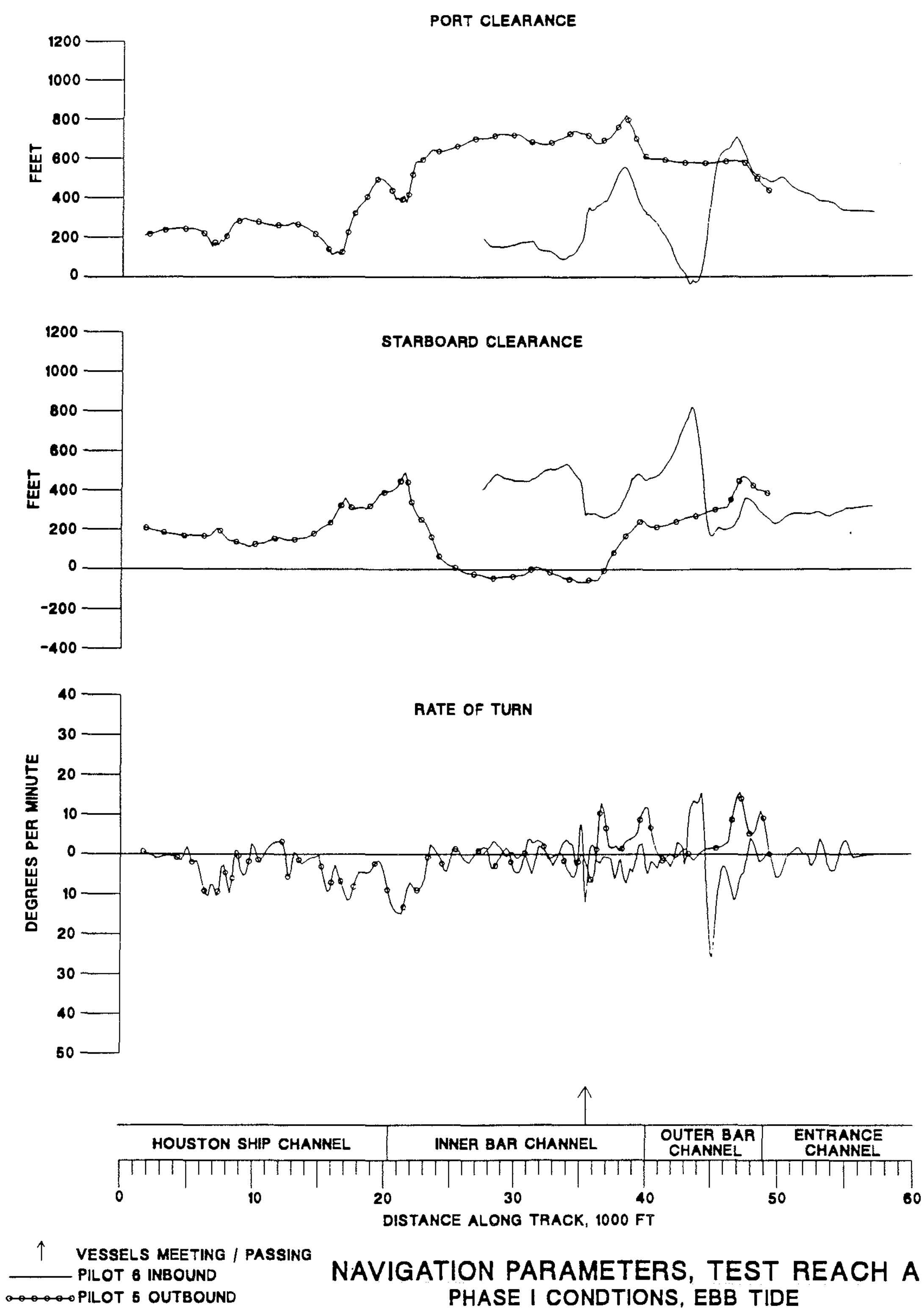


NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

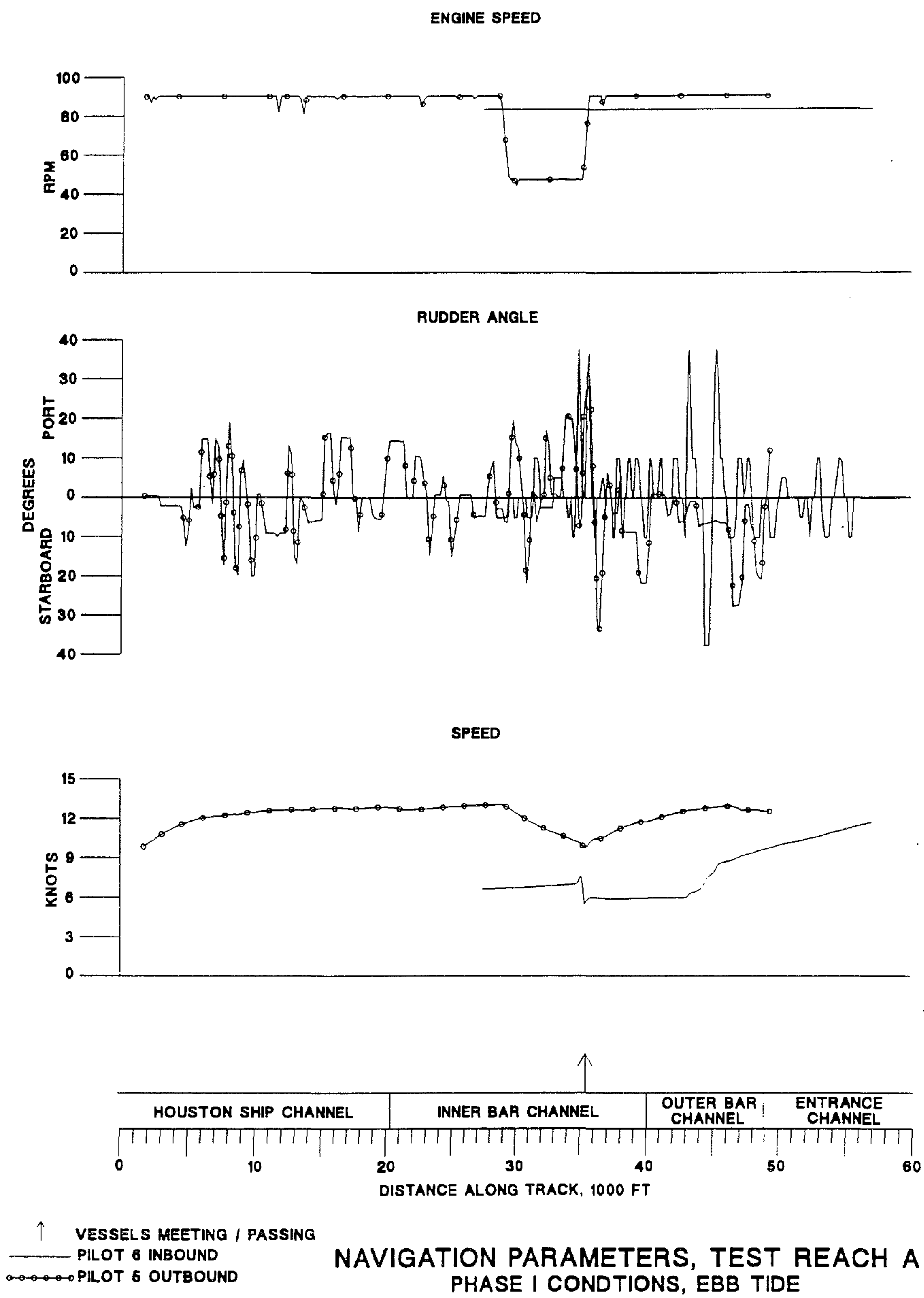
Plate 20



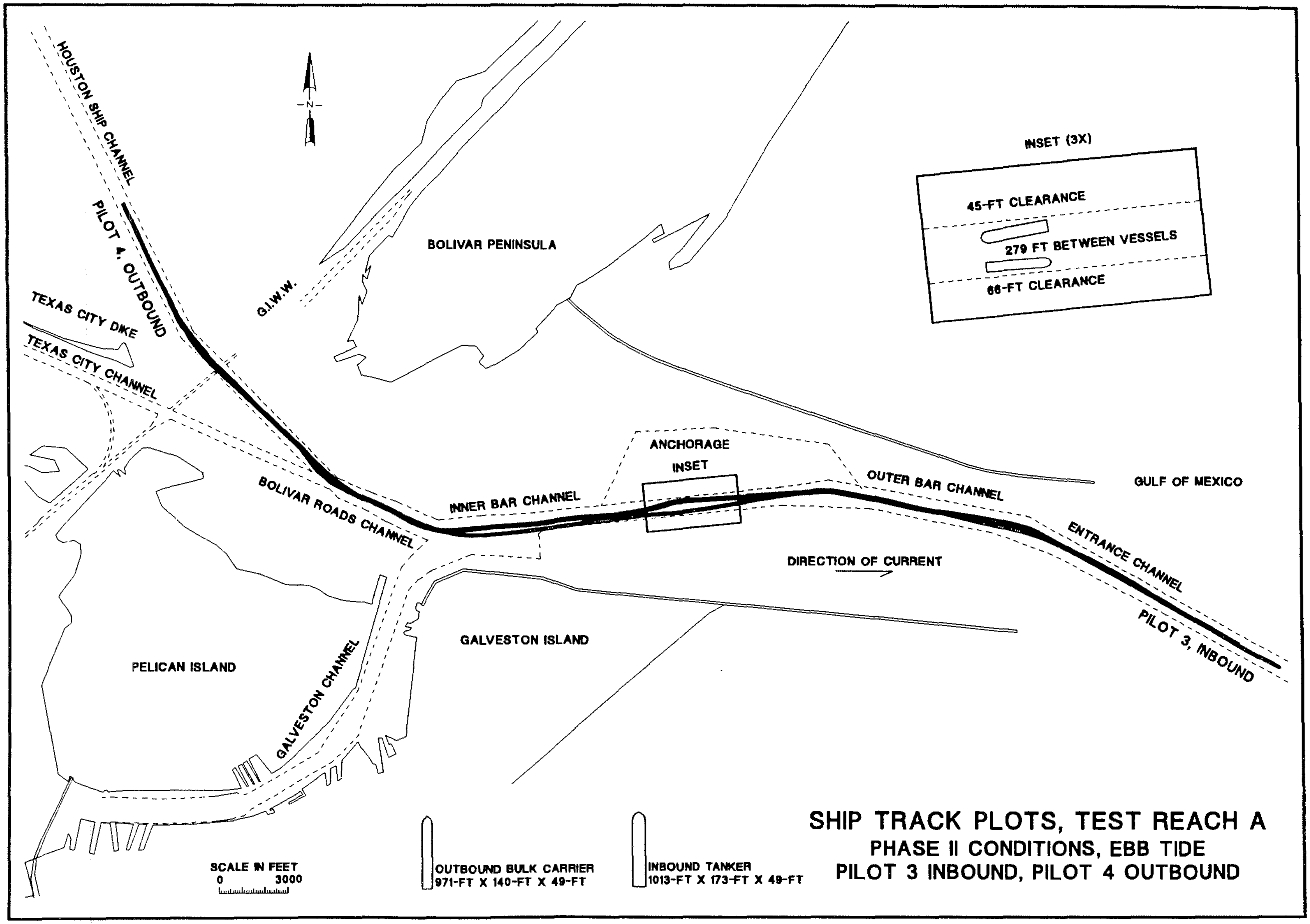
SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

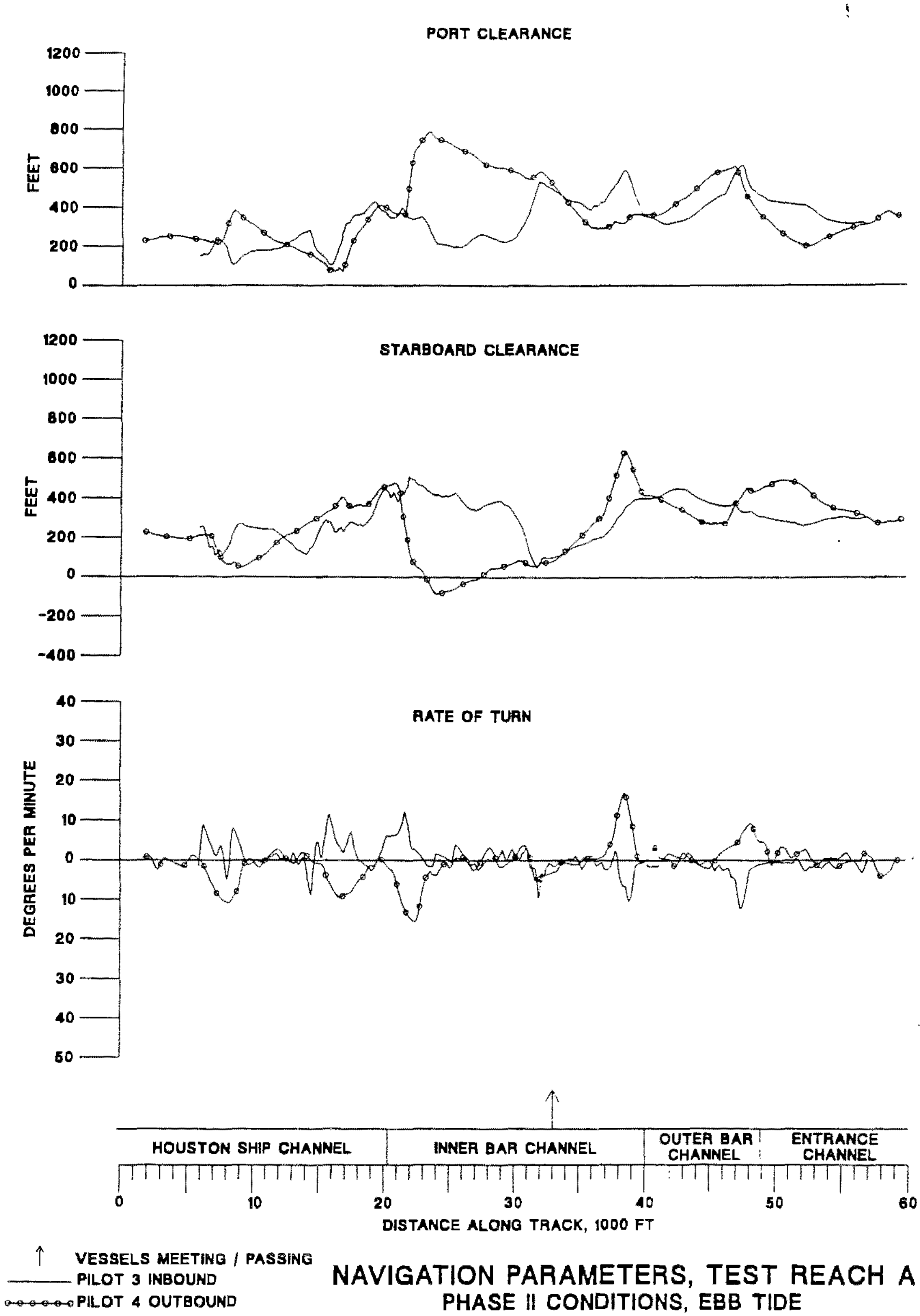


NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

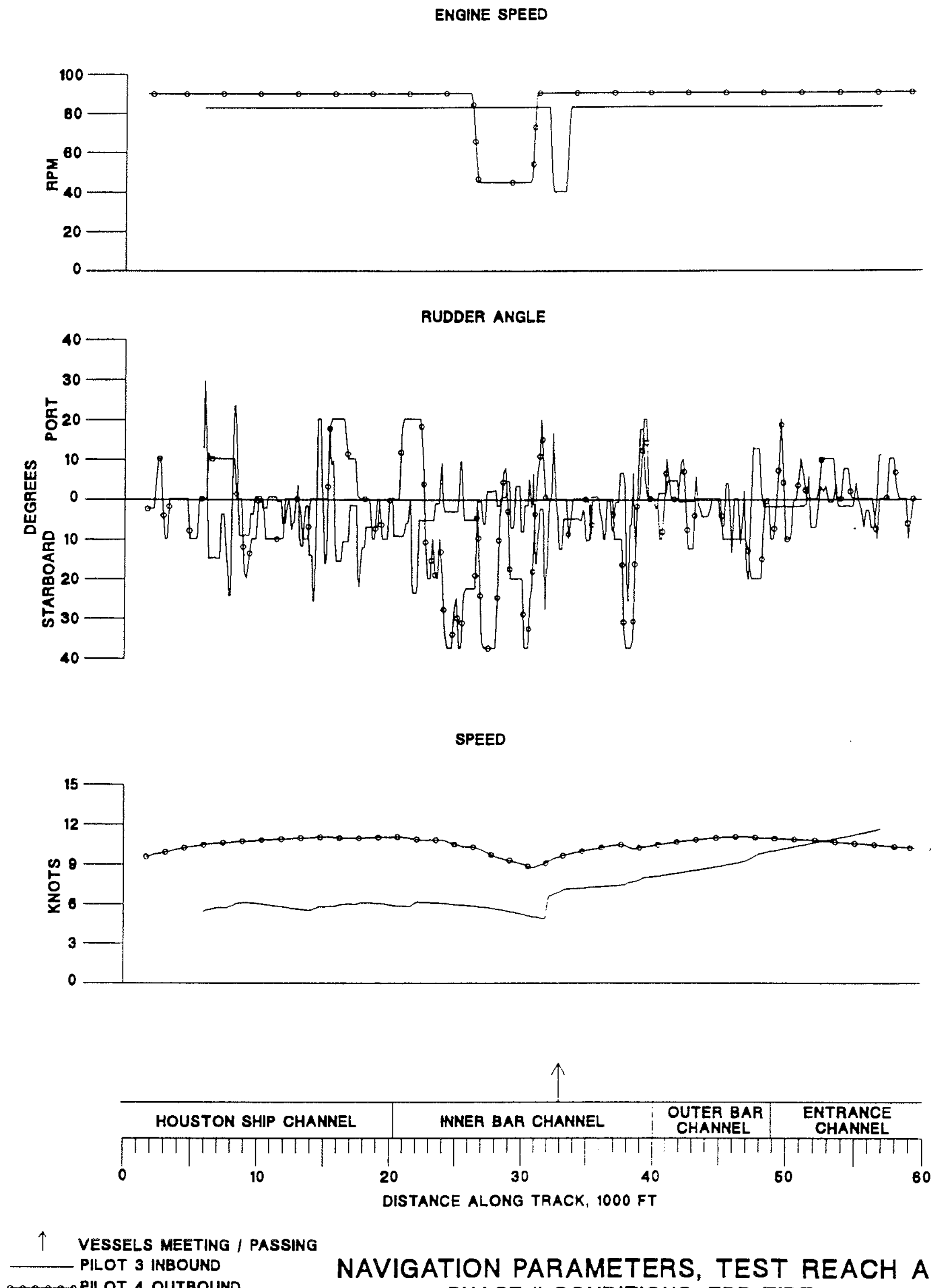


SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

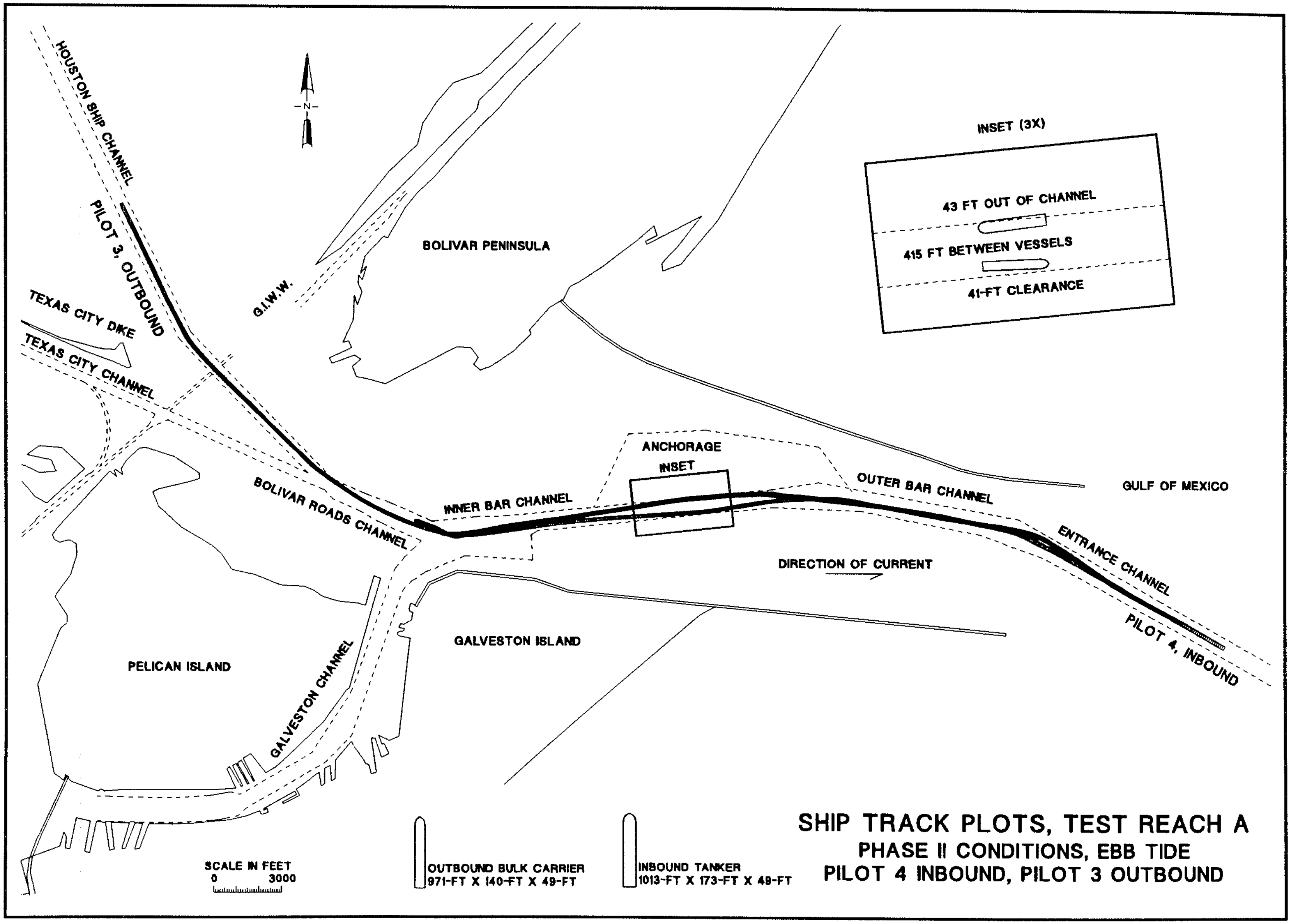
Plate 23



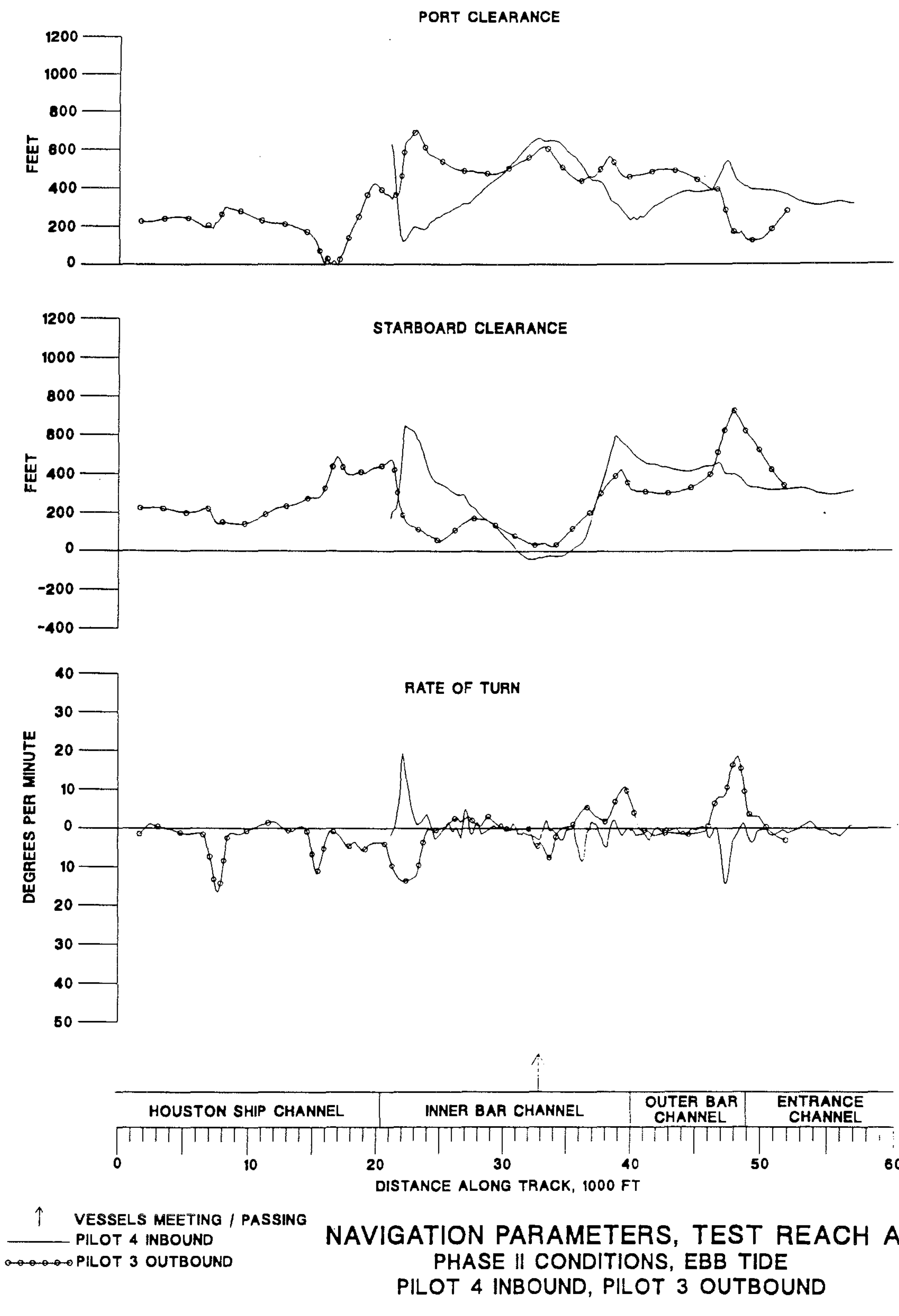
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



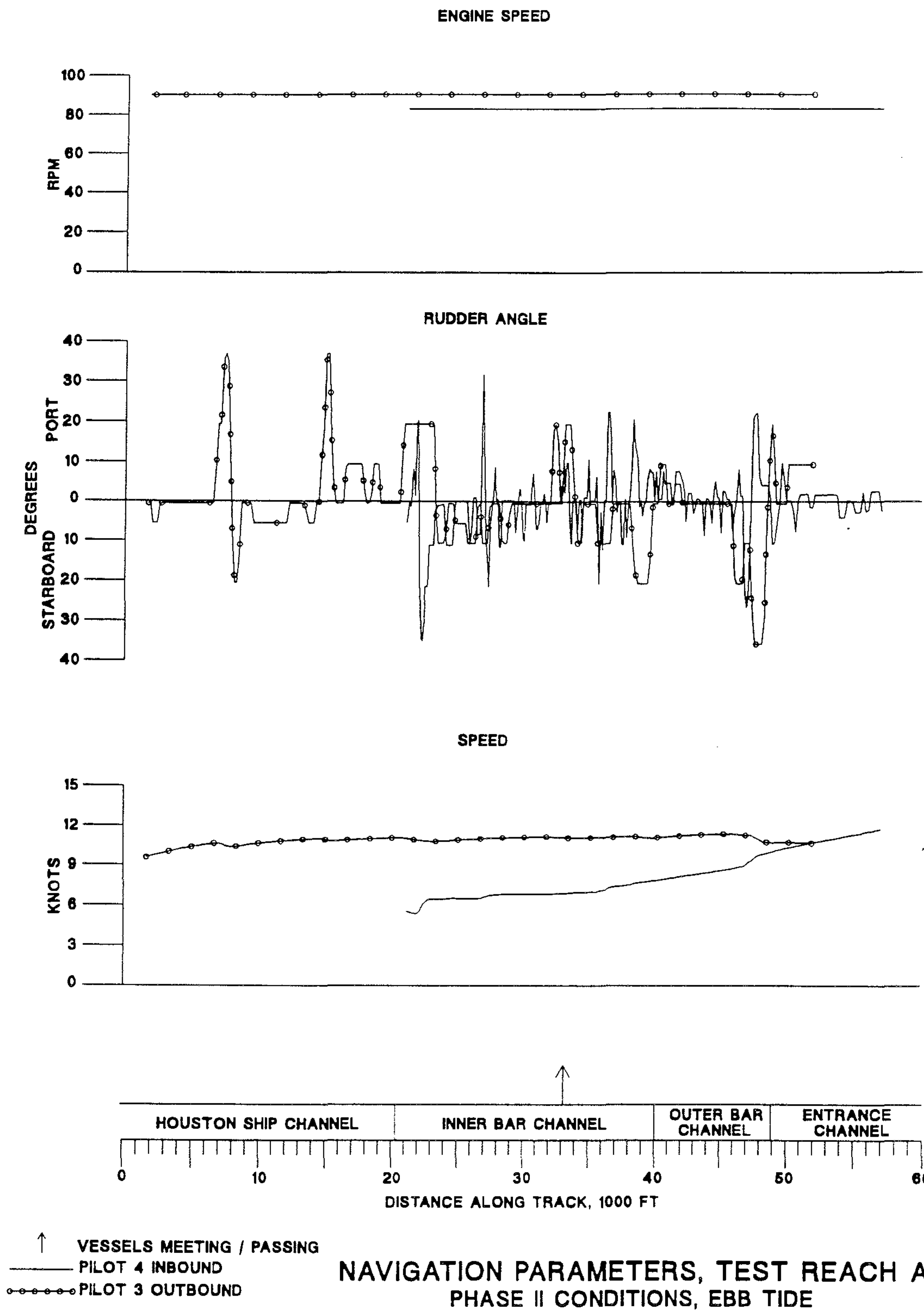
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



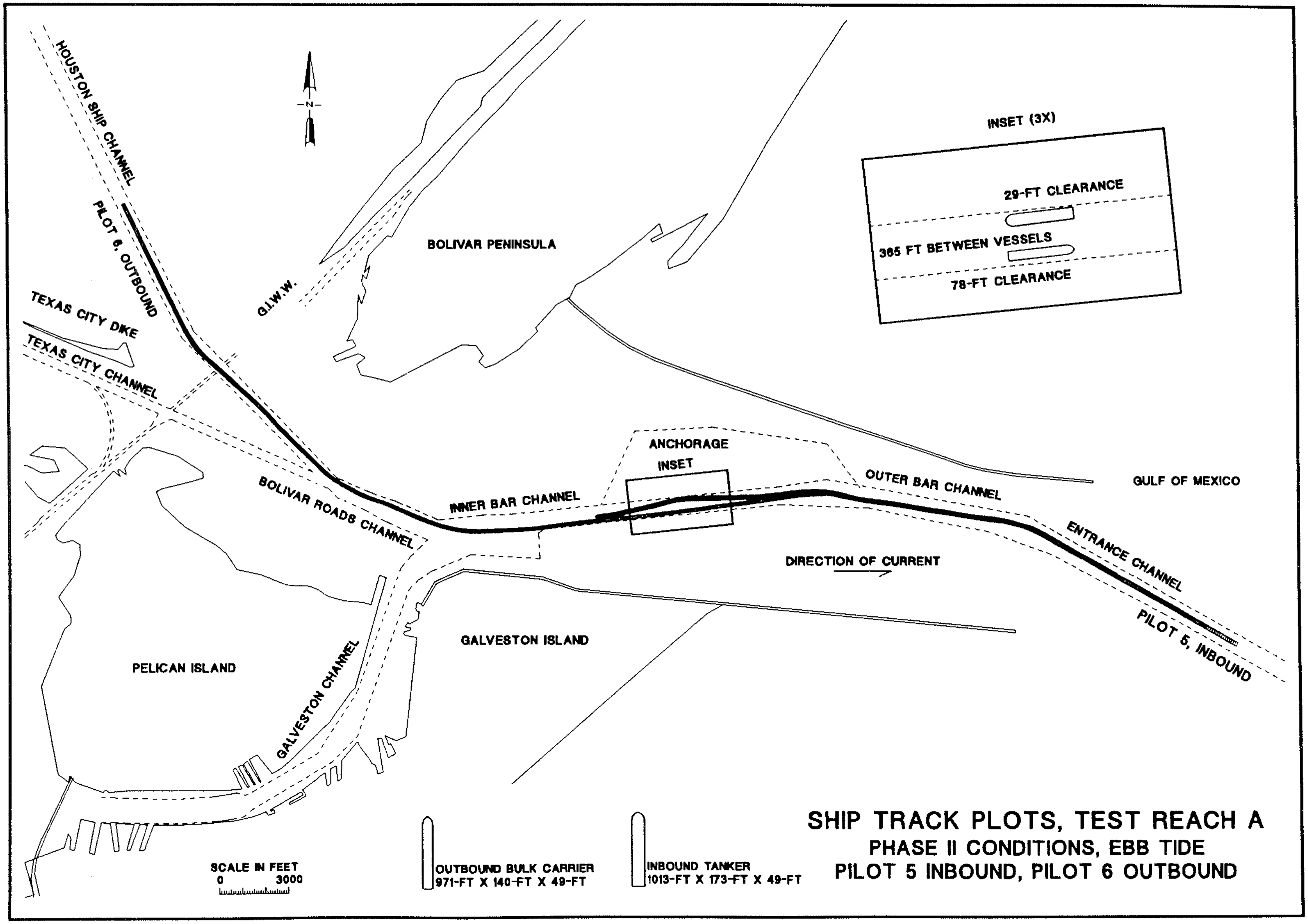
SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



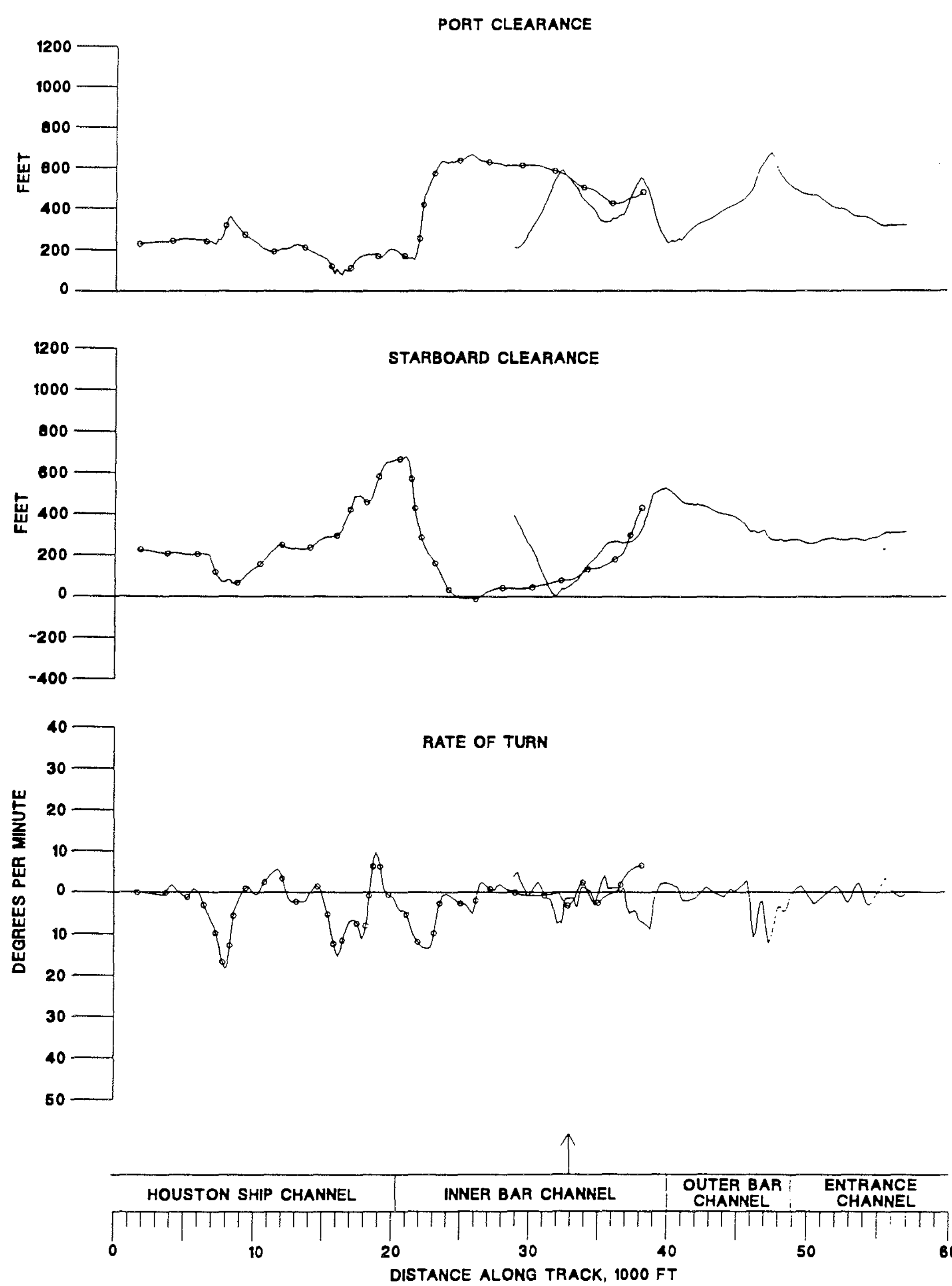
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

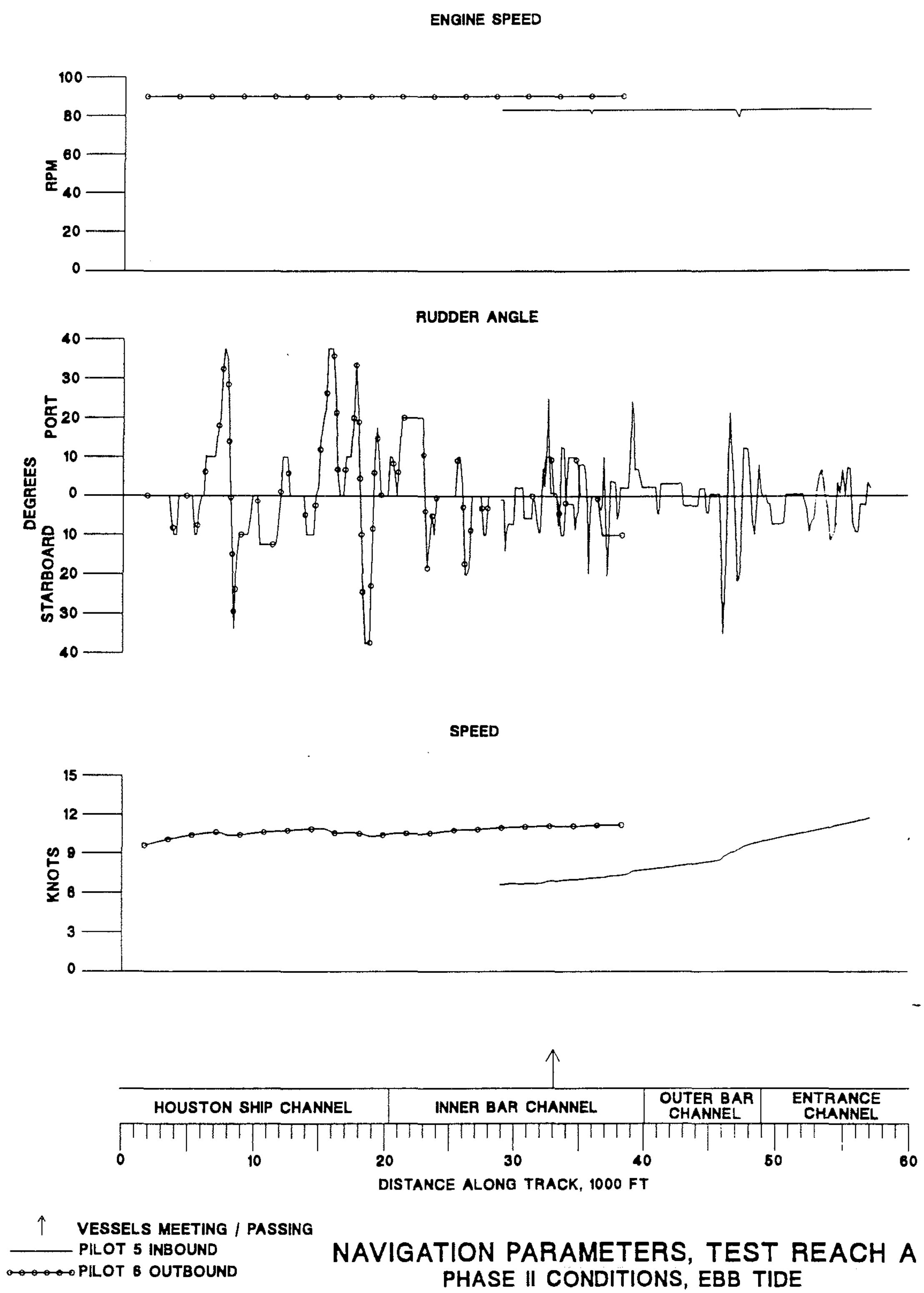


SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

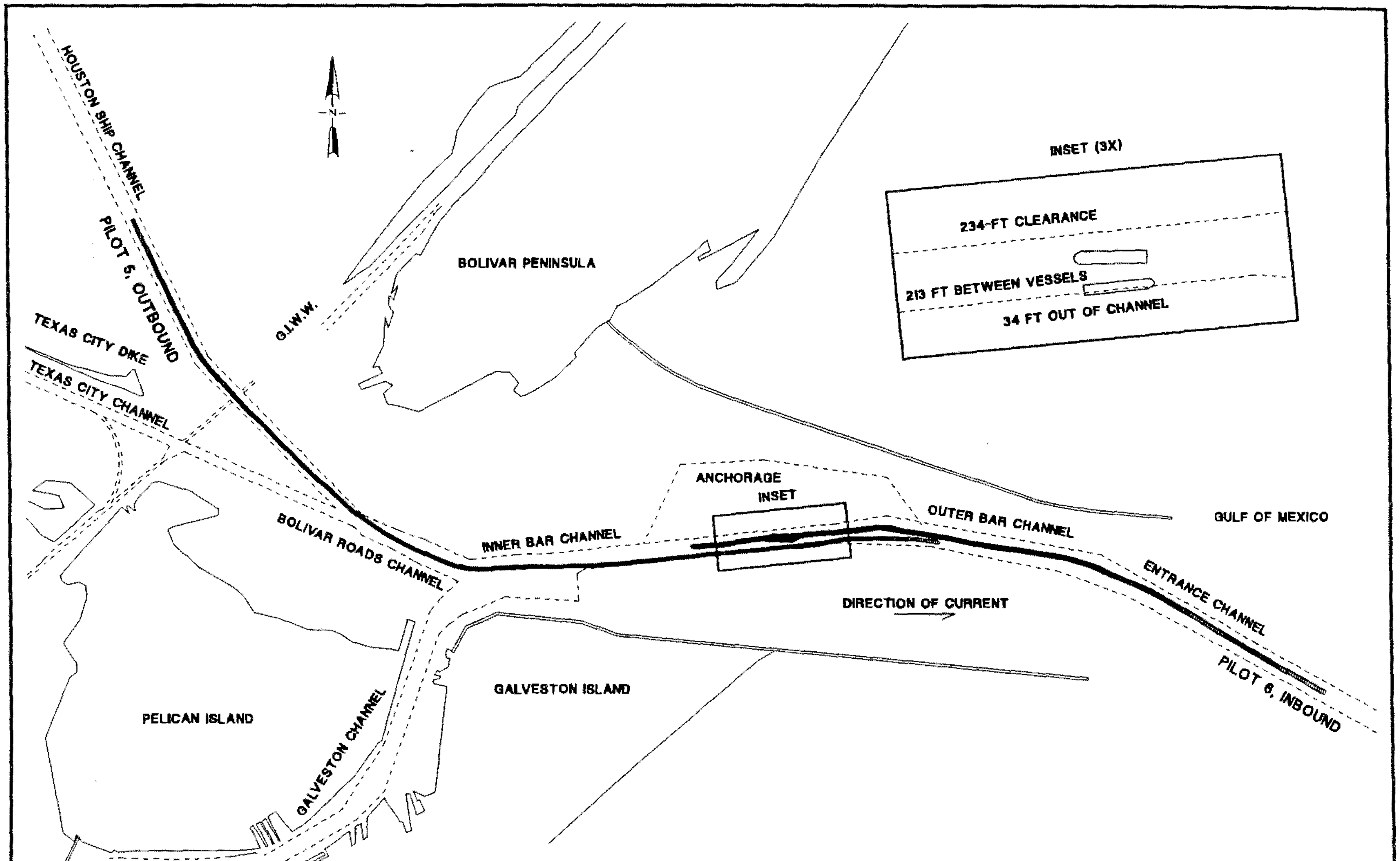


↑ VESSELS MEETING / PASSING
——— PILOT 5 INBOUND
o-o-o-o-o PILOT 6 OUTBOUND

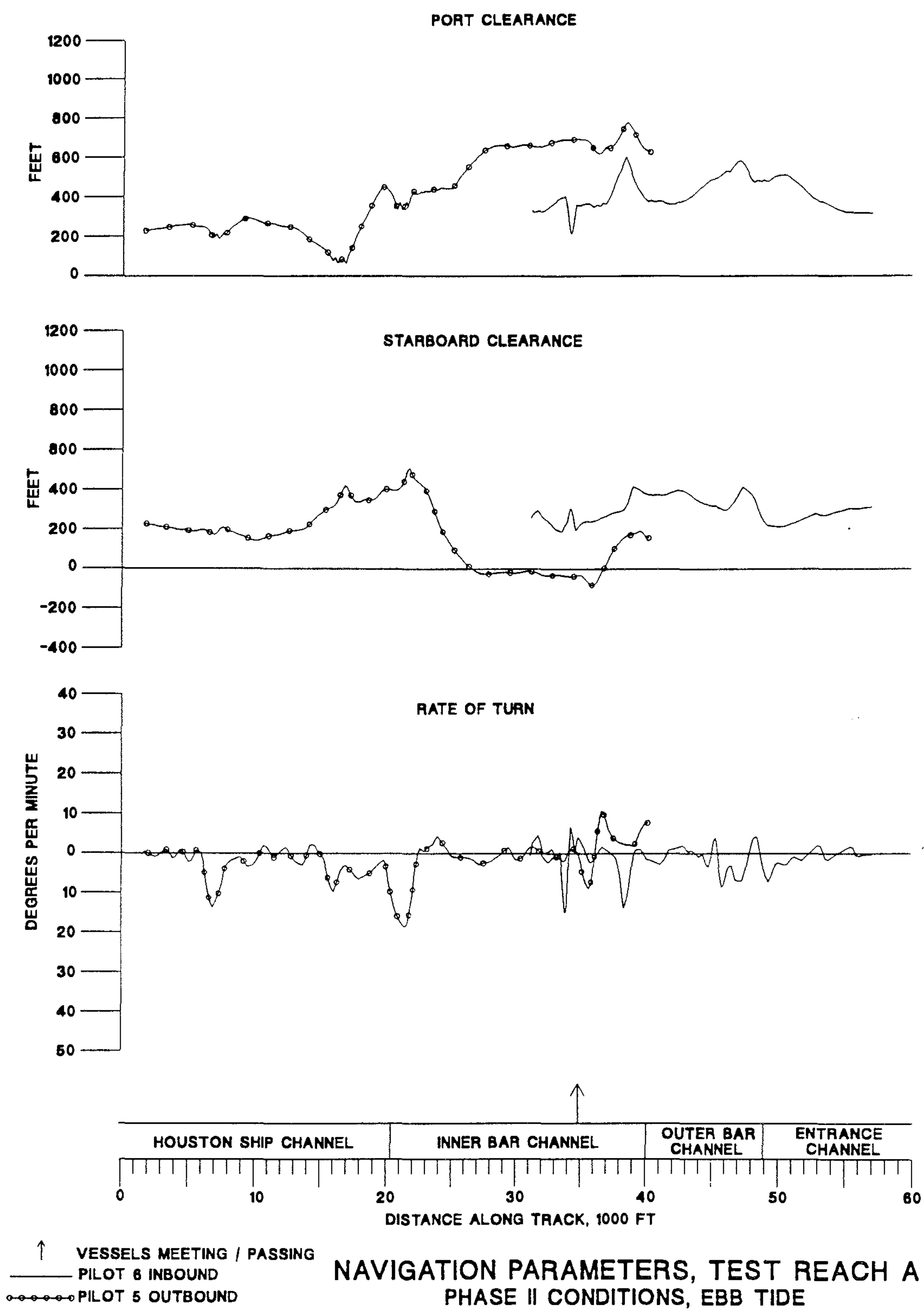
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



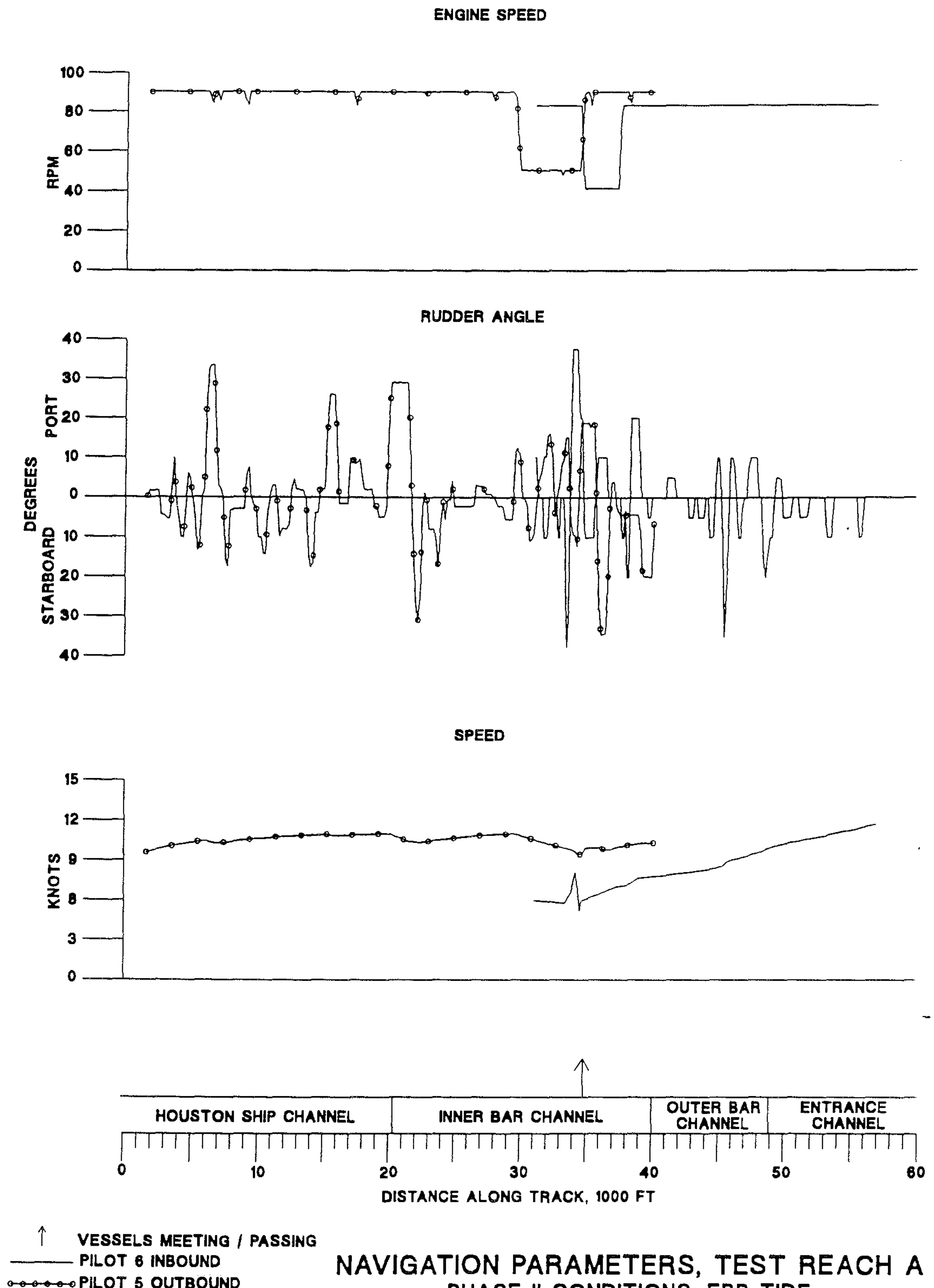
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



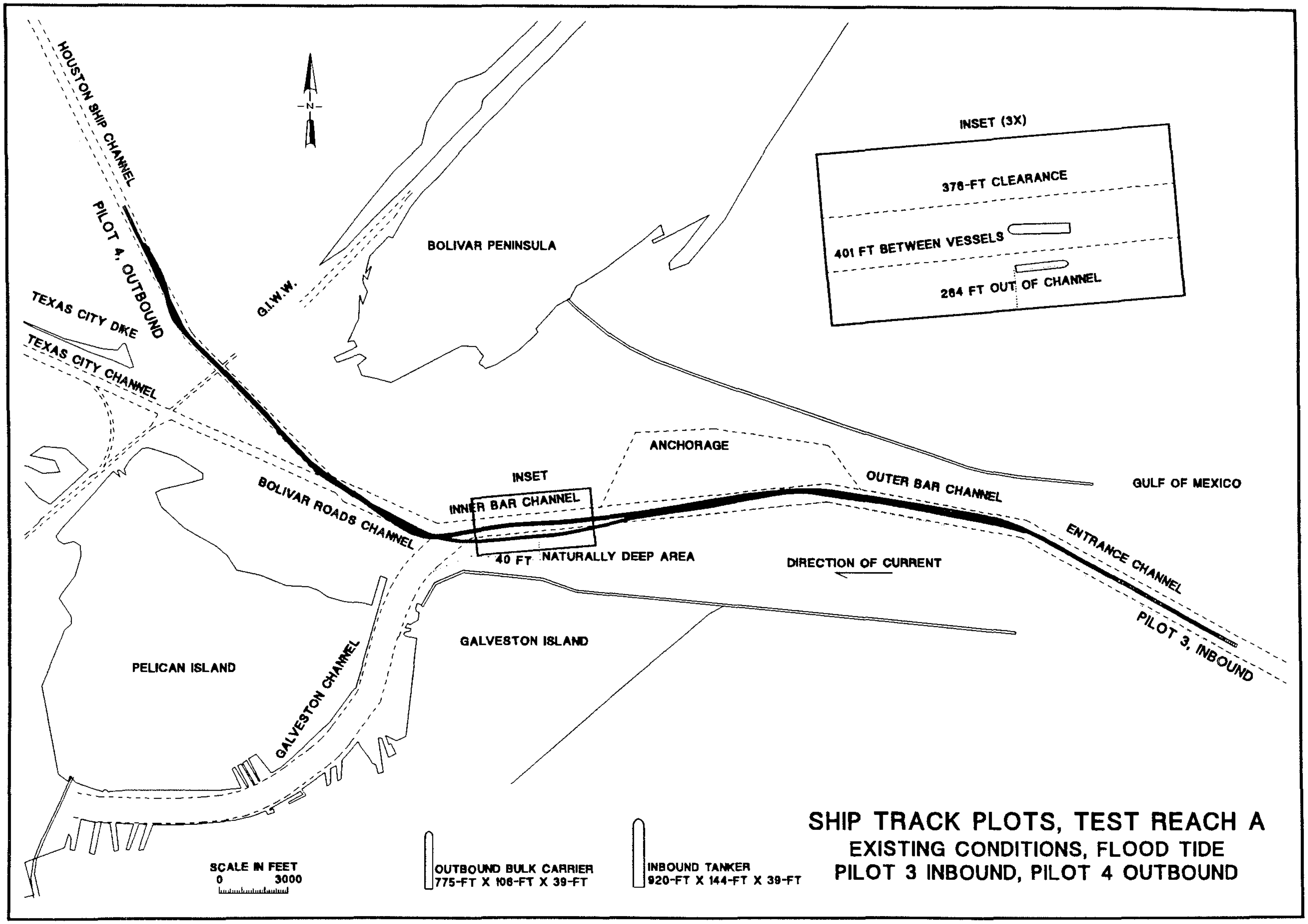
SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



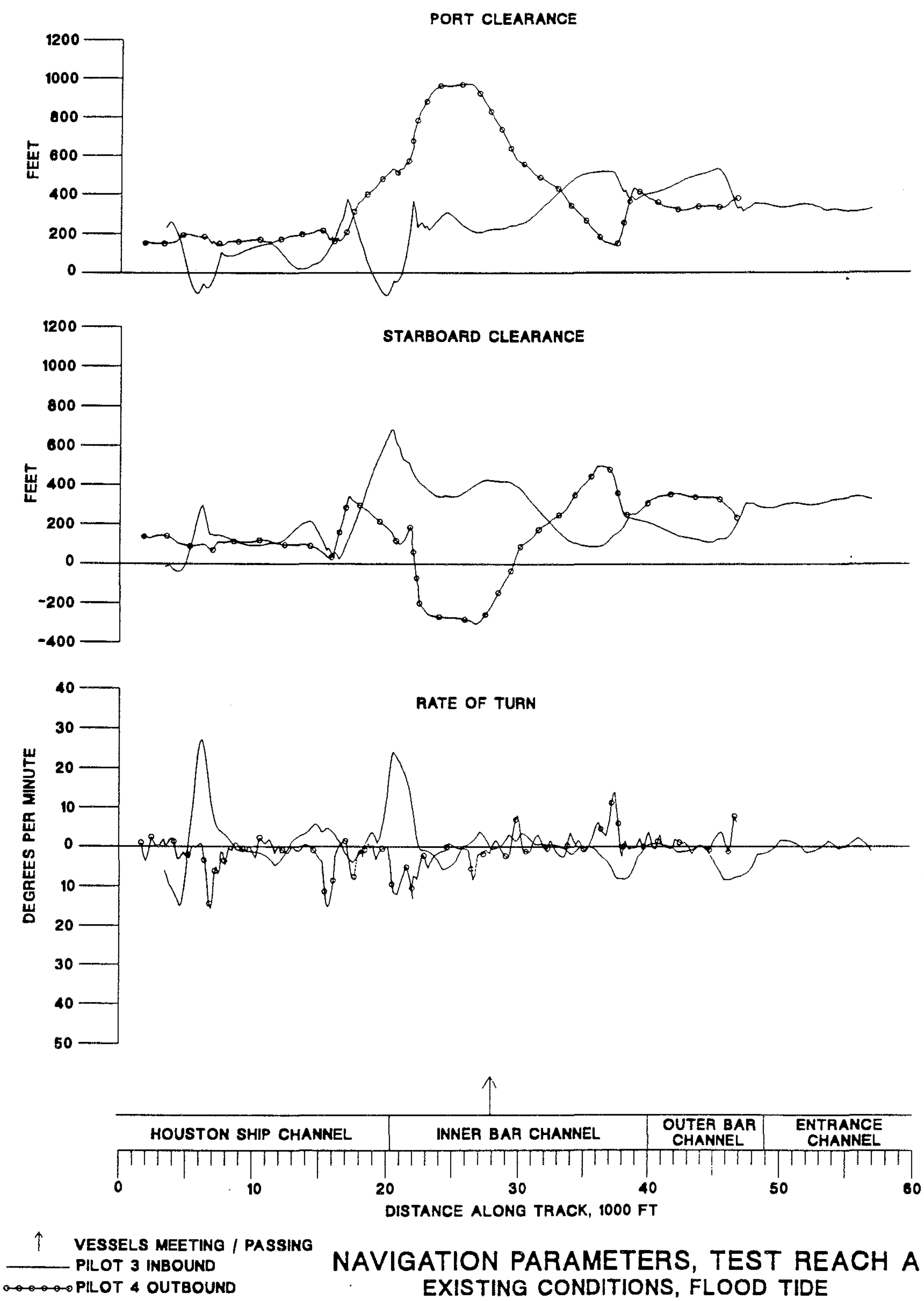
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



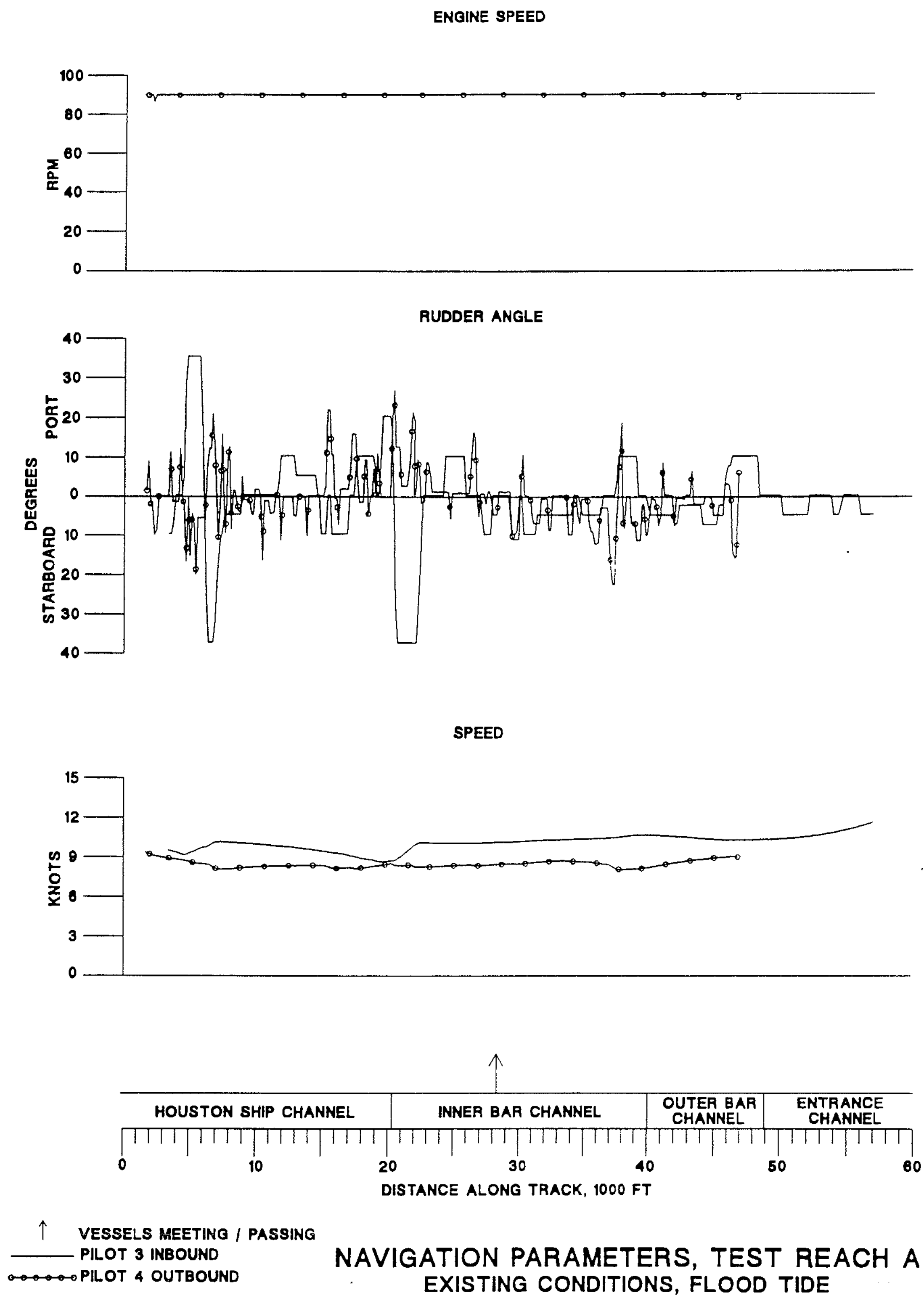
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

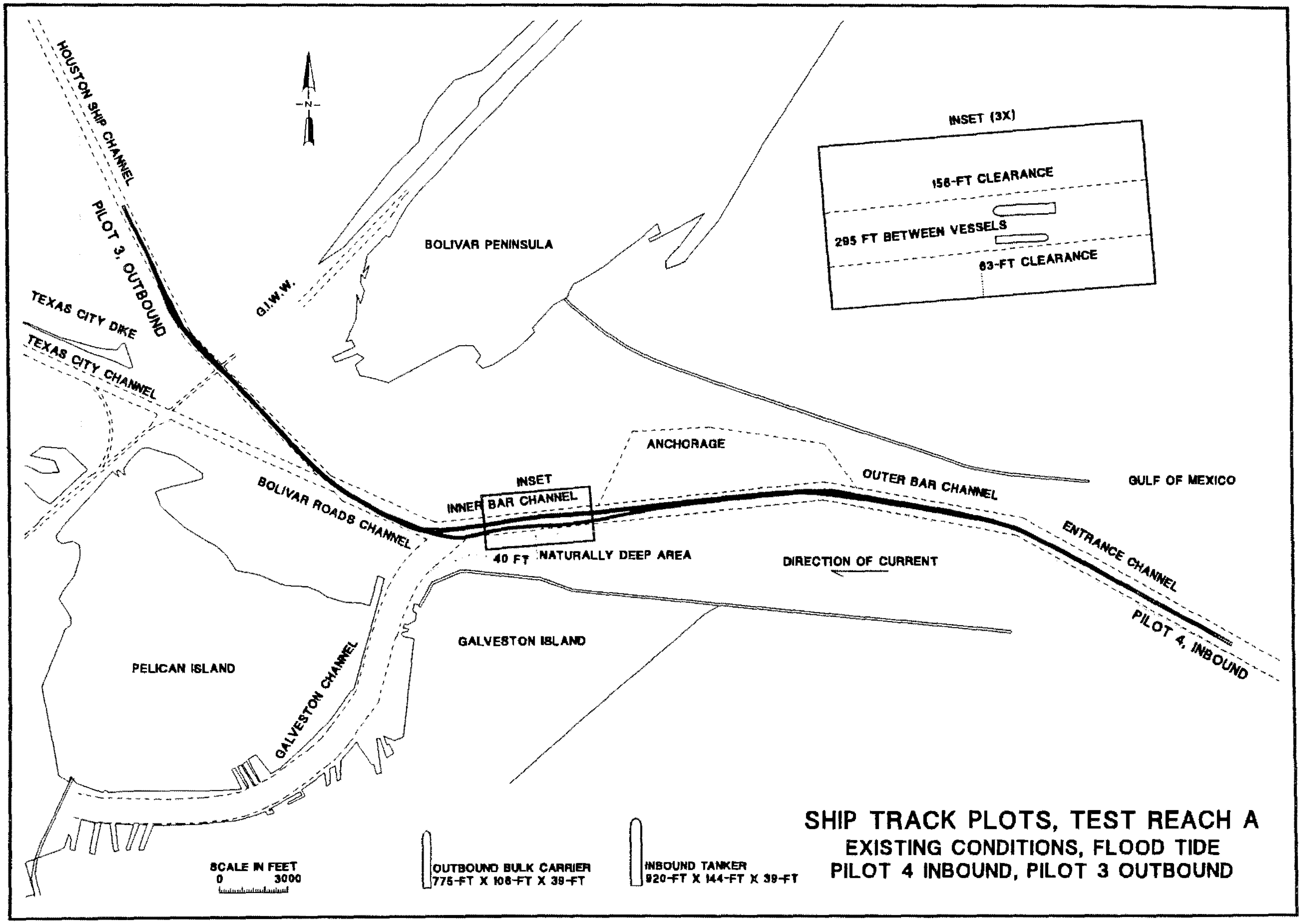


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

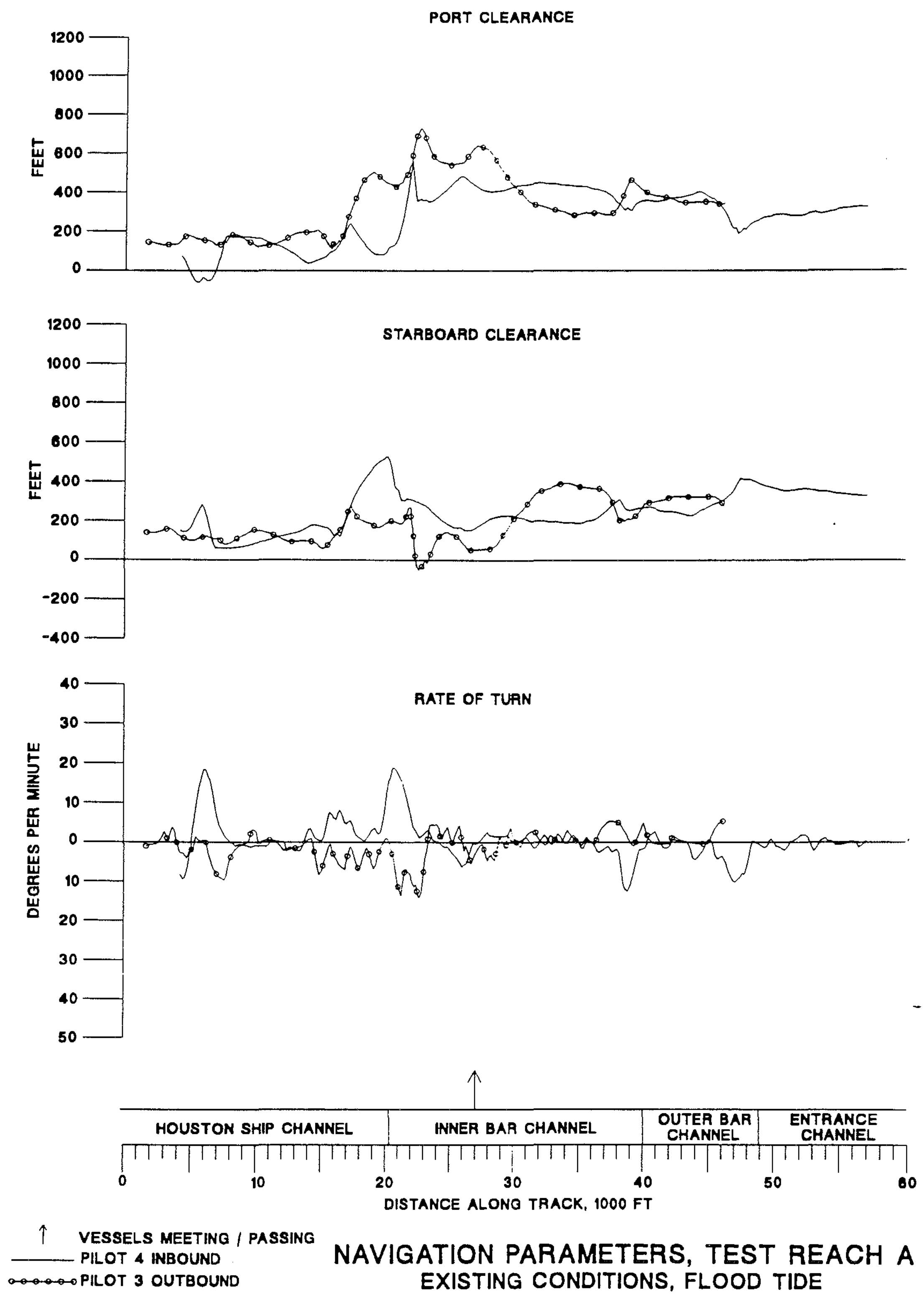


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

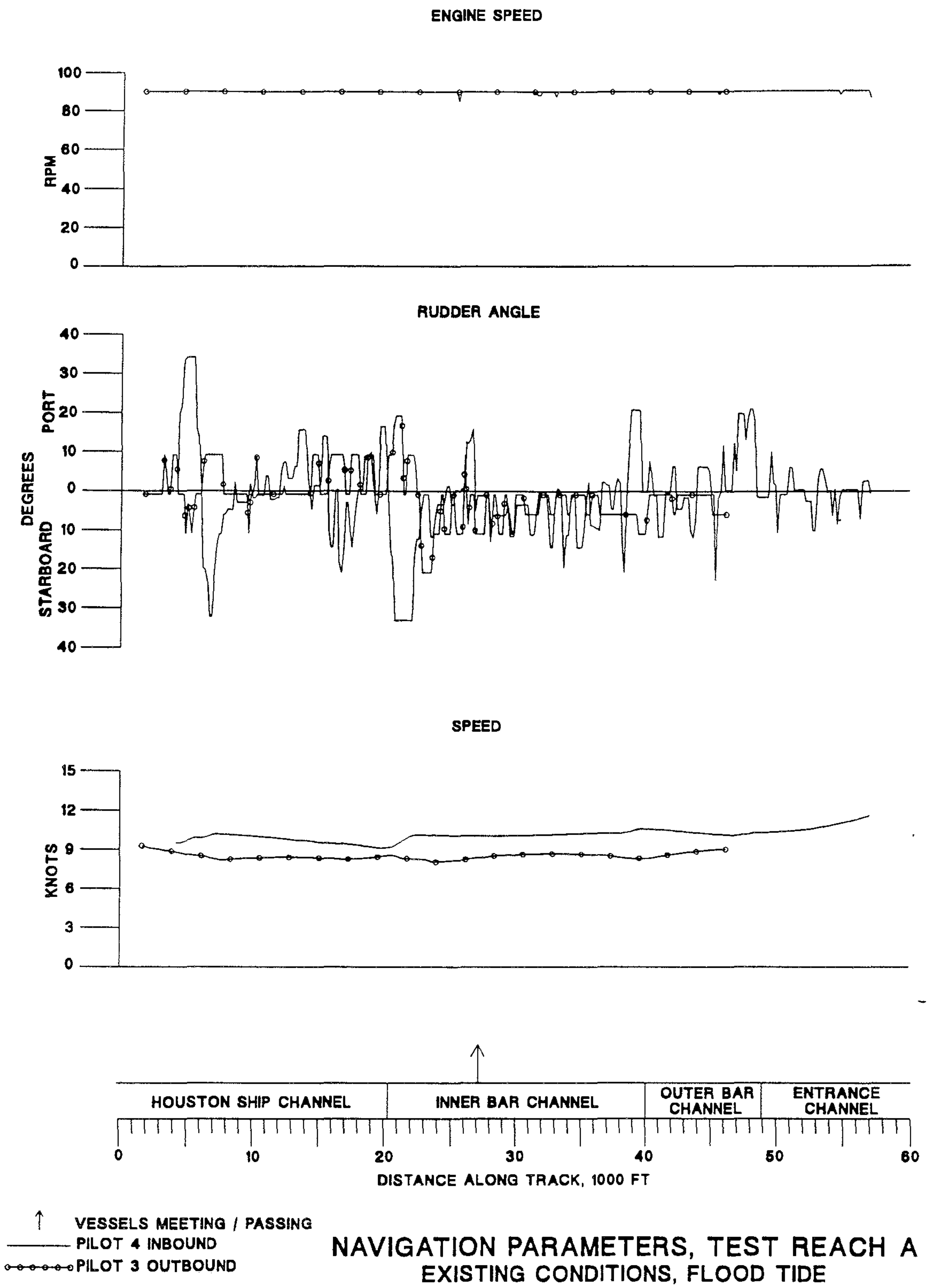
Plate 38



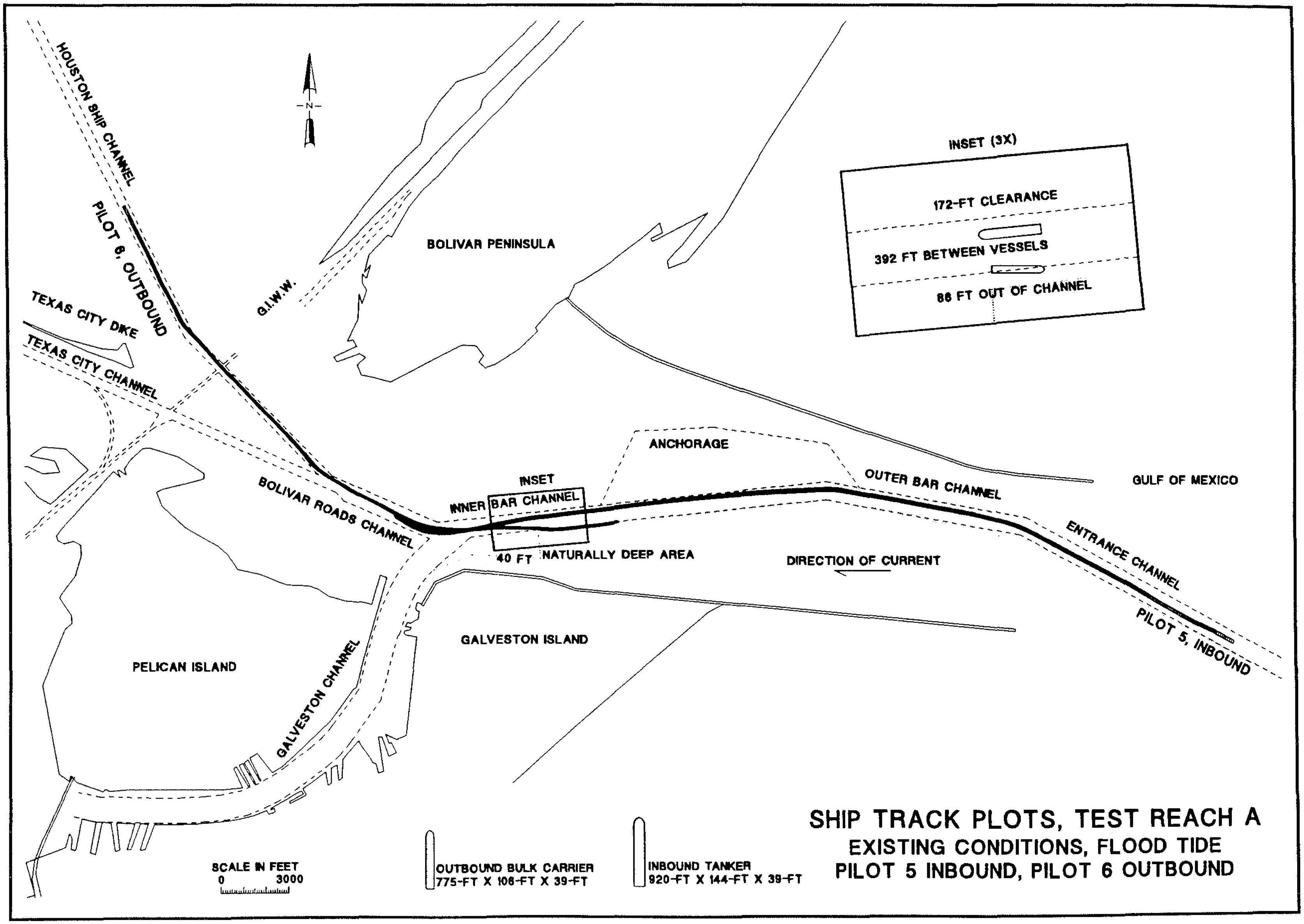
SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

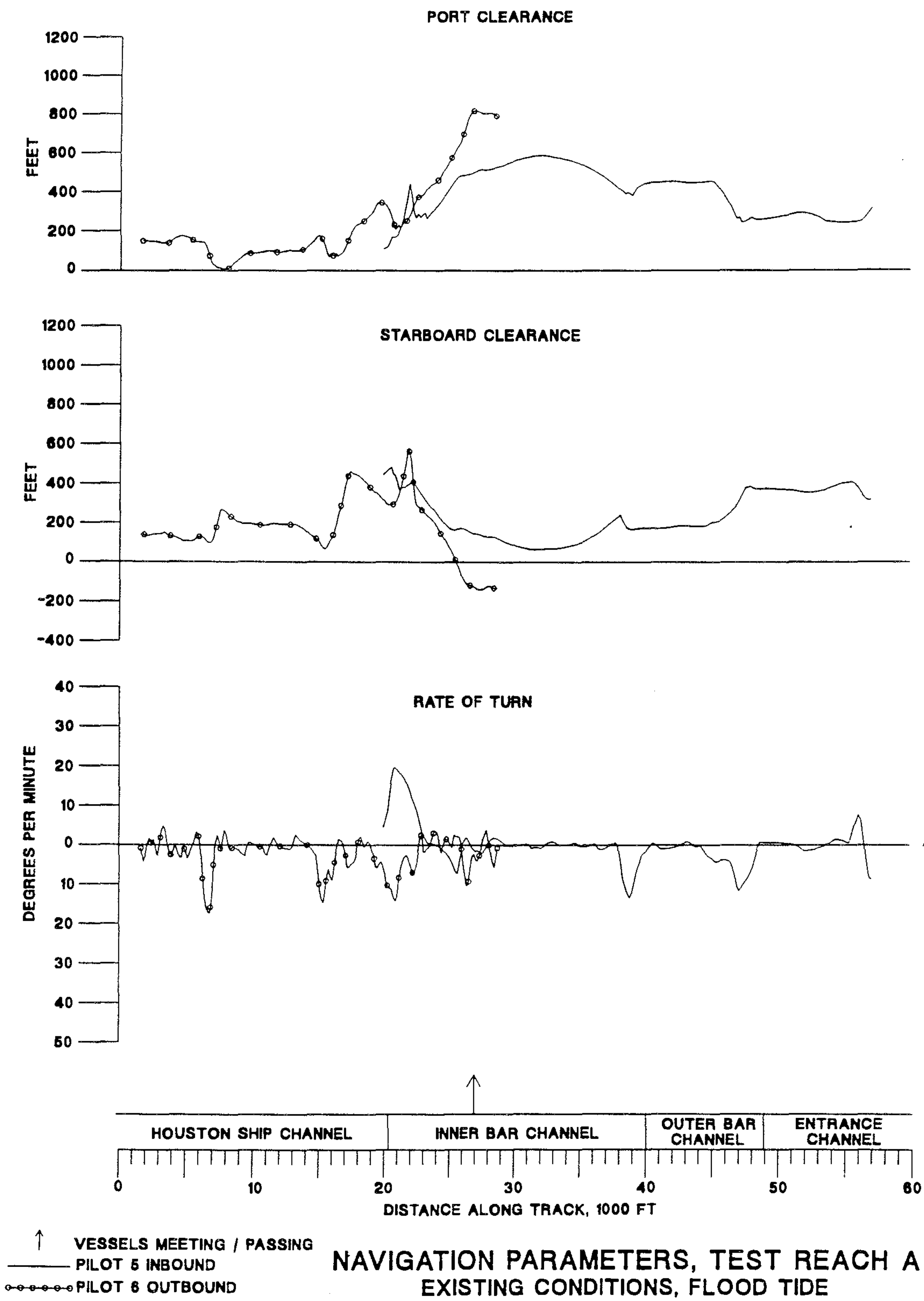


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

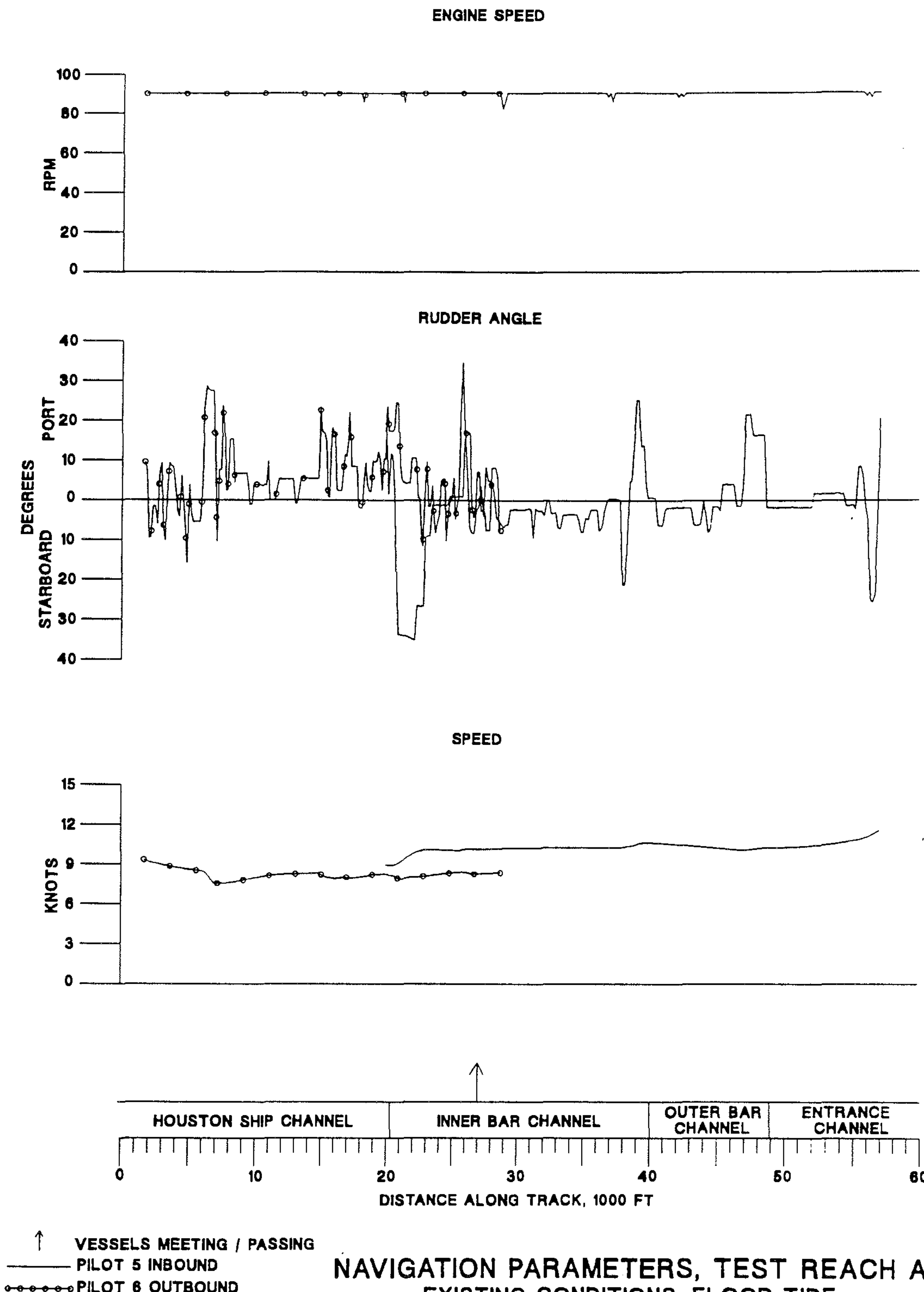


SHIP TRACK PLOTS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 41

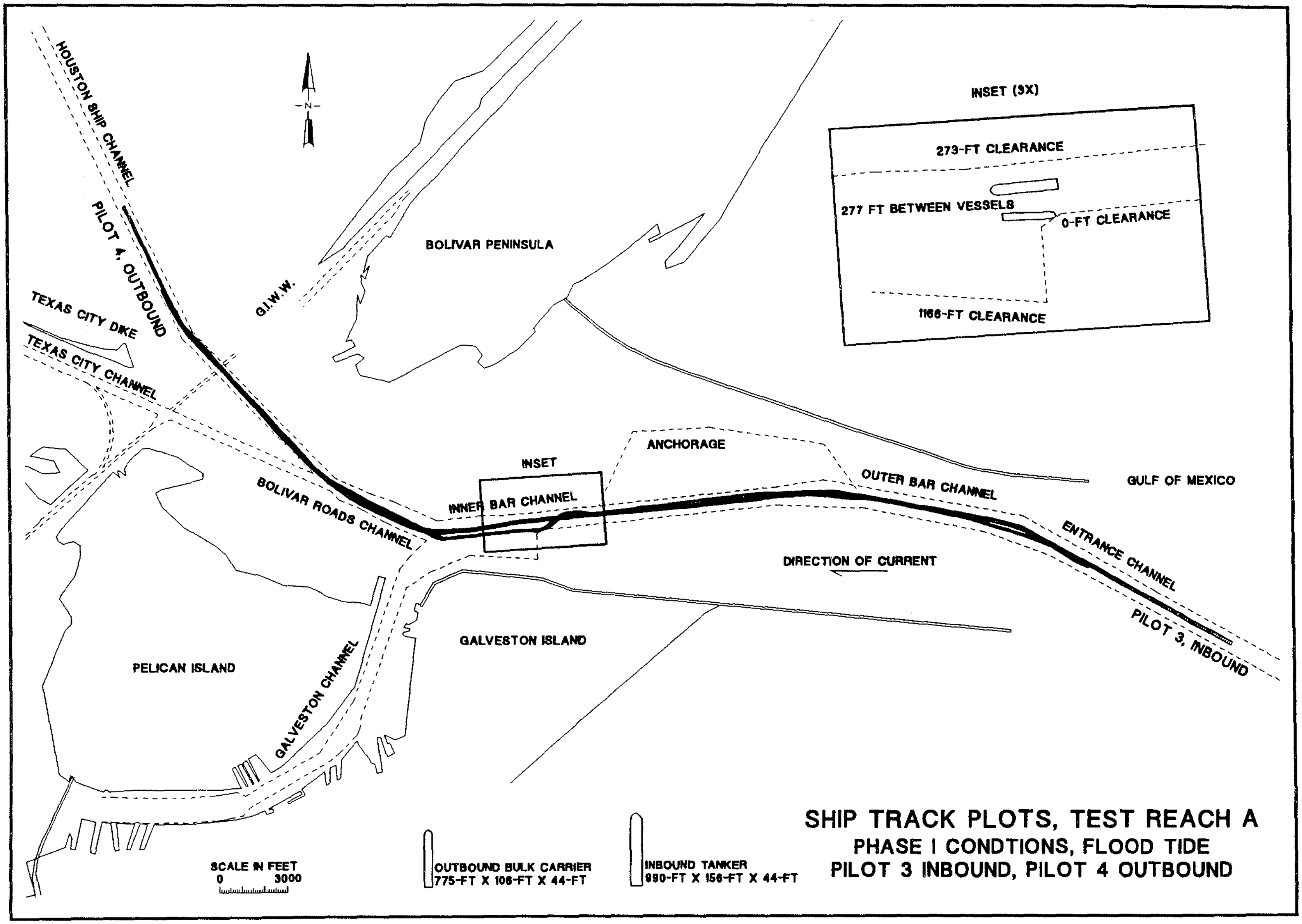


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

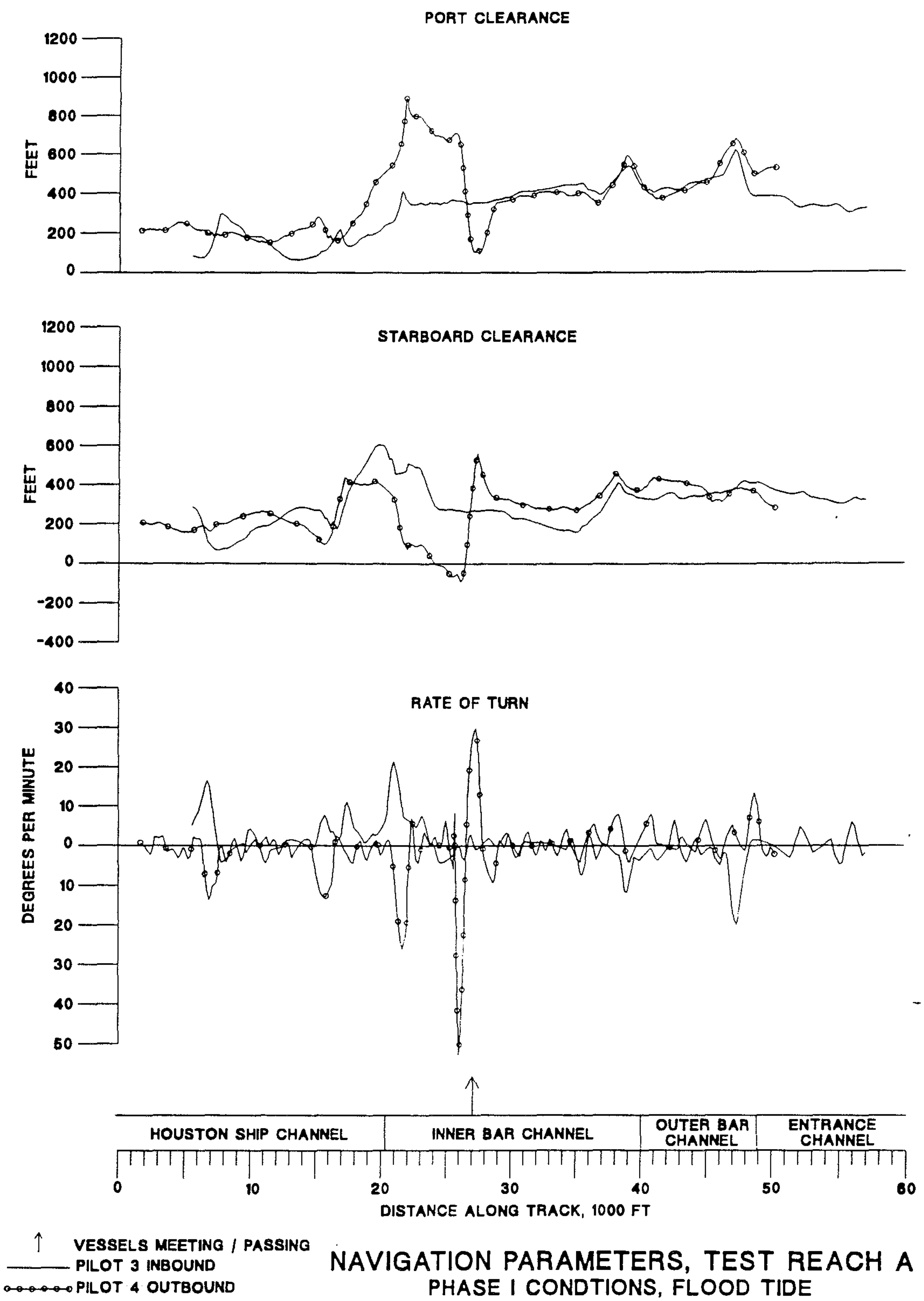


NAVIGATION PARAMETERS, TEST REACH A
EXISTING CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

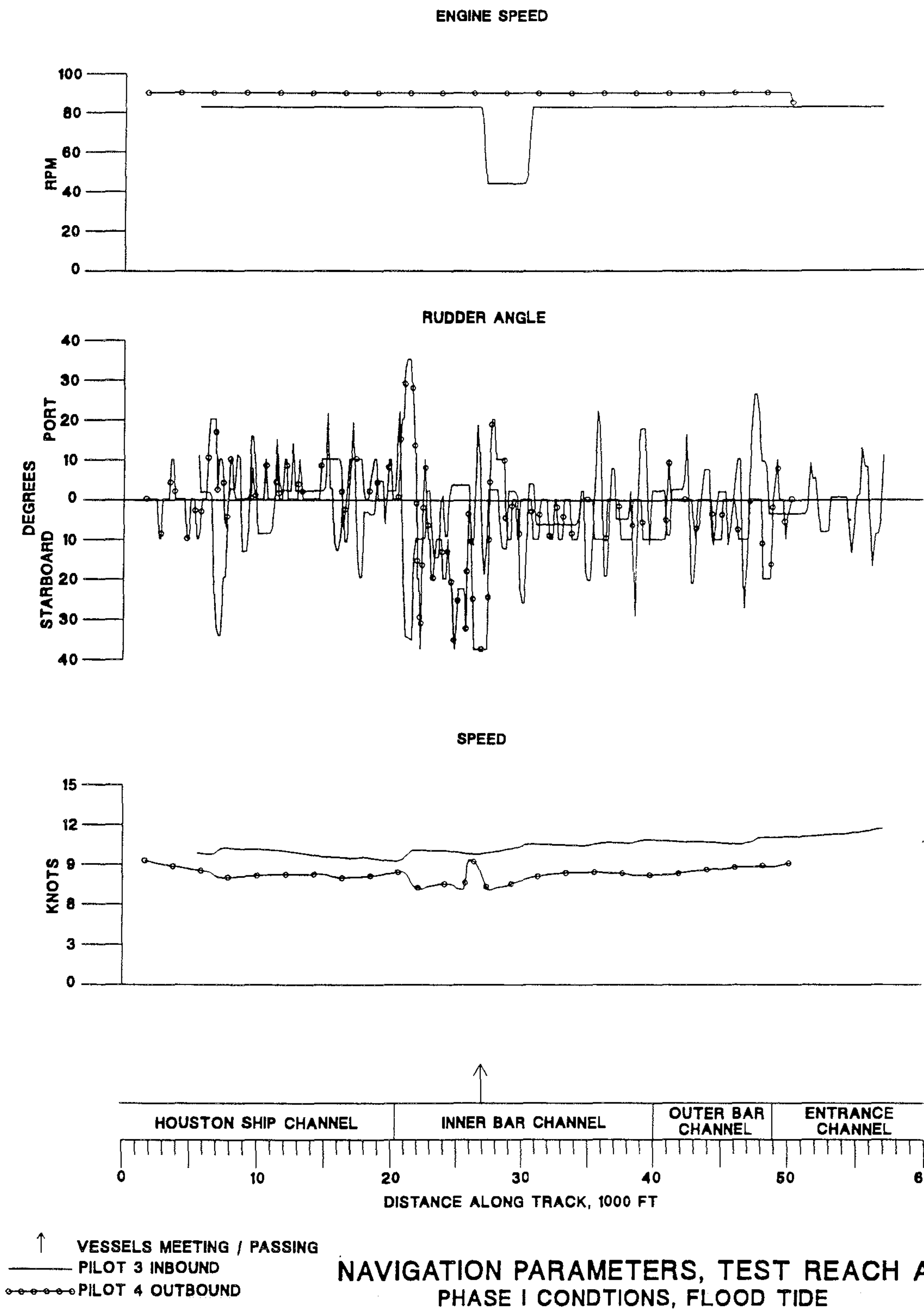
Plate 44



SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



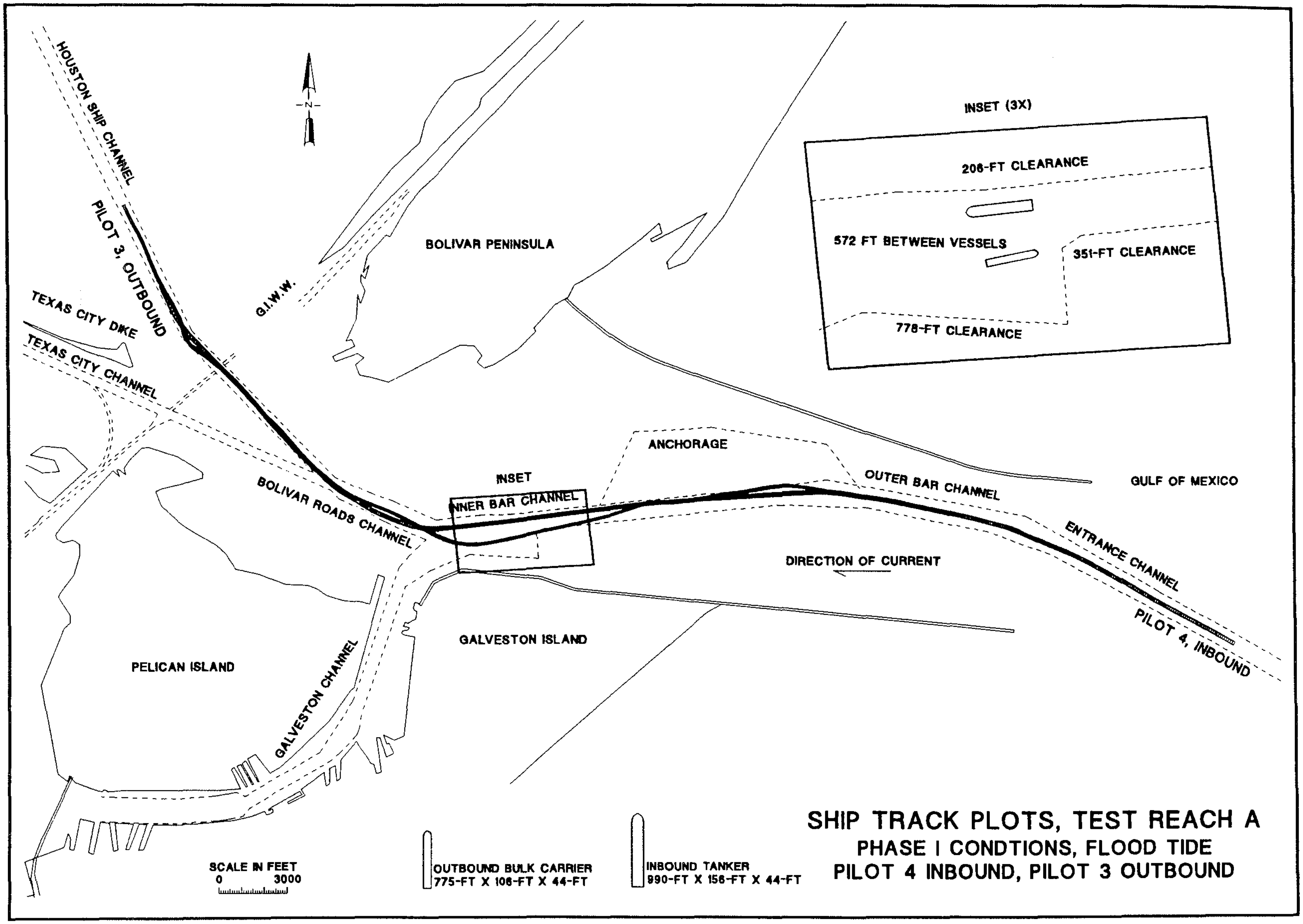
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A

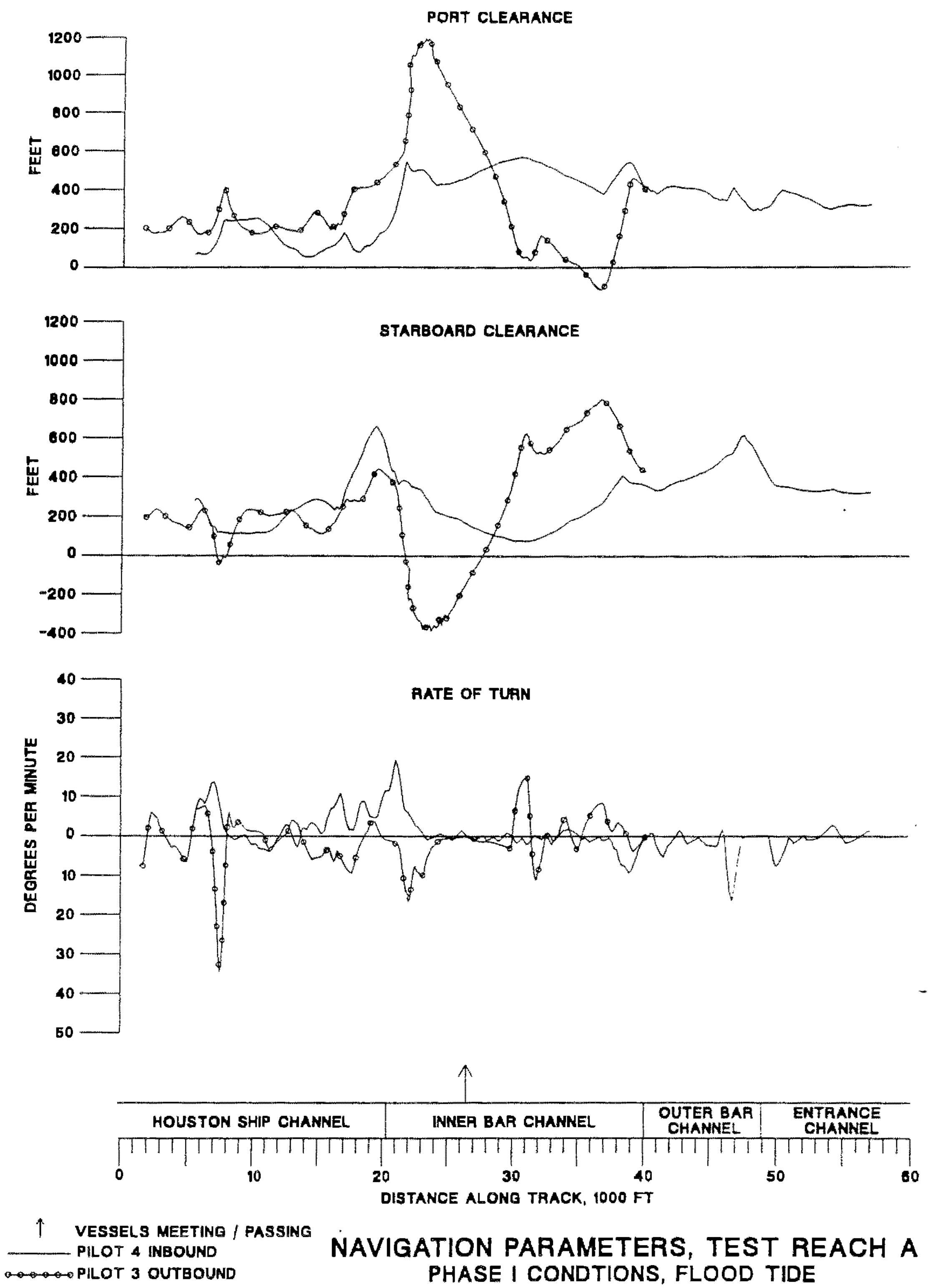
PHASE I CONDTIONS, FLOOD TIDE

PILOT 3 INBOUND, PILOT 4 OUTBOUND

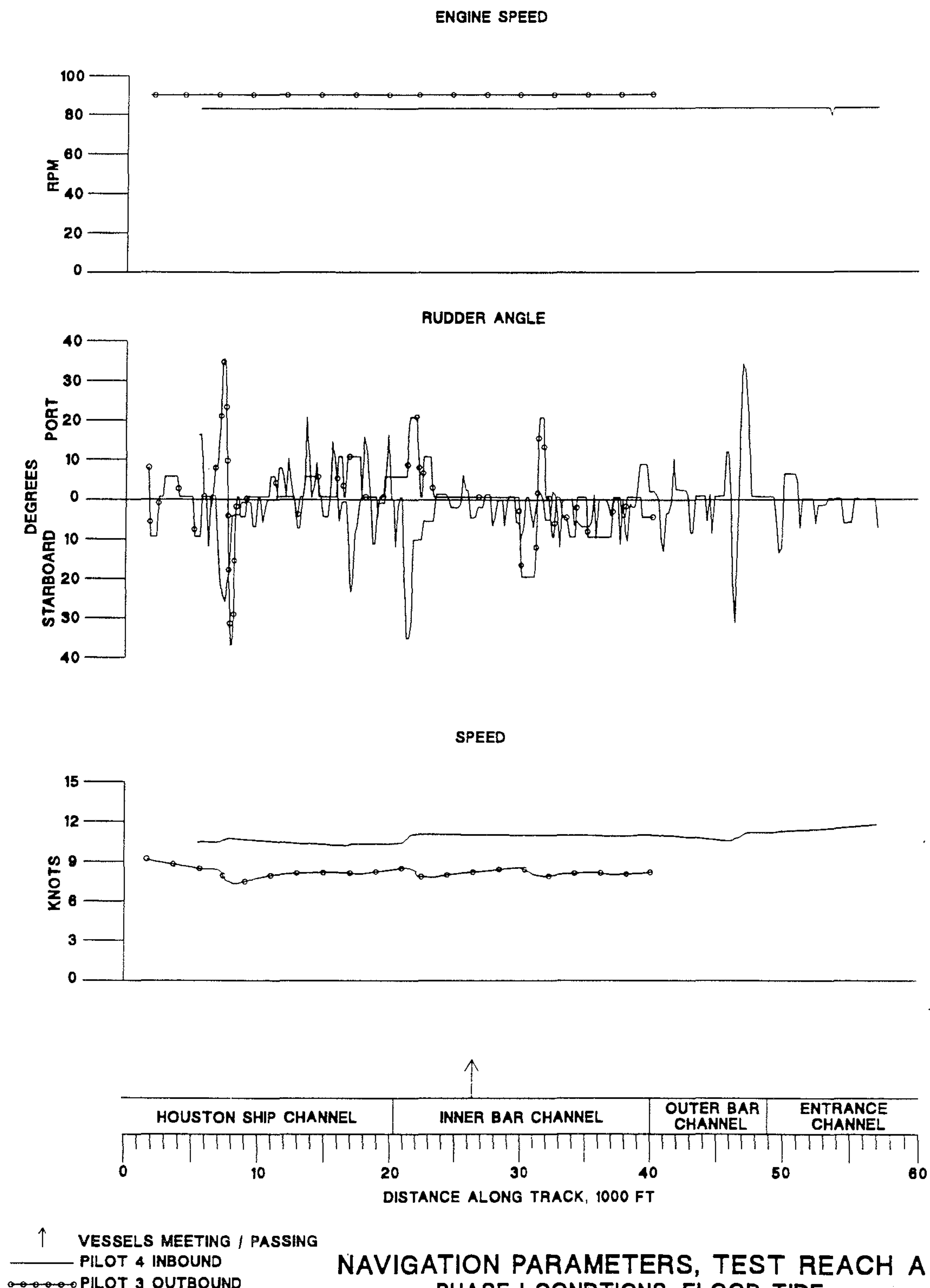


SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

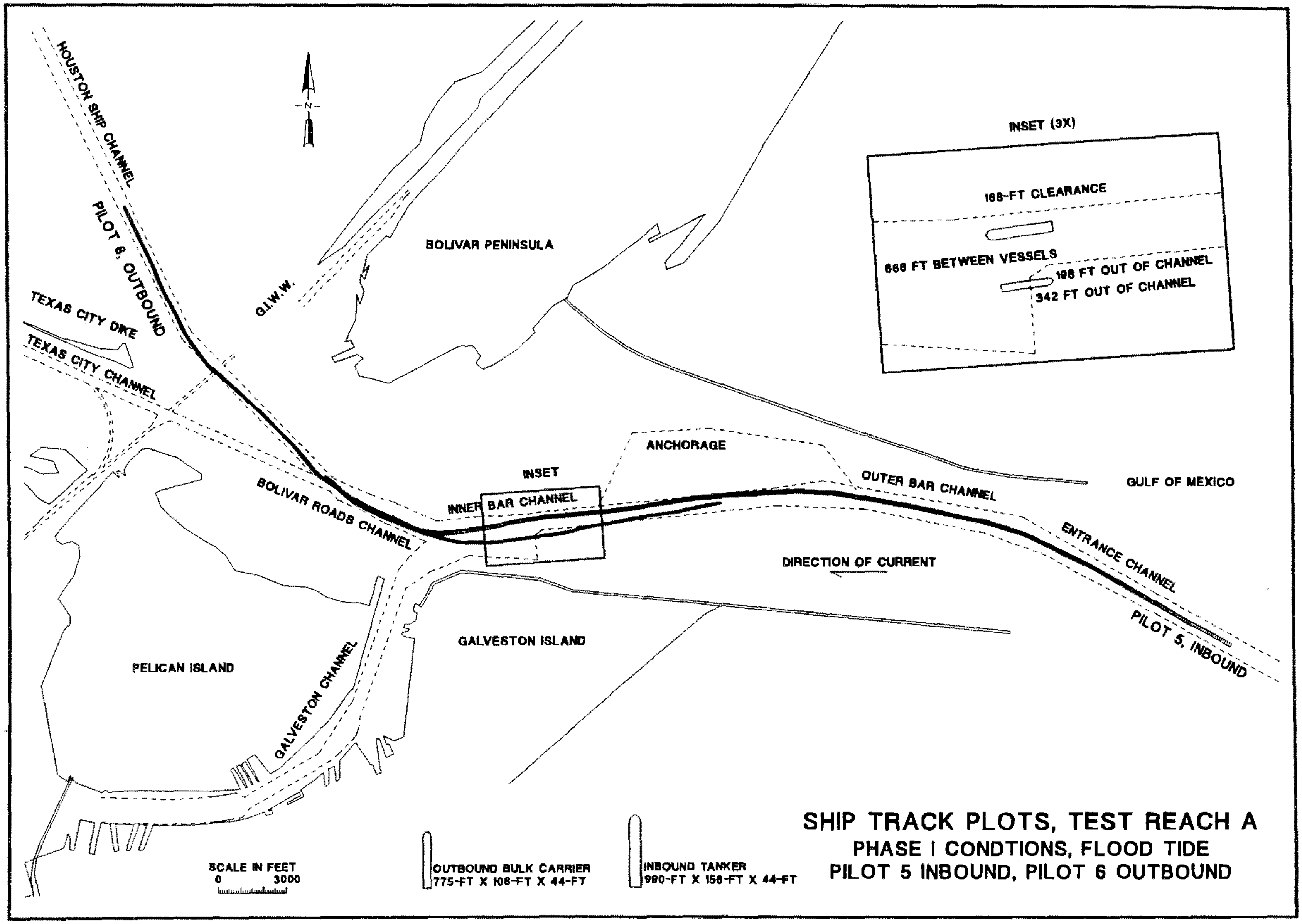
Plate 47



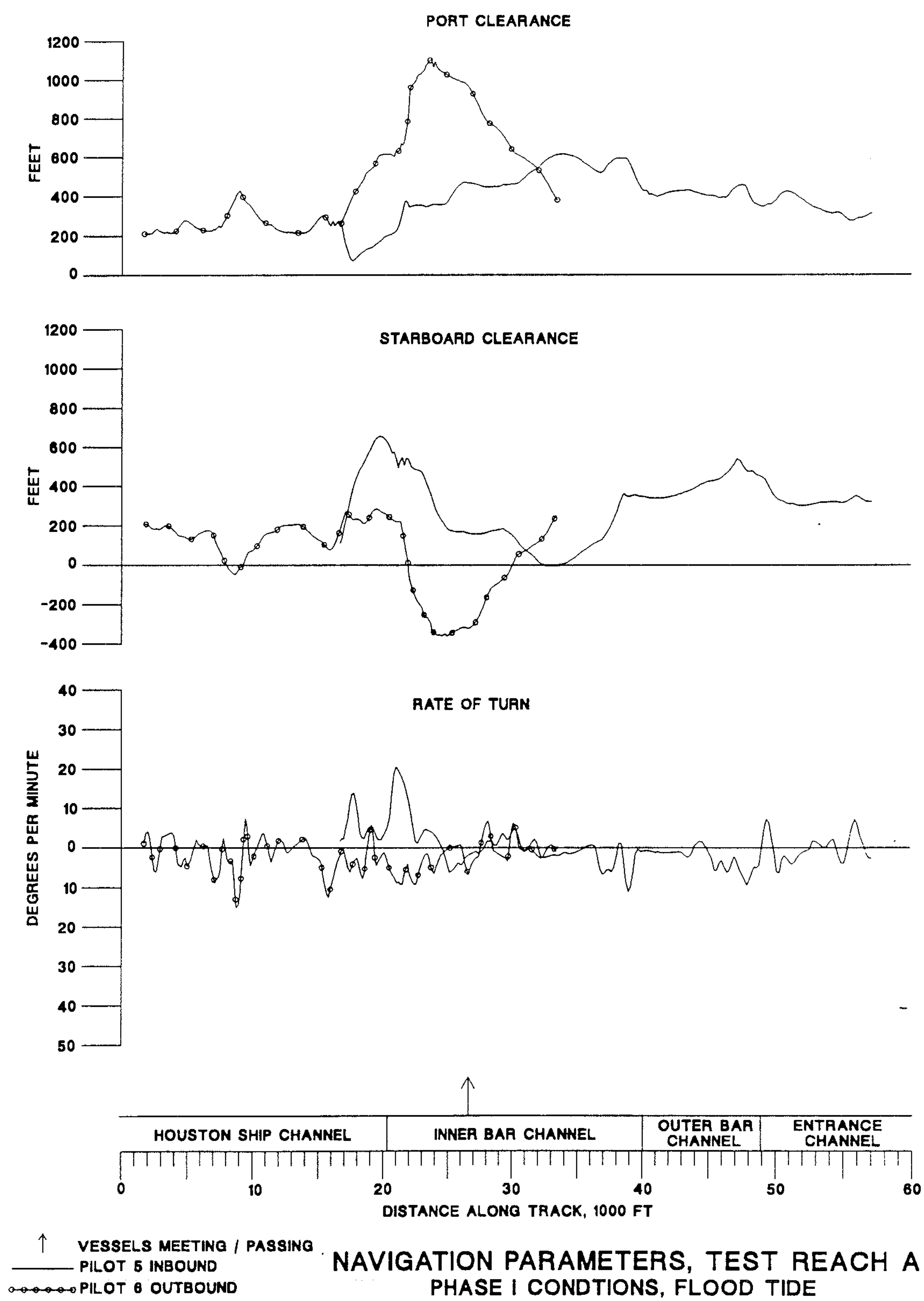
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



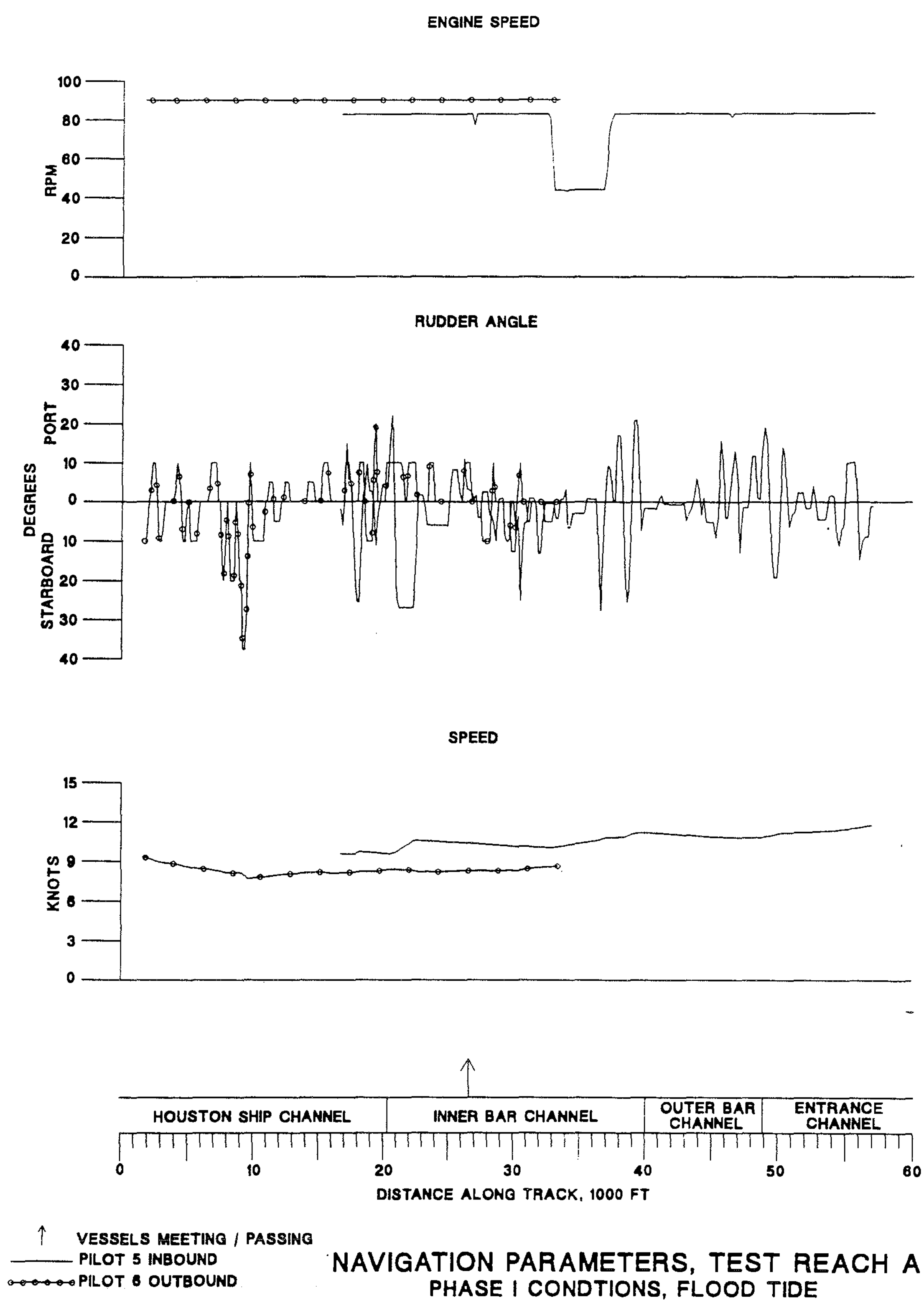
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



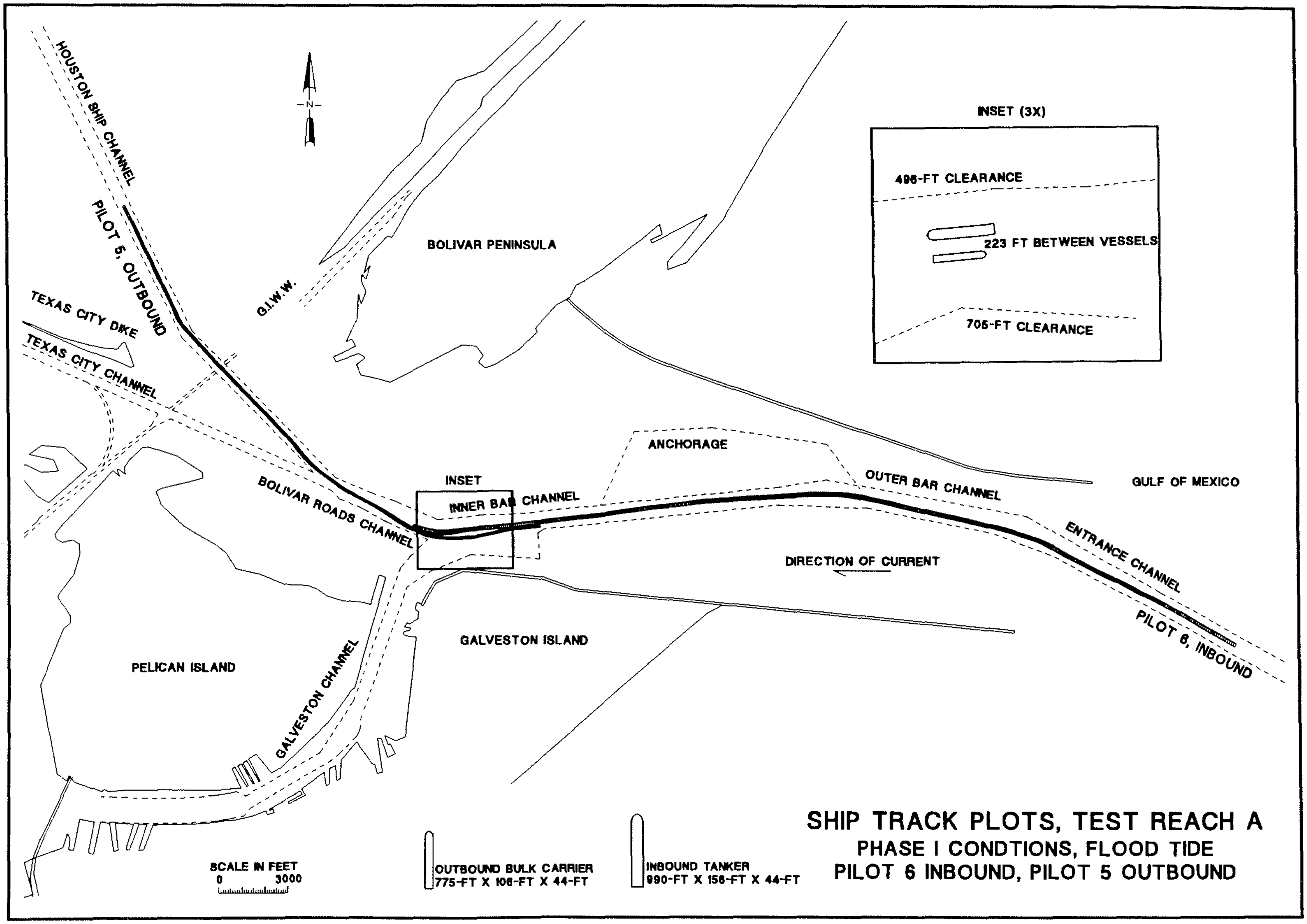
SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



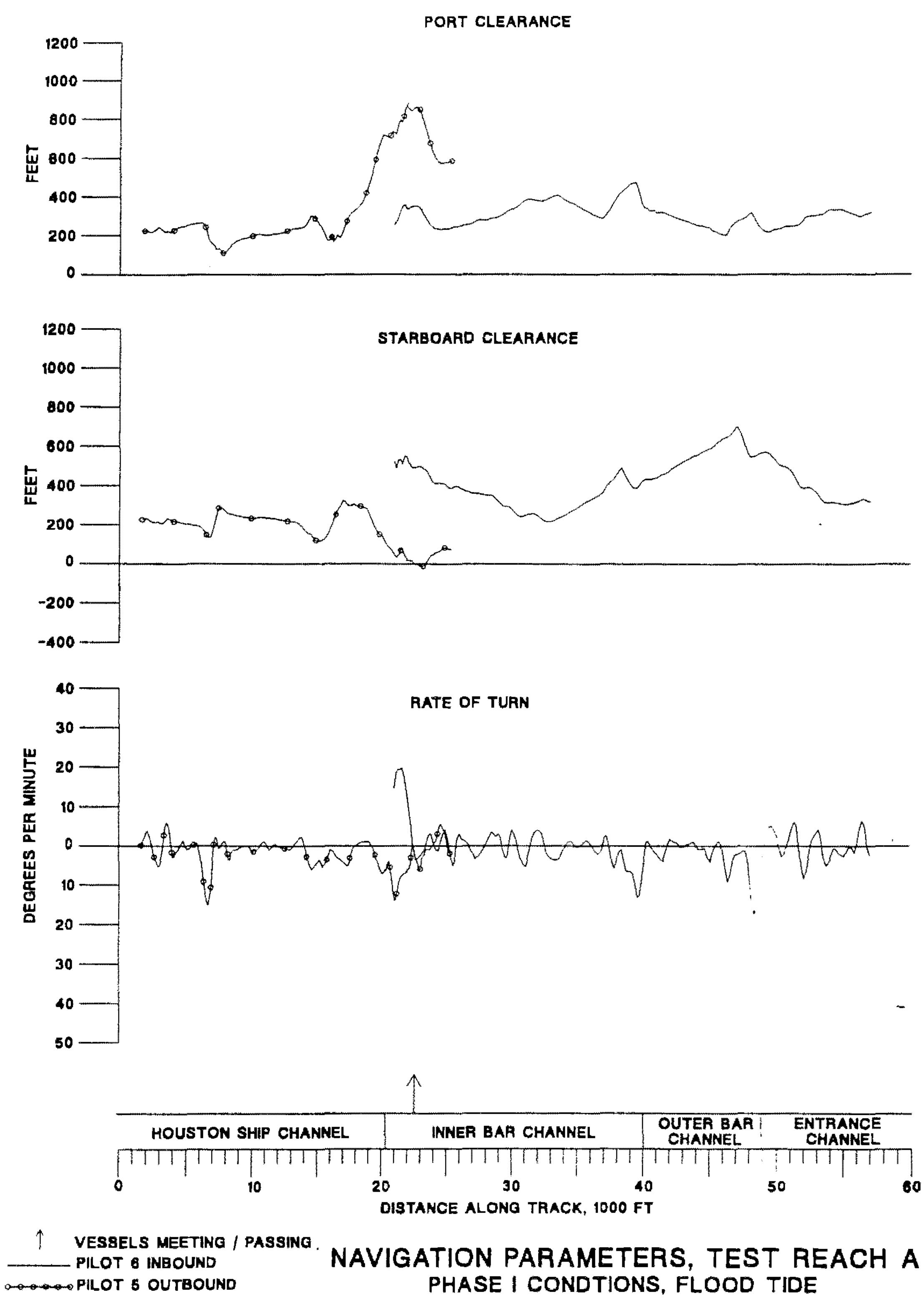
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



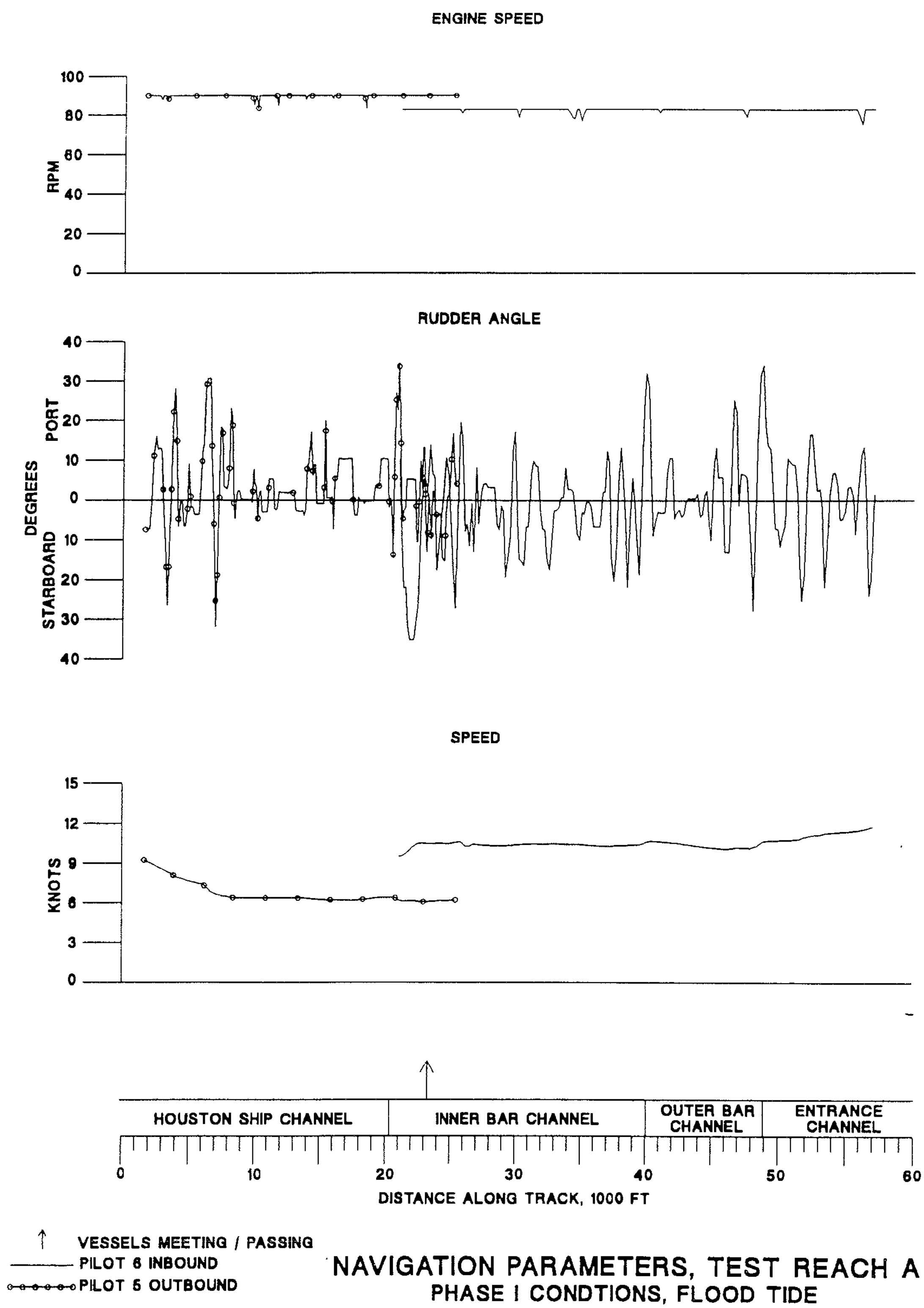
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



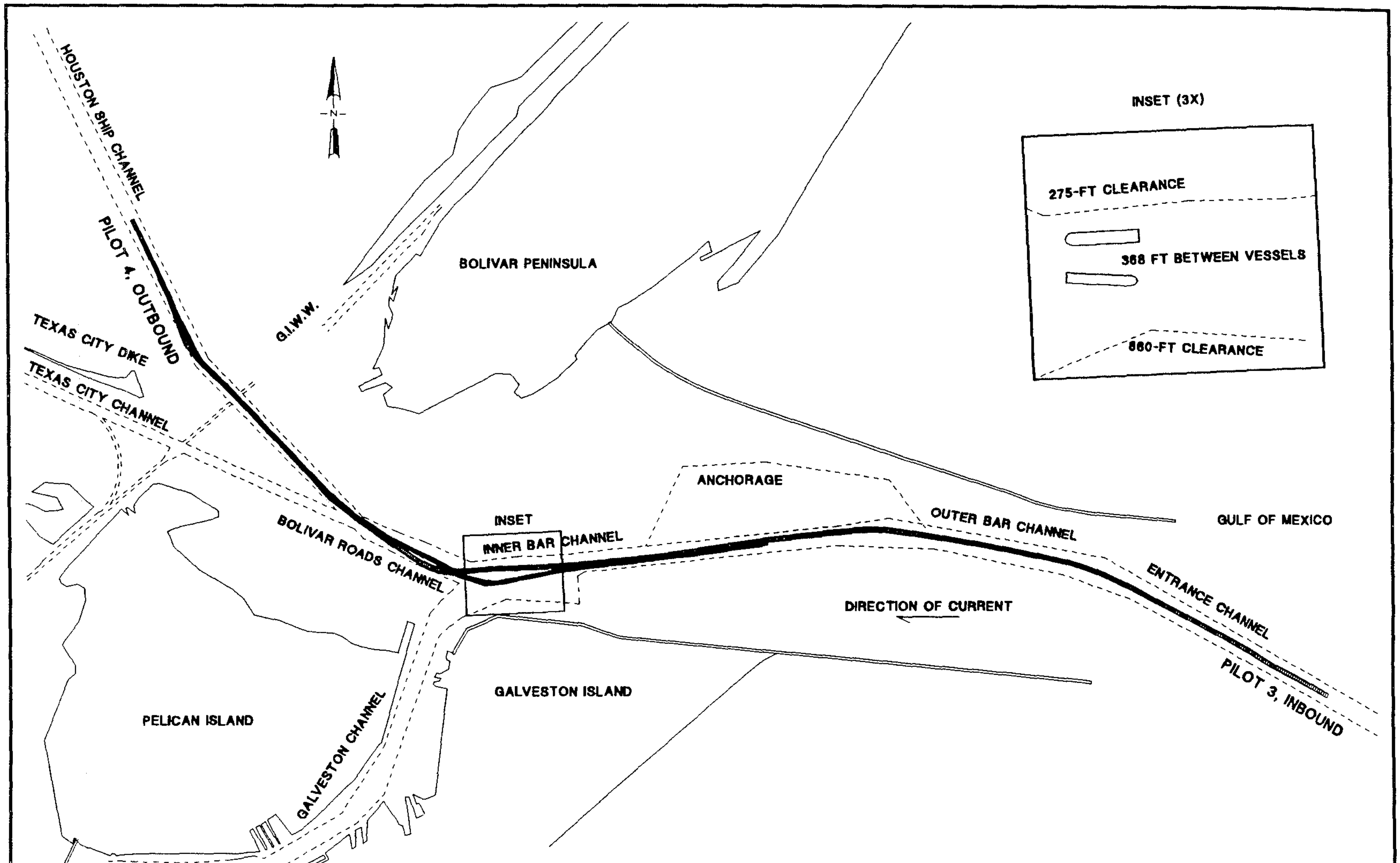
SHIP TRACK PLOTS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



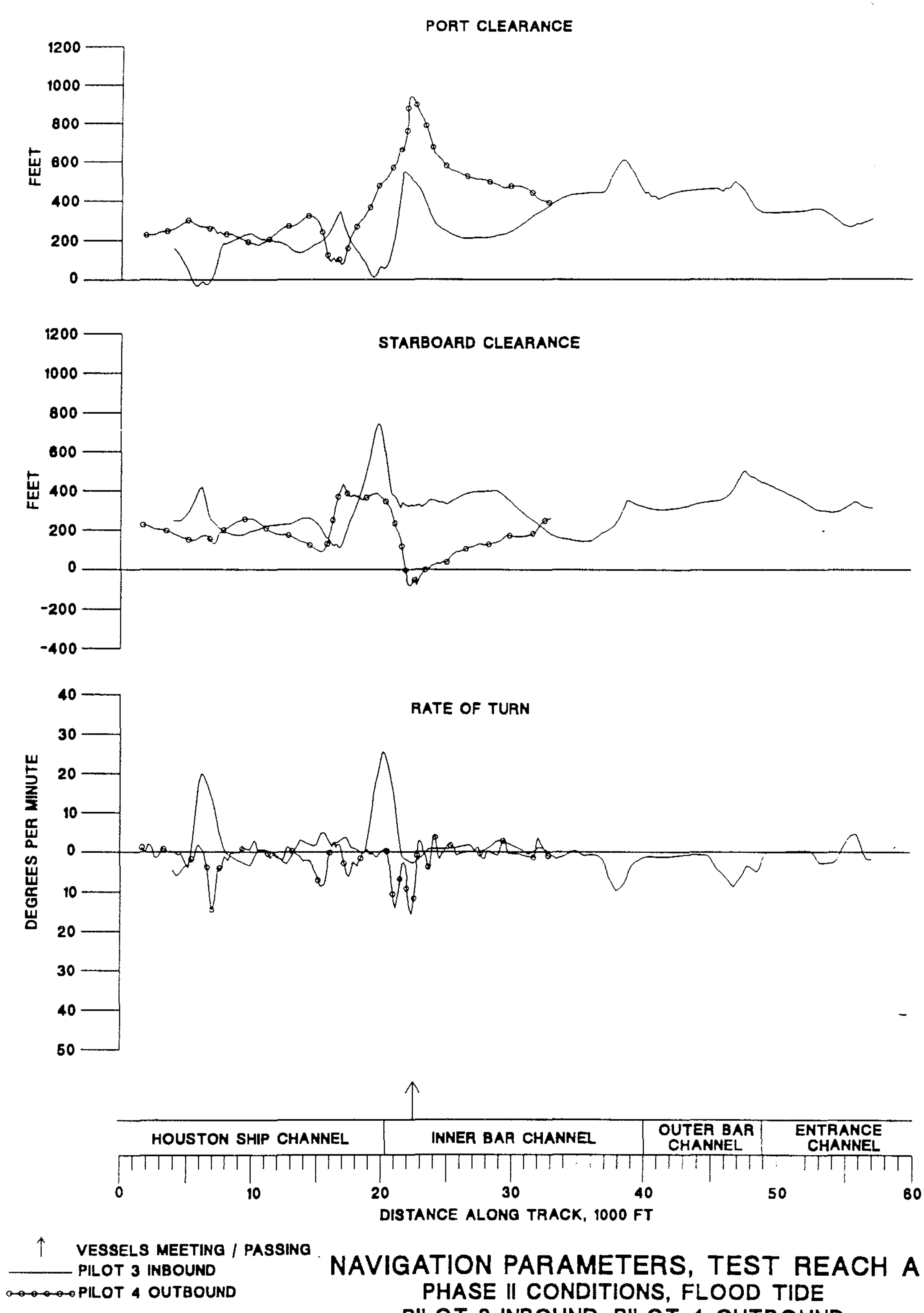
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



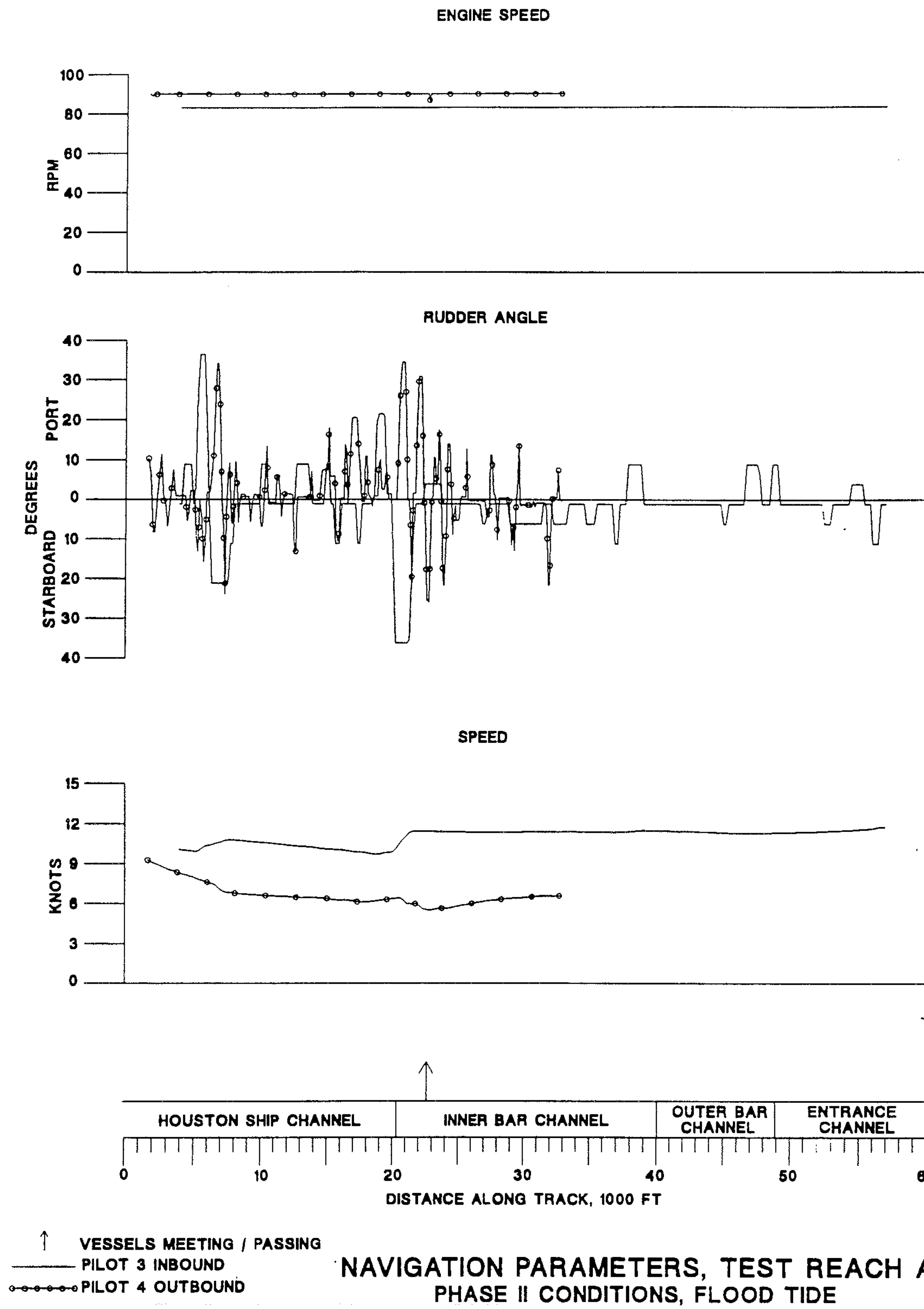
NAVIGATION PARAMETERS, TEST REACH A
PHASE I CONDTIONS, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



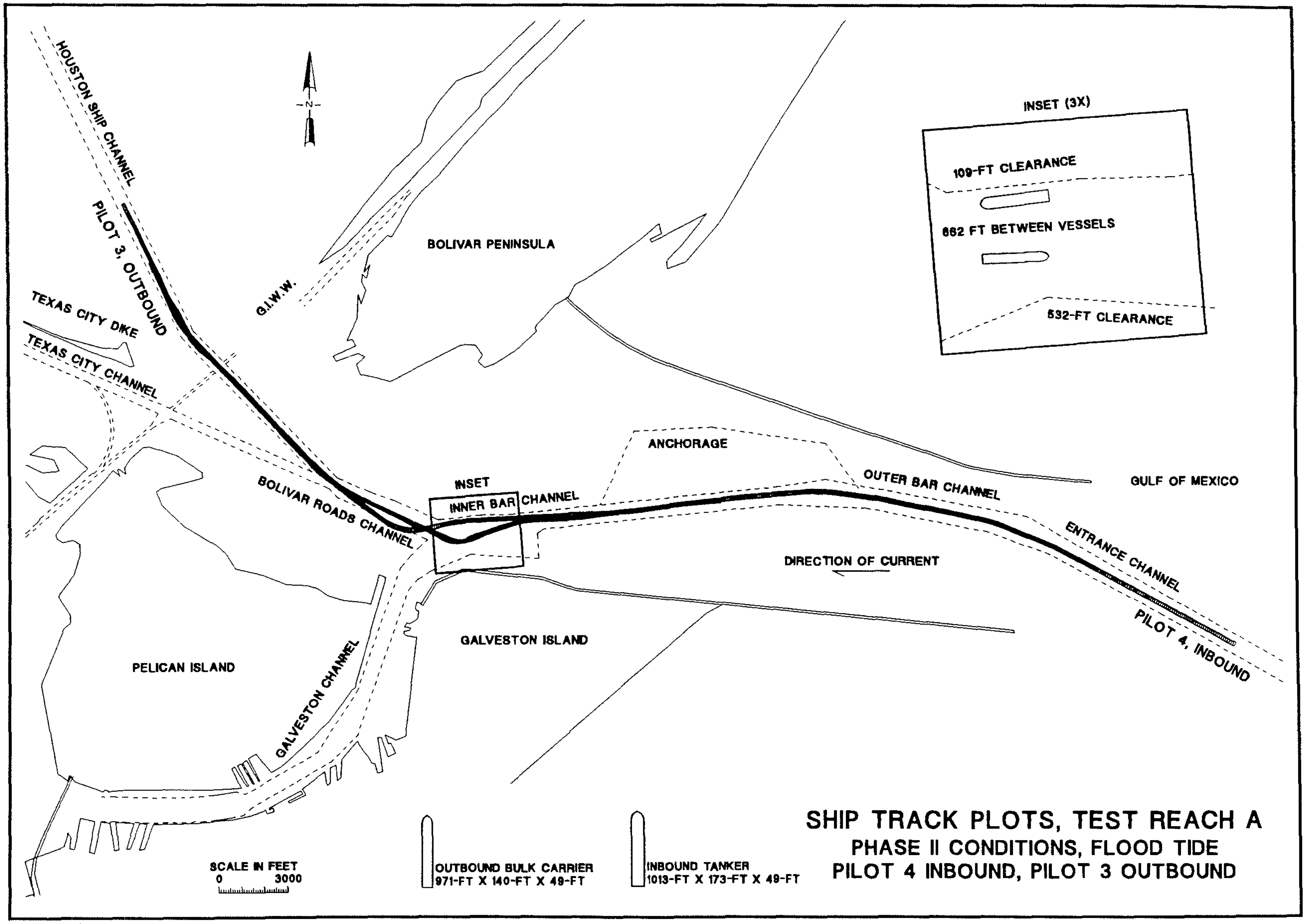
SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

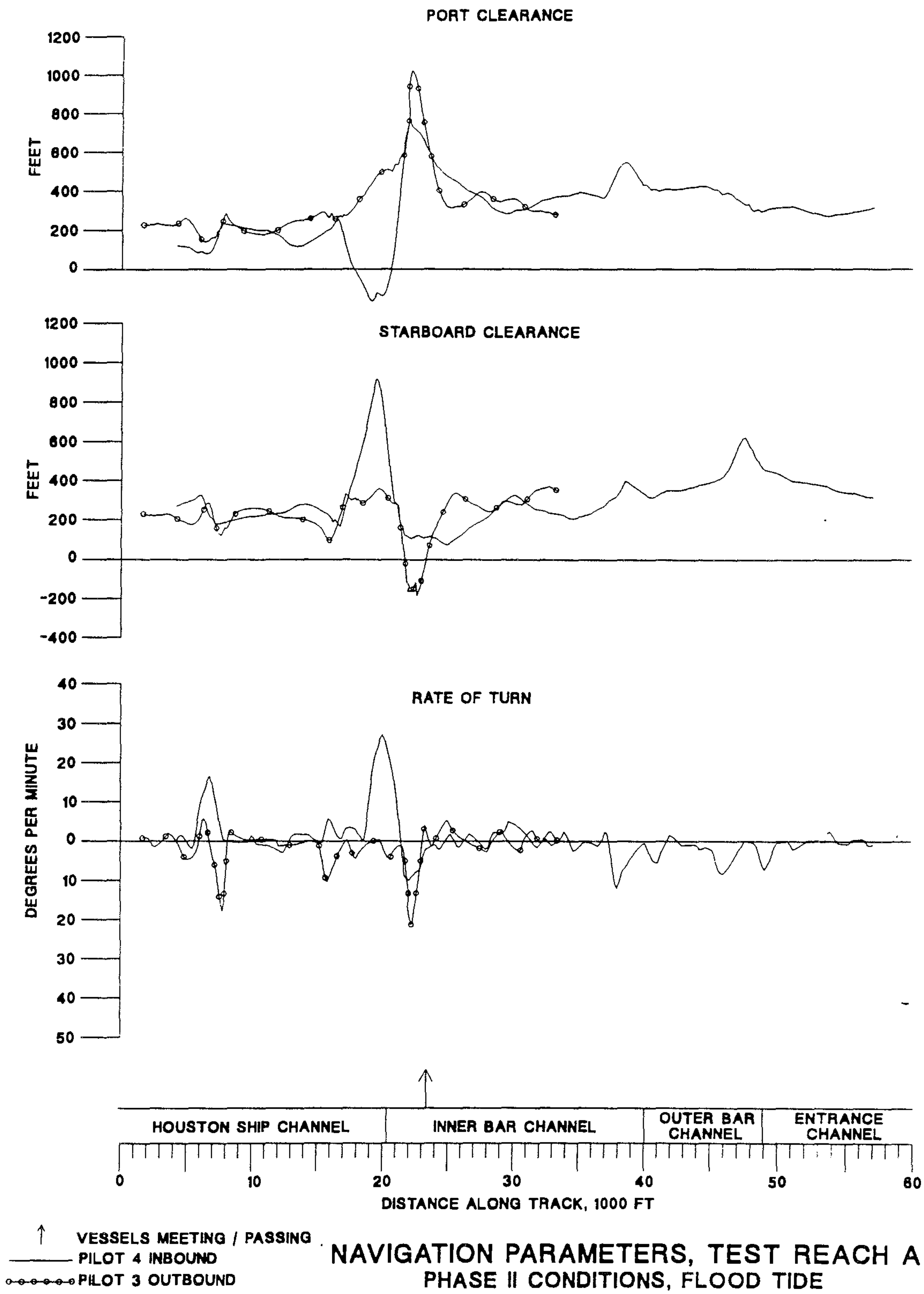


NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

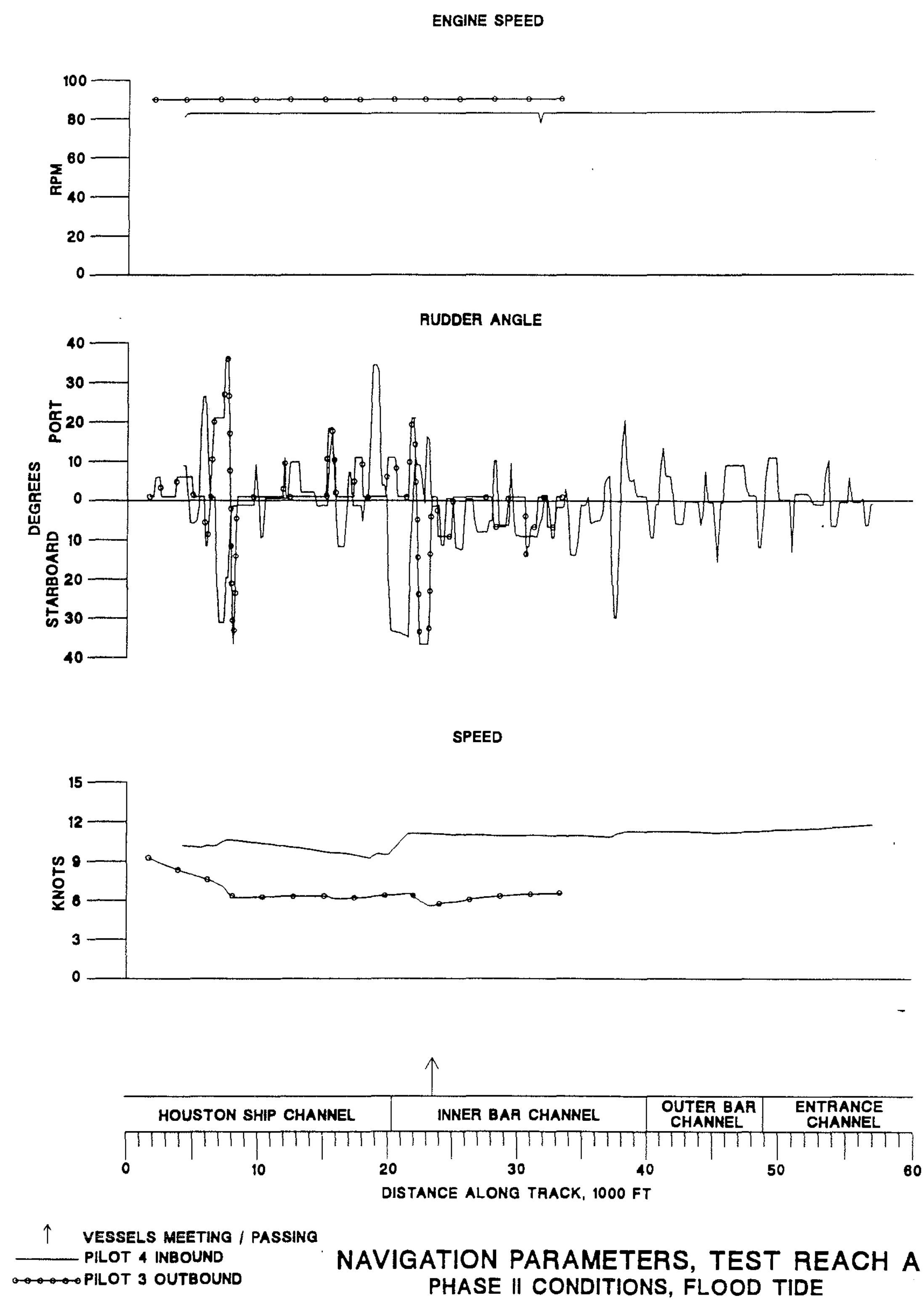


SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

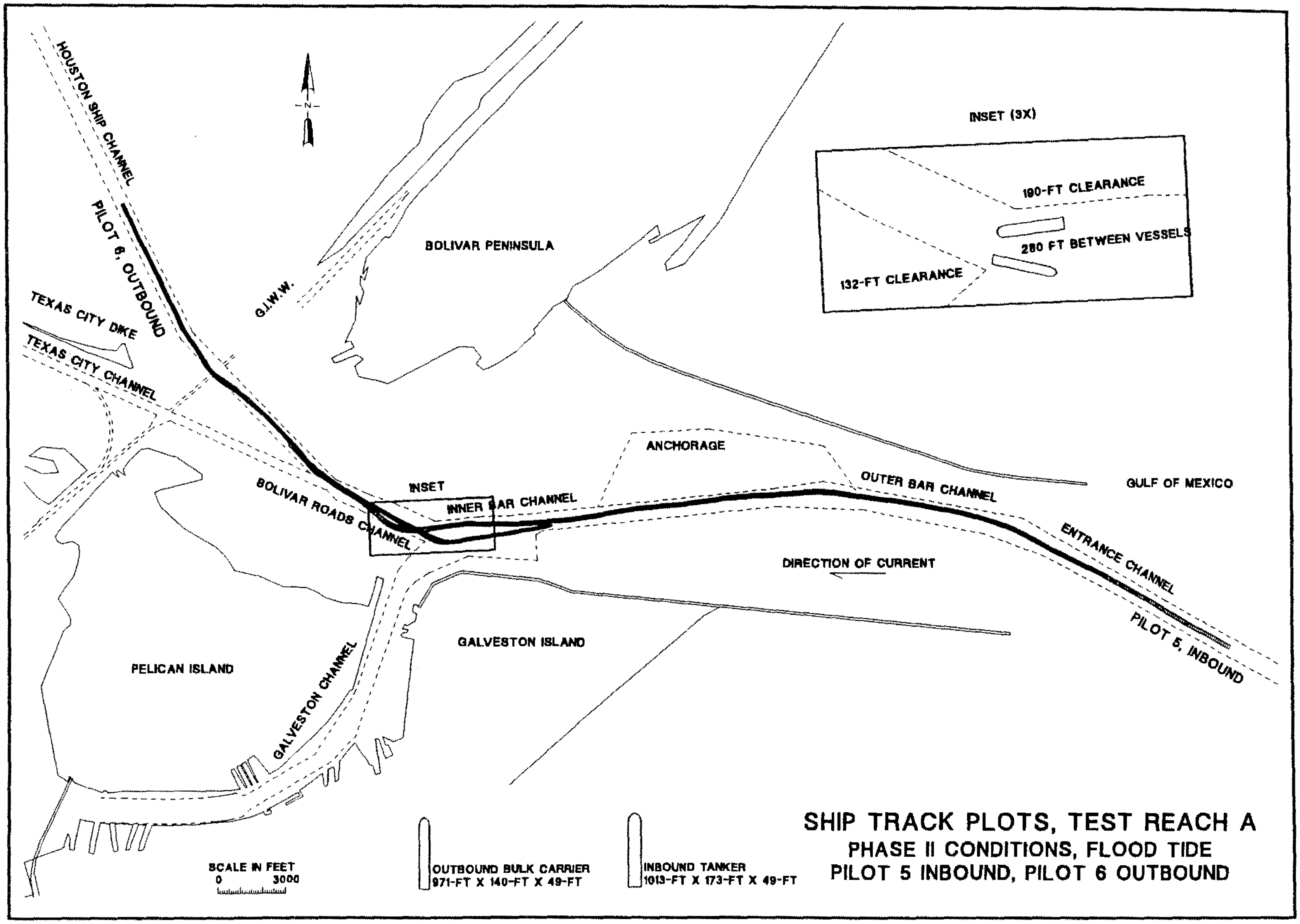
Plate 59



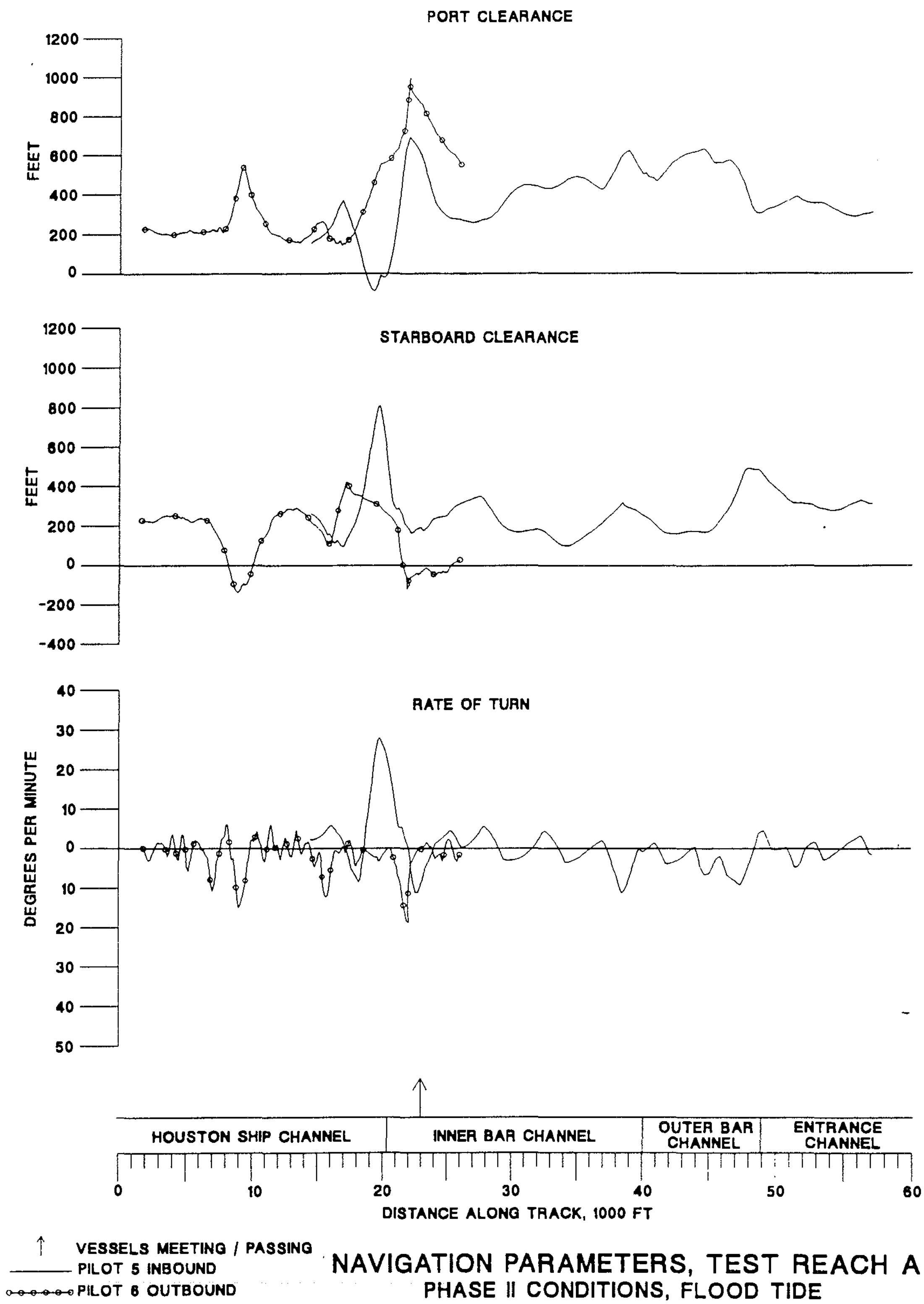
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



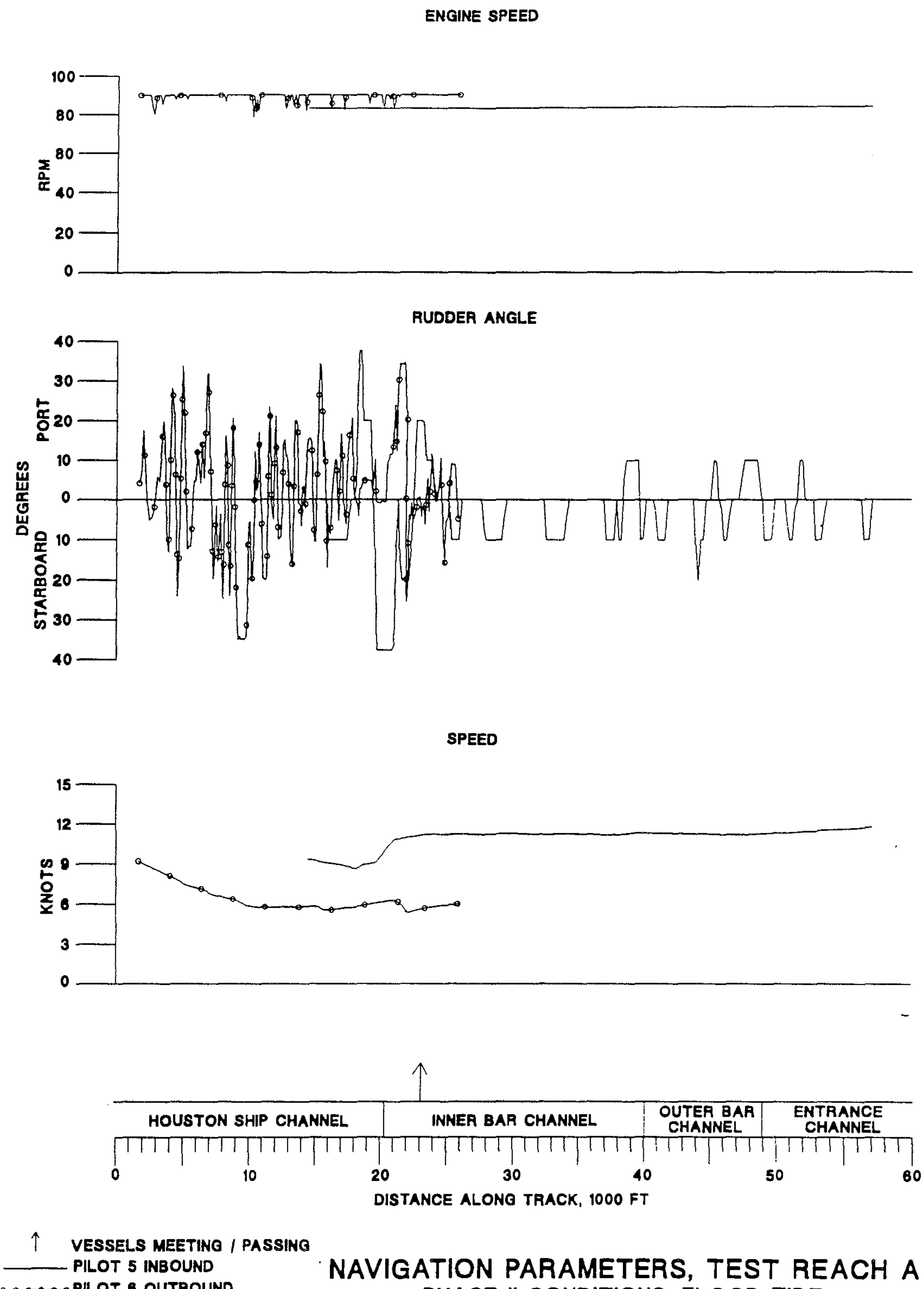
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



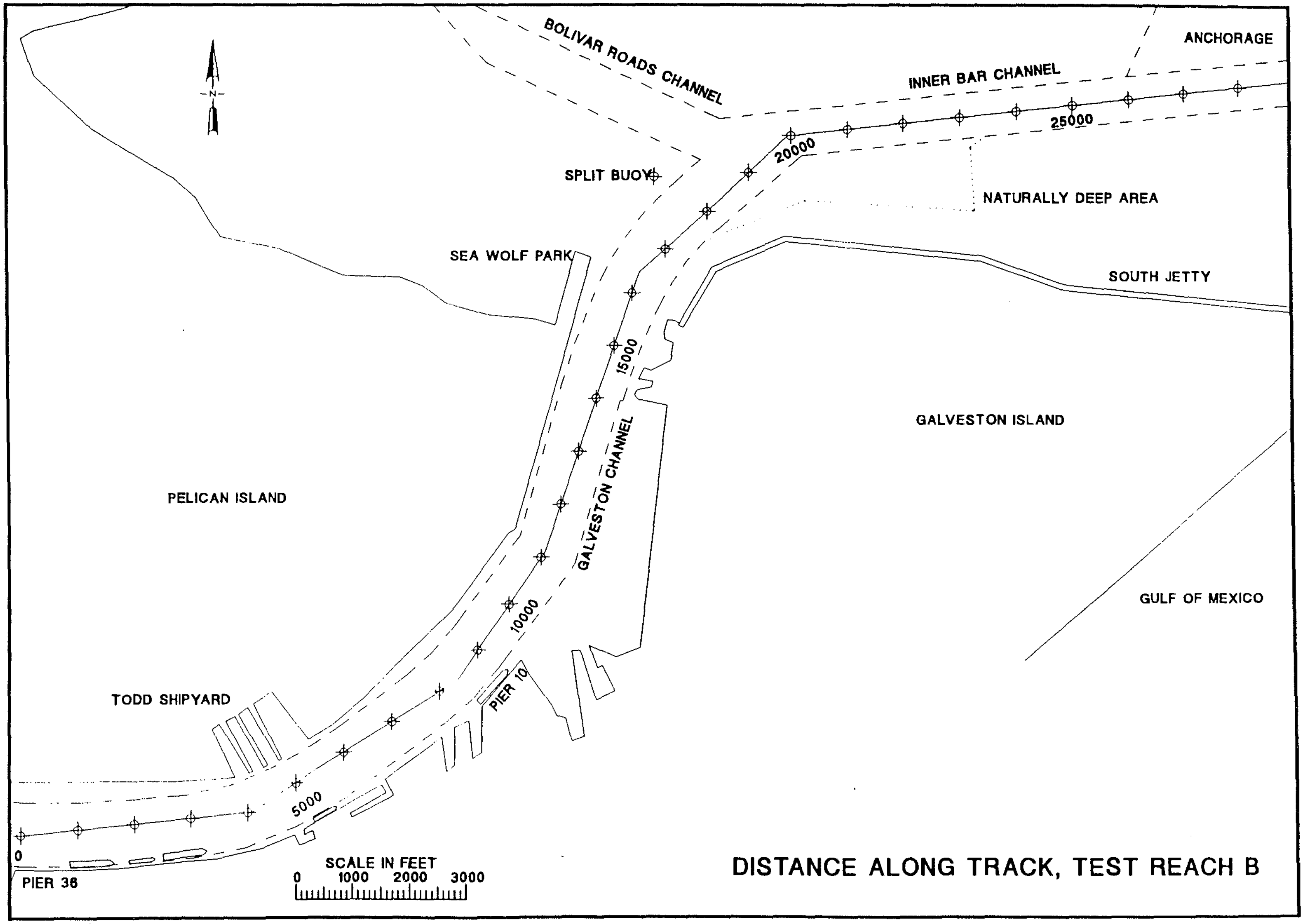
SHIP TRACK PLOTS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



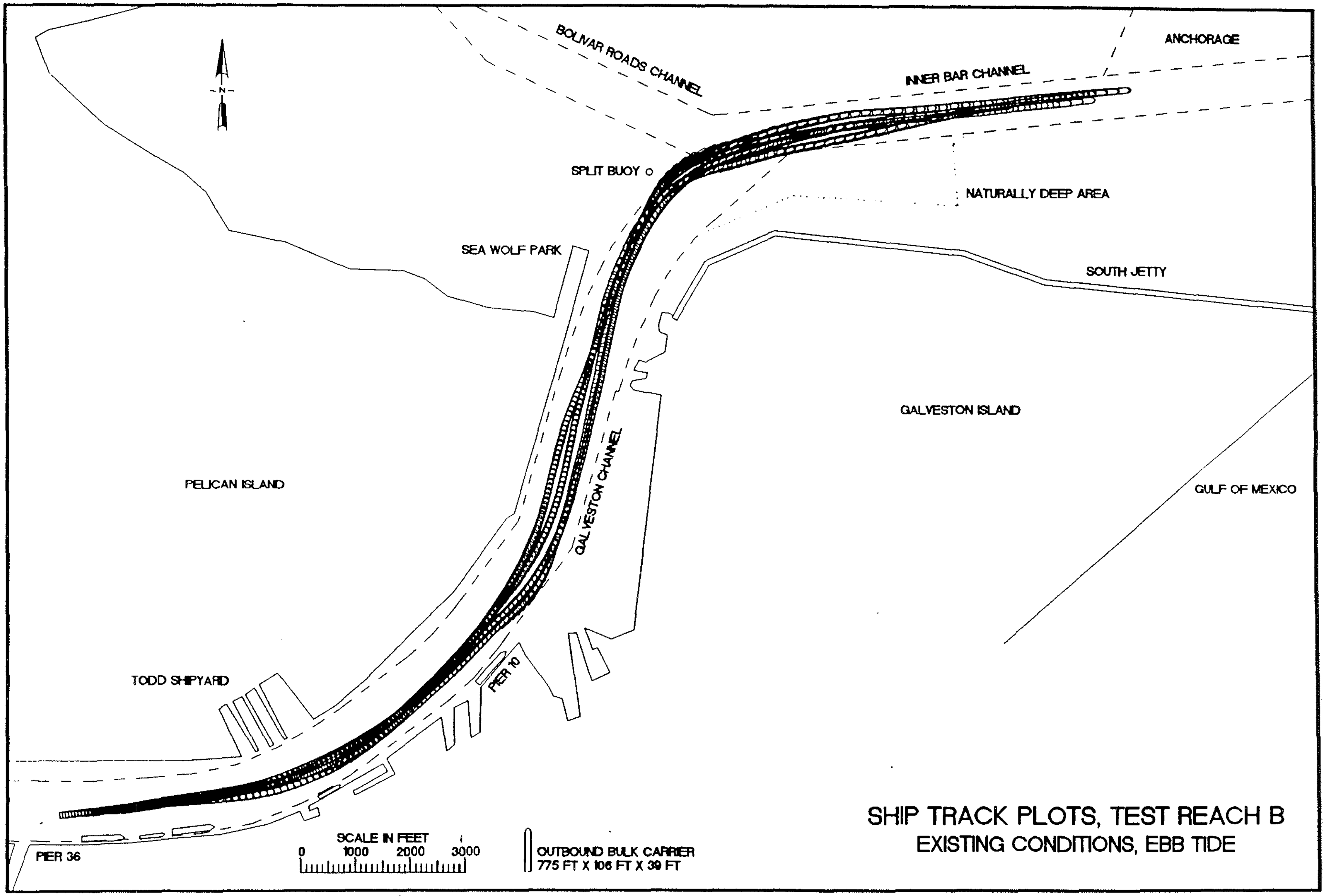
NAVIGATION PARAMETERS, TEST REACH A
PHASE II CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



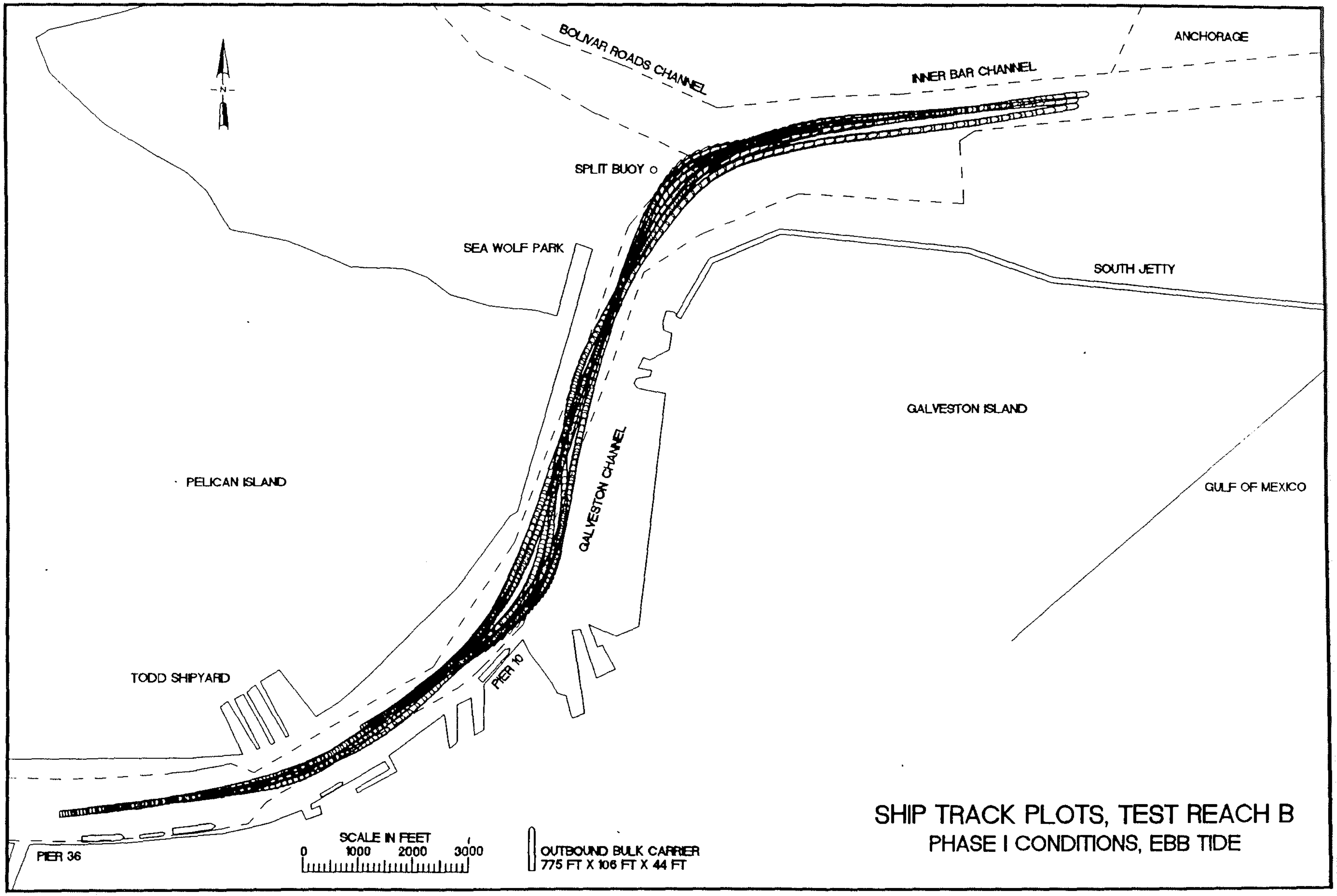
DISTANCE ALONG TRACK, TEST REACH B

Plate 65

Plate 66

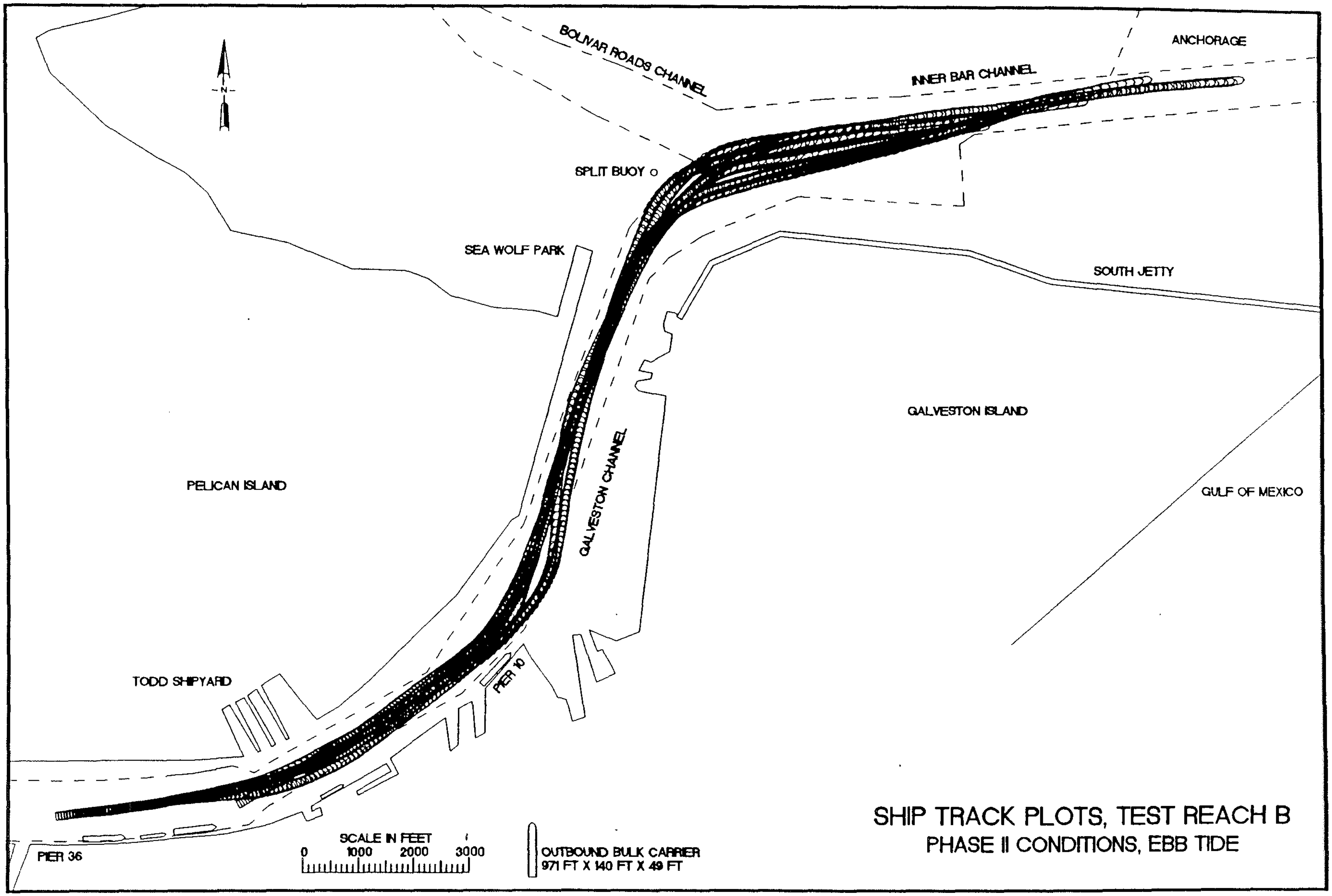


SHIP TRACK PLOTS, TEST REACH B
EXISTING CONDITIONS, EBB TIDE

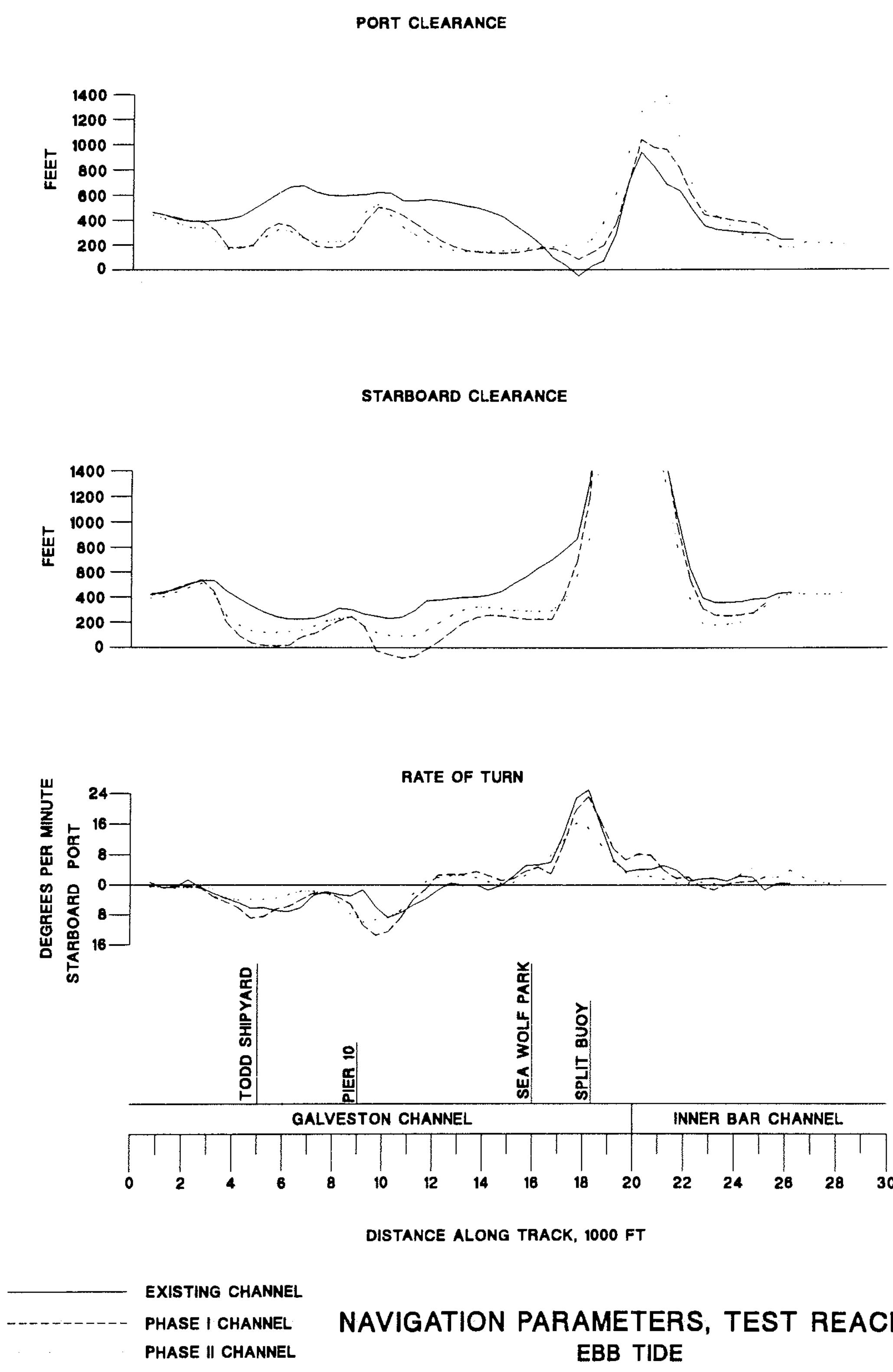


SHIP TRACK PLOTS, TEST REACH B
PHASE I CONDITIONS, EBB TIDE

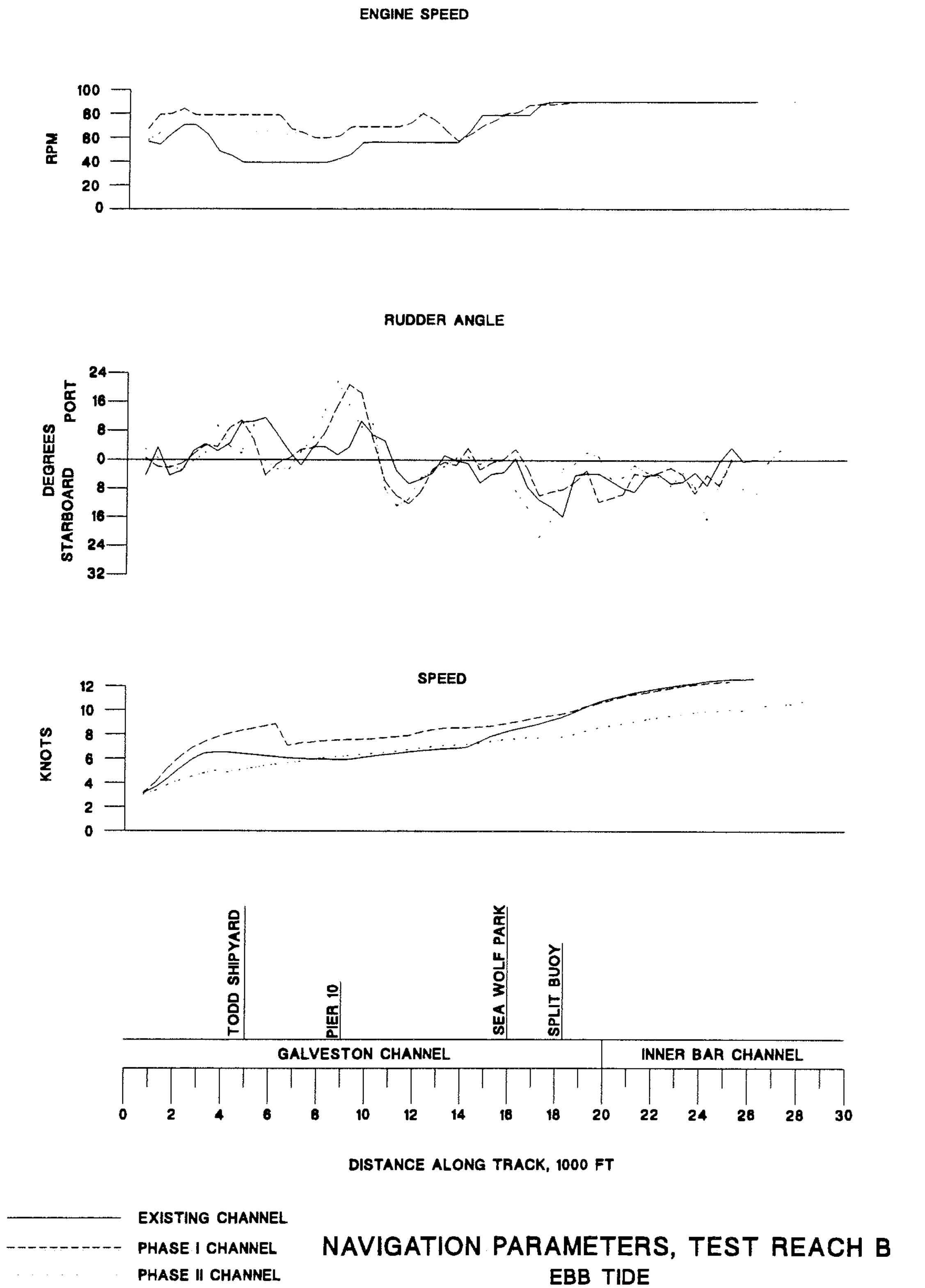
Plate 68



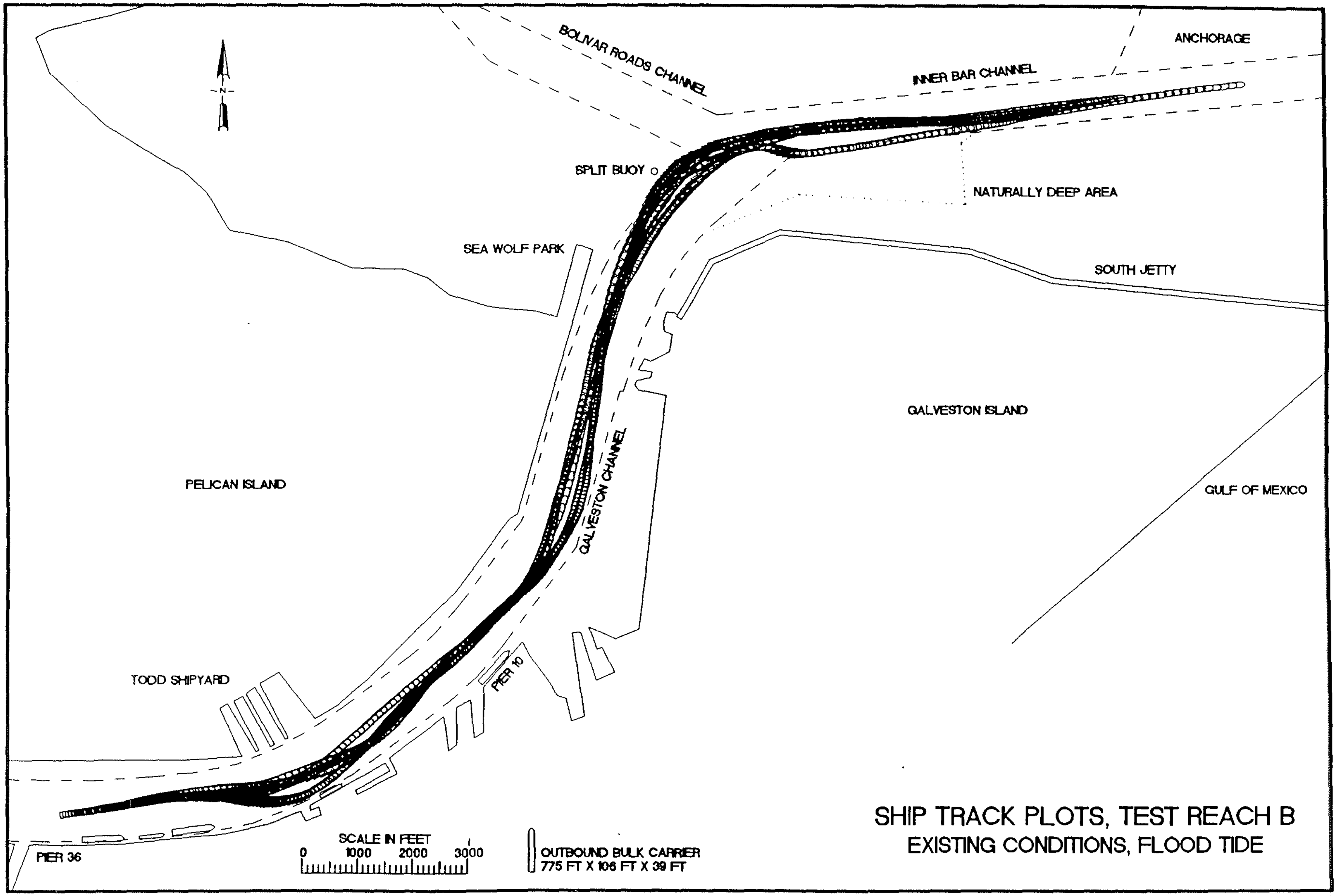
SHIP TRACK PLOTS, TEST REACH B
PHASE II CONDITIONS, EBB TIDE



NAVIGATION PARAMETERS, TEST REACH B
EBB TIDE

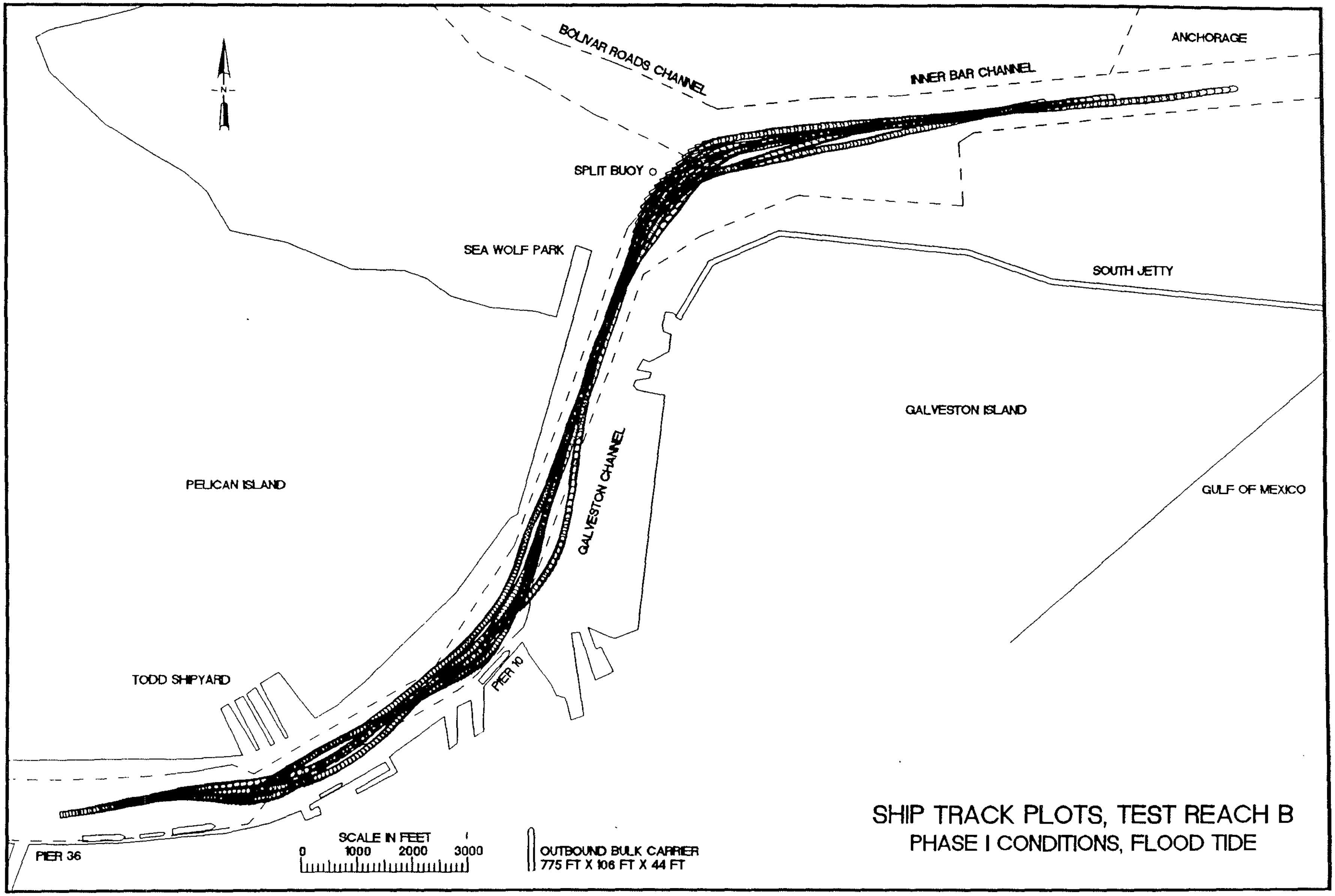


NAVIGATION PARAMETERS, TEST REACH B
EBB TIDE

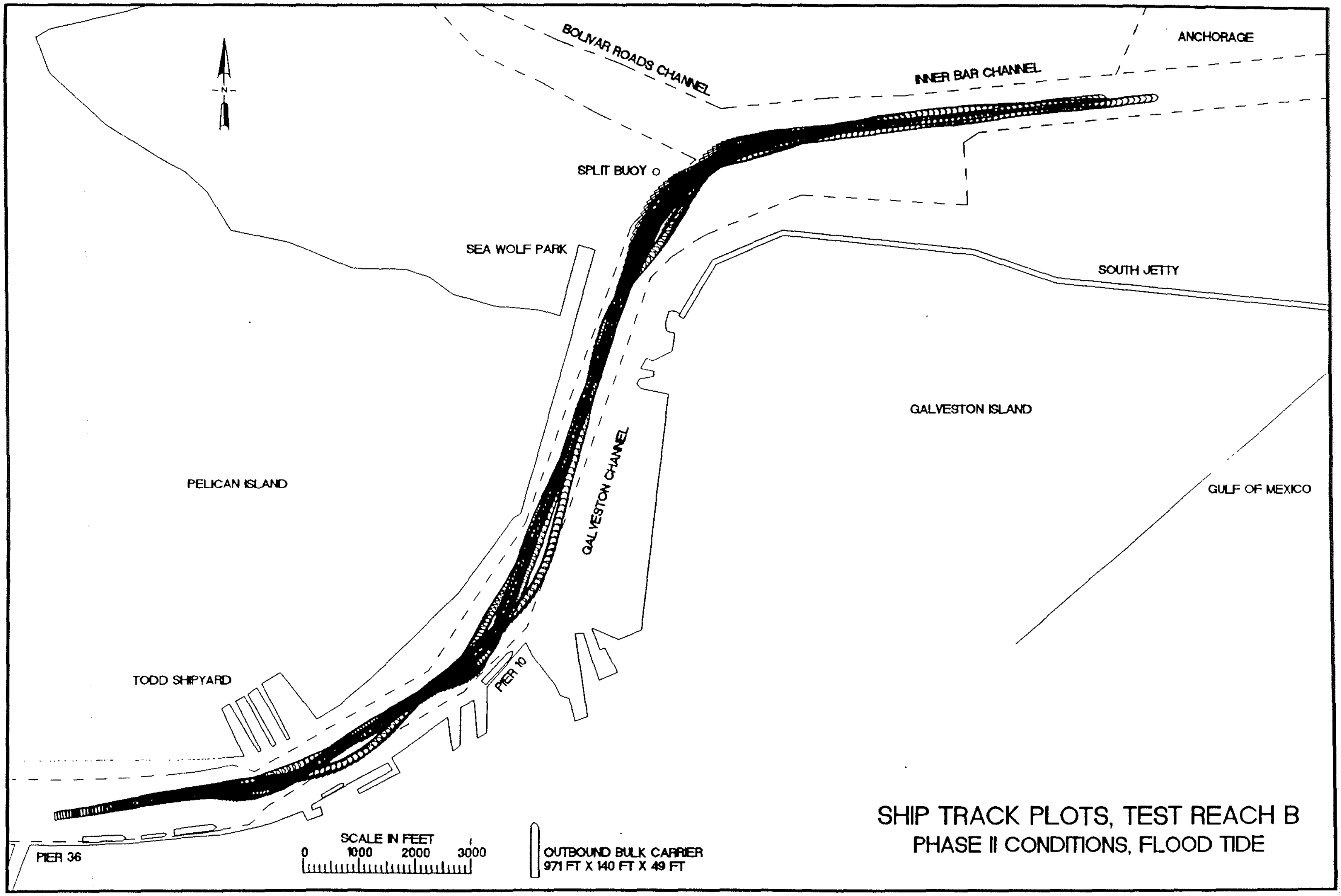


SHIP TRACK PLOTS, TEST REACH B
EXISTING CONDITIONS, FLOOD TIDE

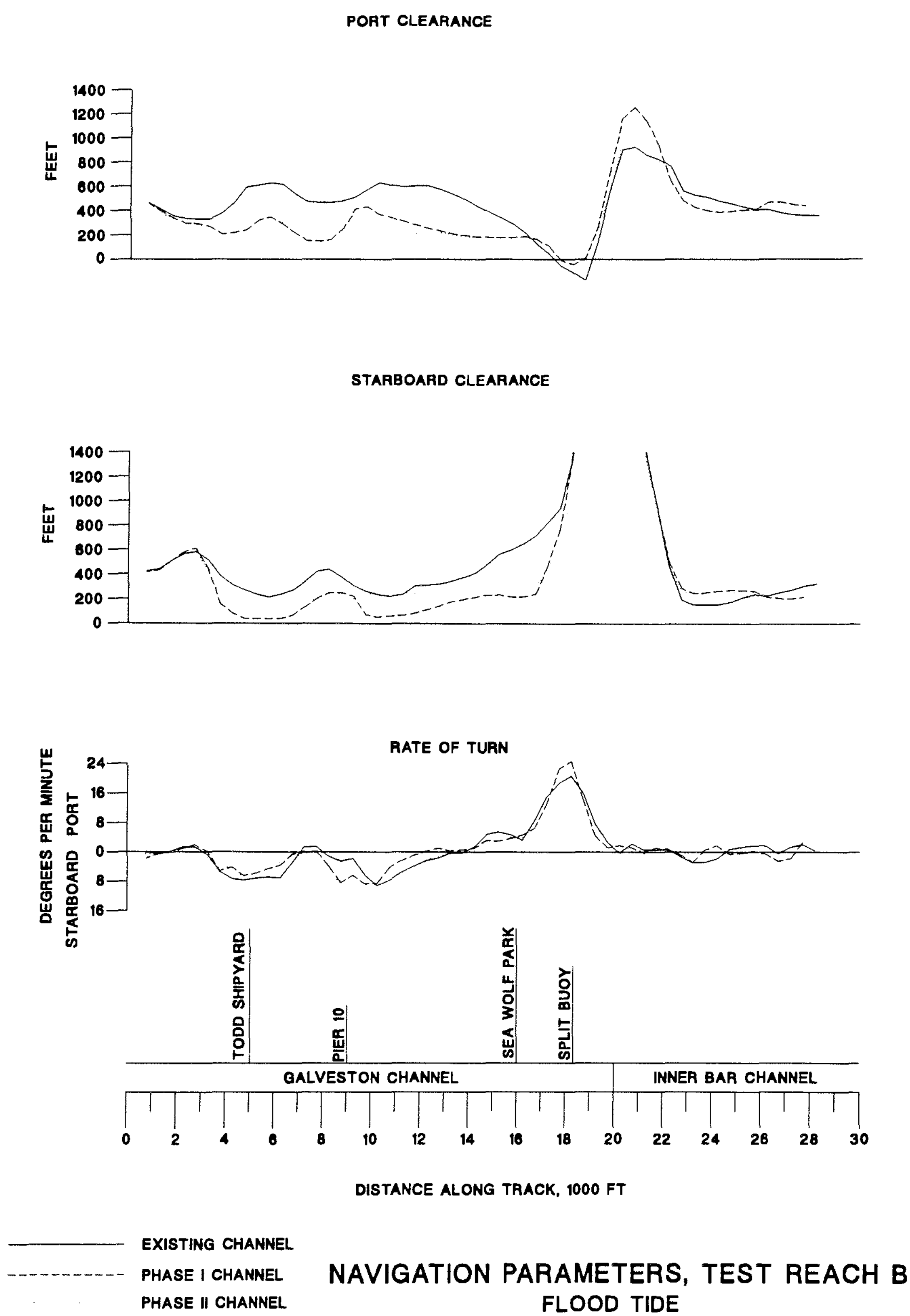
Plate 72



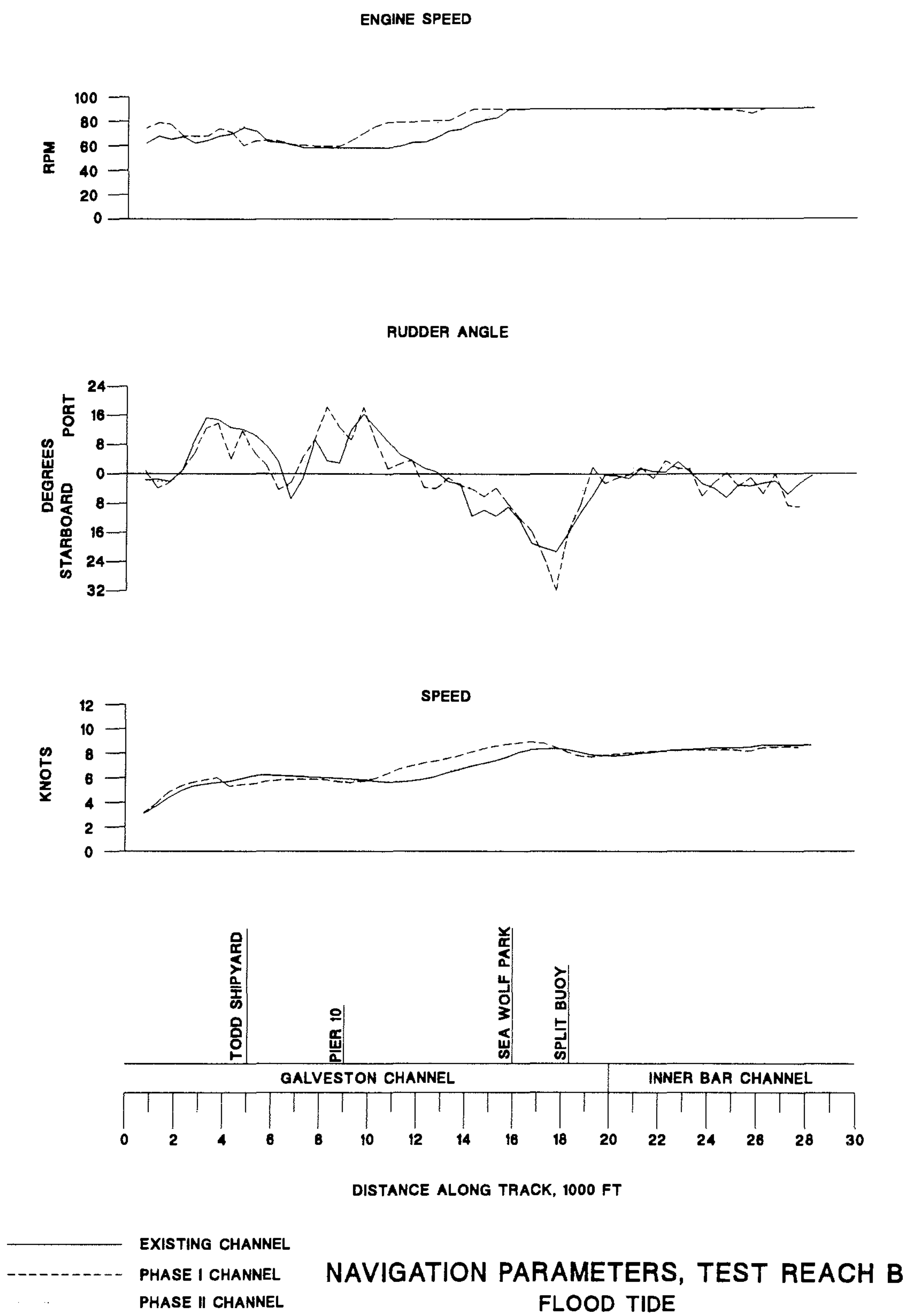
SHIP TRACK PLOTS, TEST REACH B
PHASE I CONDITIONS, FLOOD TIDE



SHIP TRACK PLOTS, TEST REACH B
PHASE II CONDITIONS, FLOOD TIDE

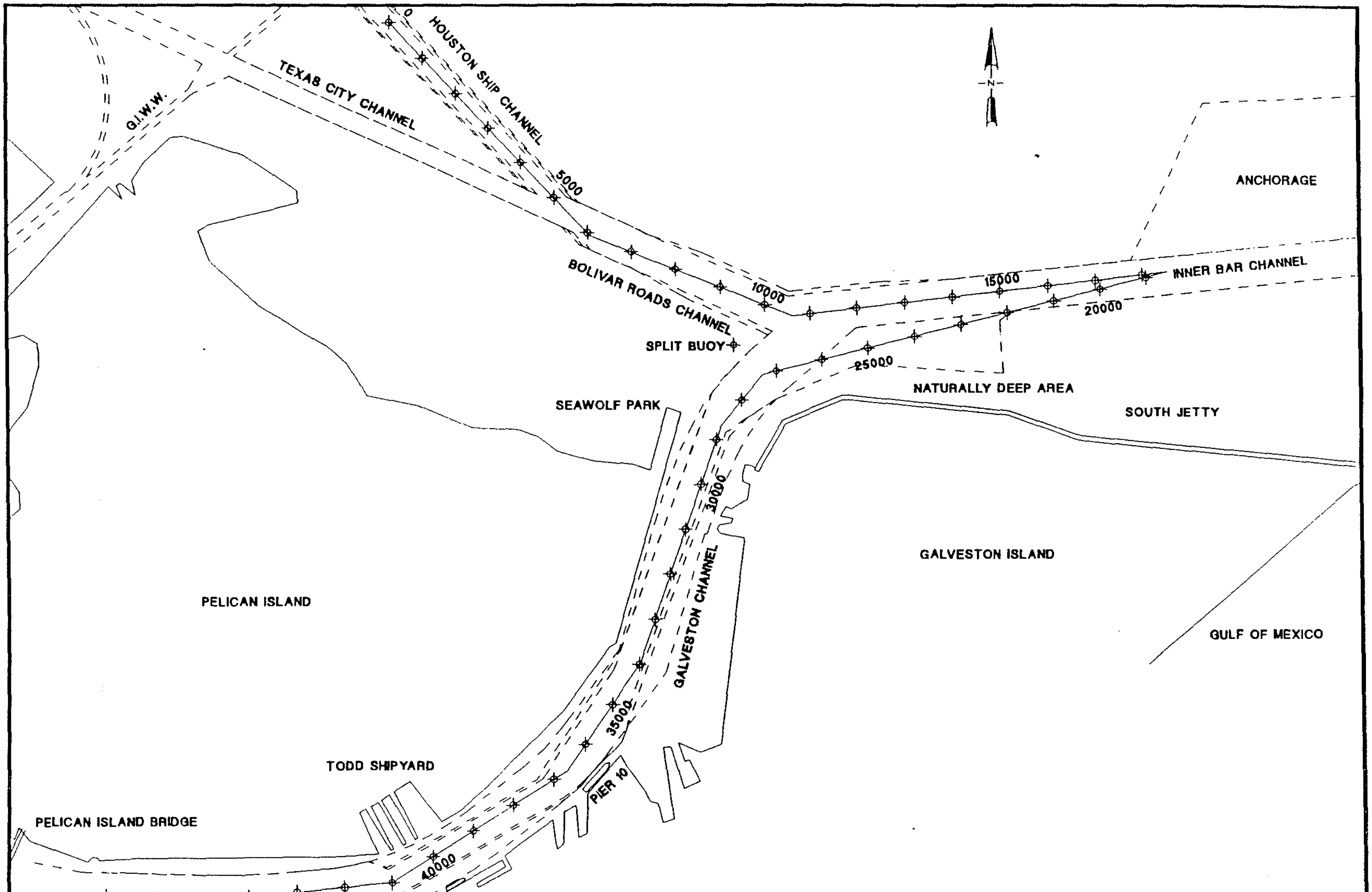


NAVIGATION PARAMETERS, TEST REACH B
FLOOD TIDE

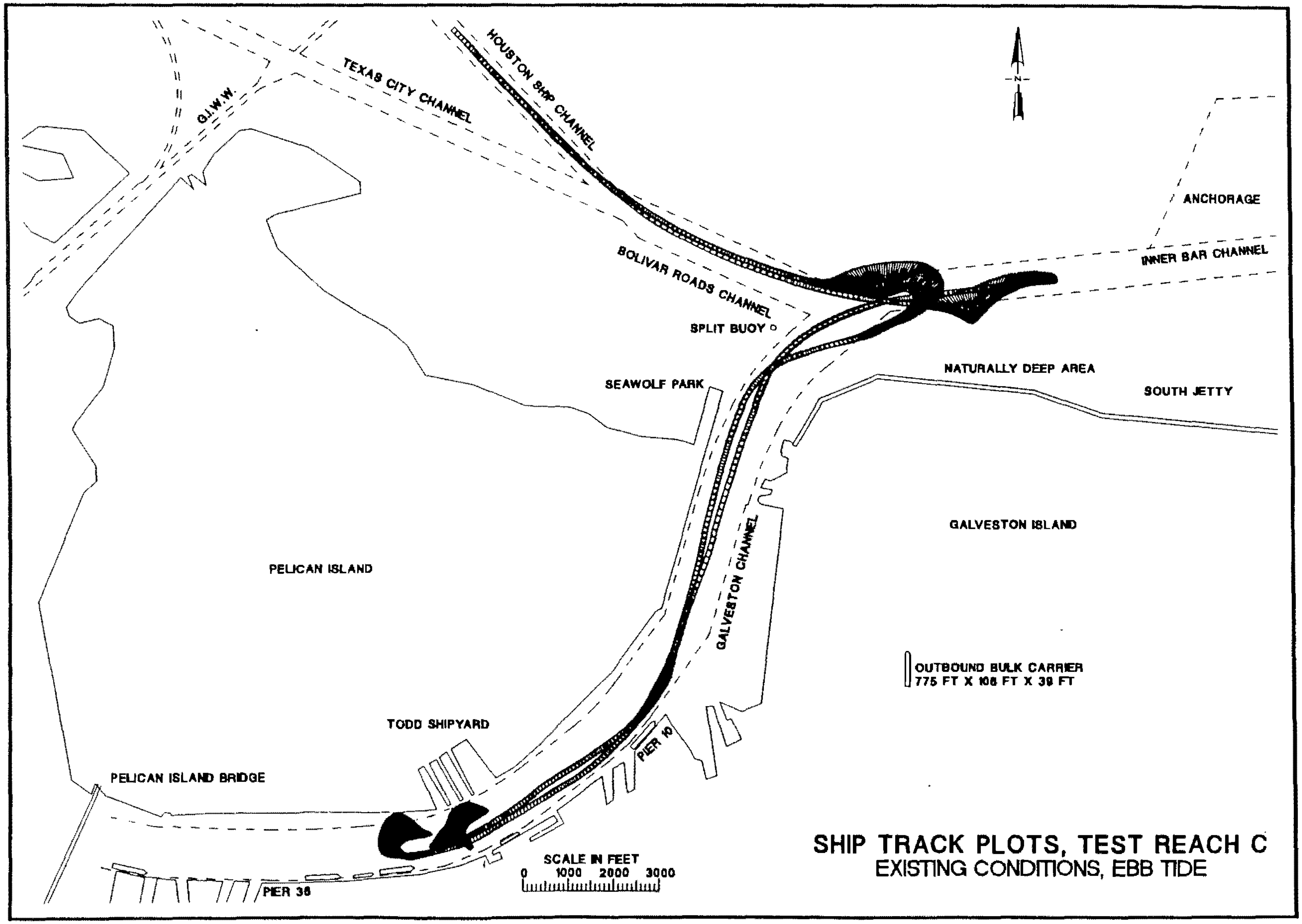


NAVIGATION PARAMETERS, TEST REACH B
FLOOD TIDE

Plate 76

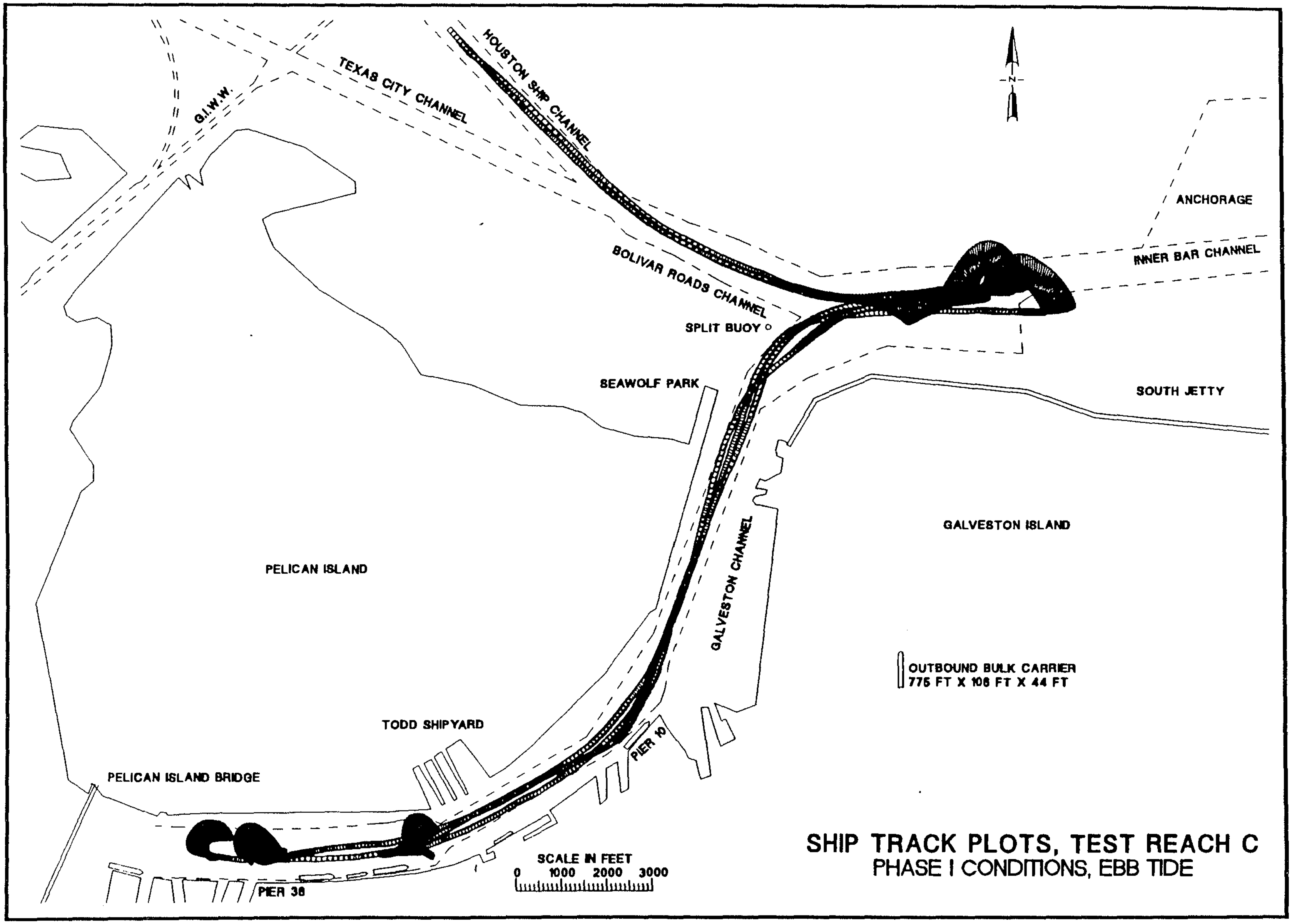


DISTANCE ALONG TRACK, TEST REACH C

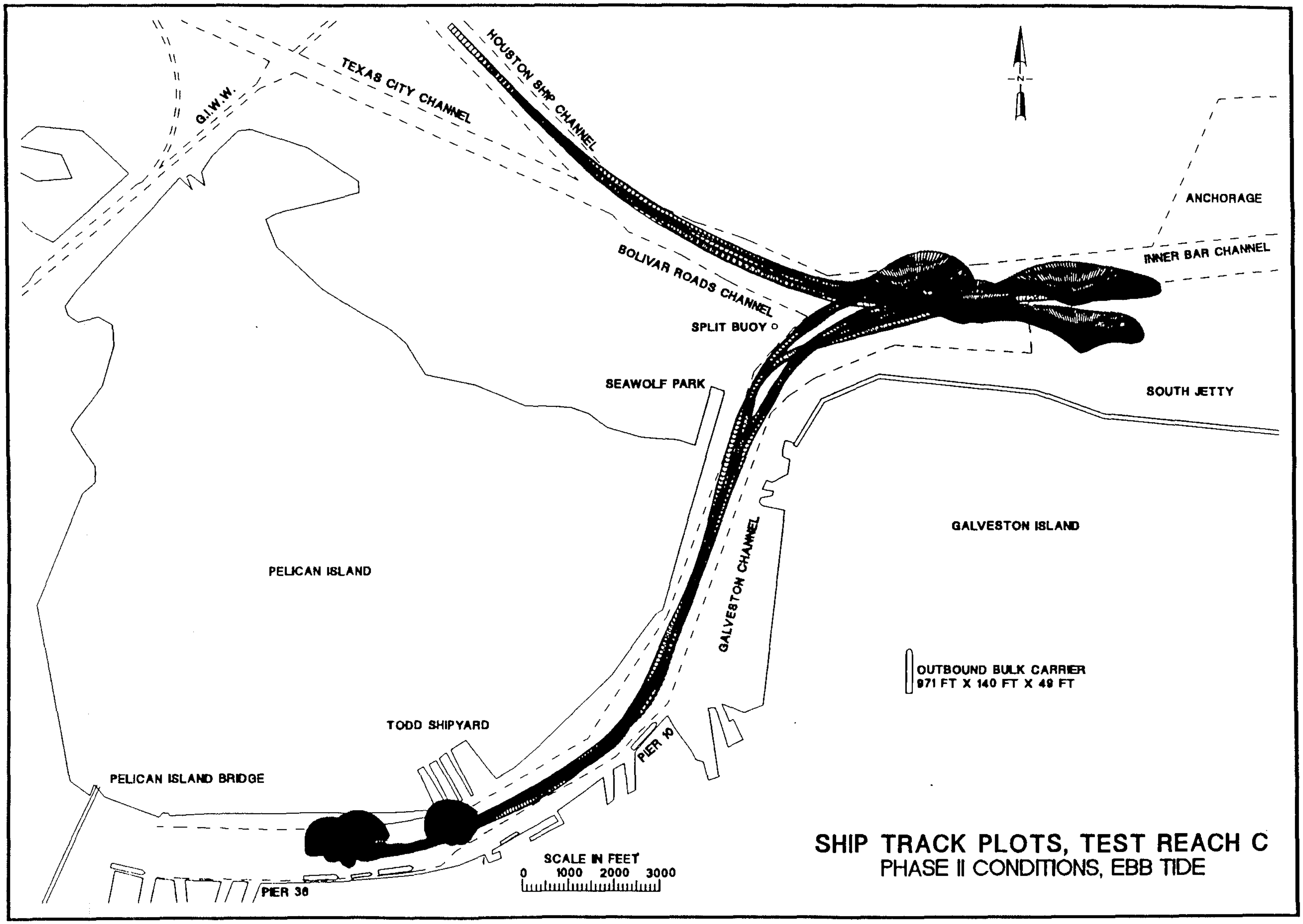


SHIP TRACK PLOTS, TEST REACH C
EXISTING CONDITIONS, EBB TIDE

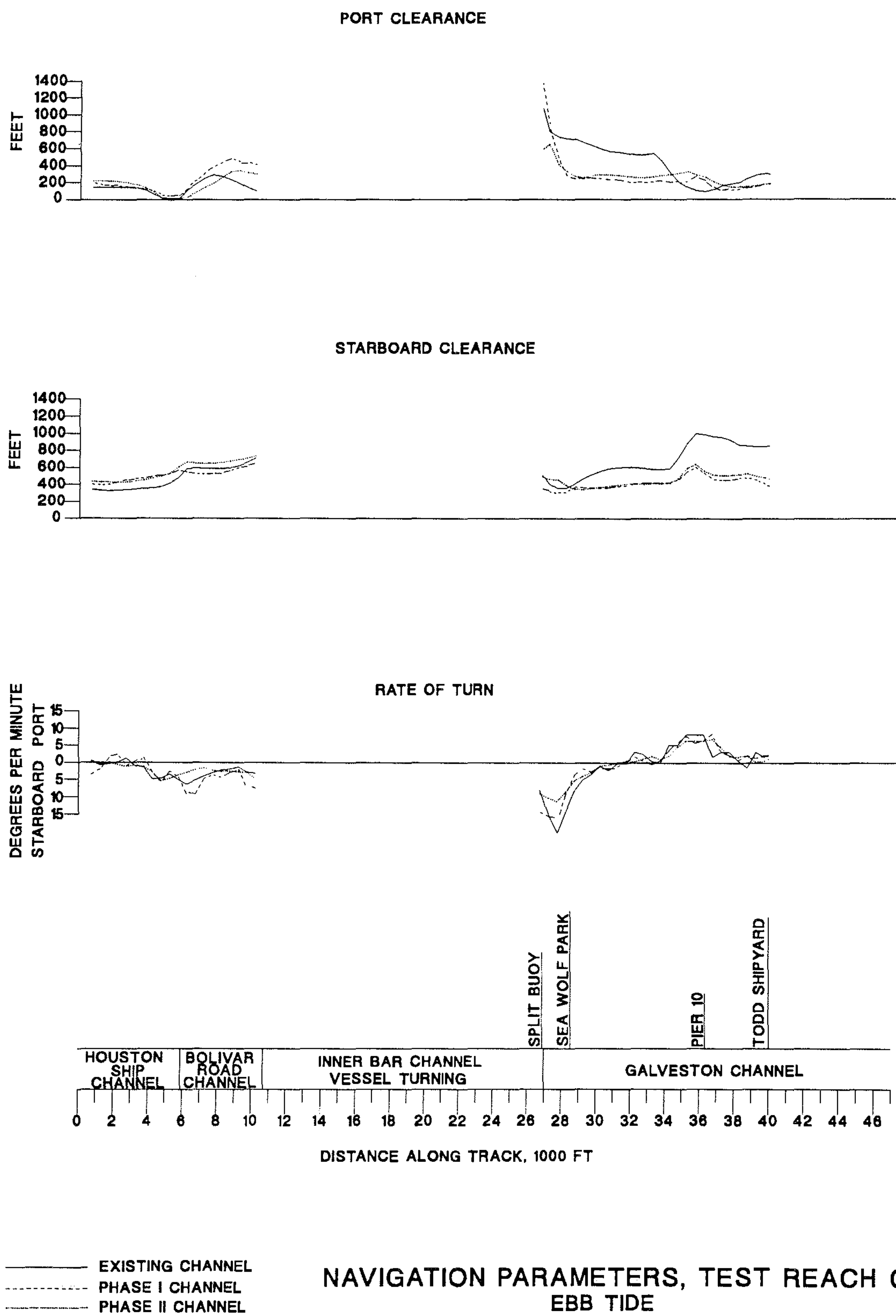
Plate 77



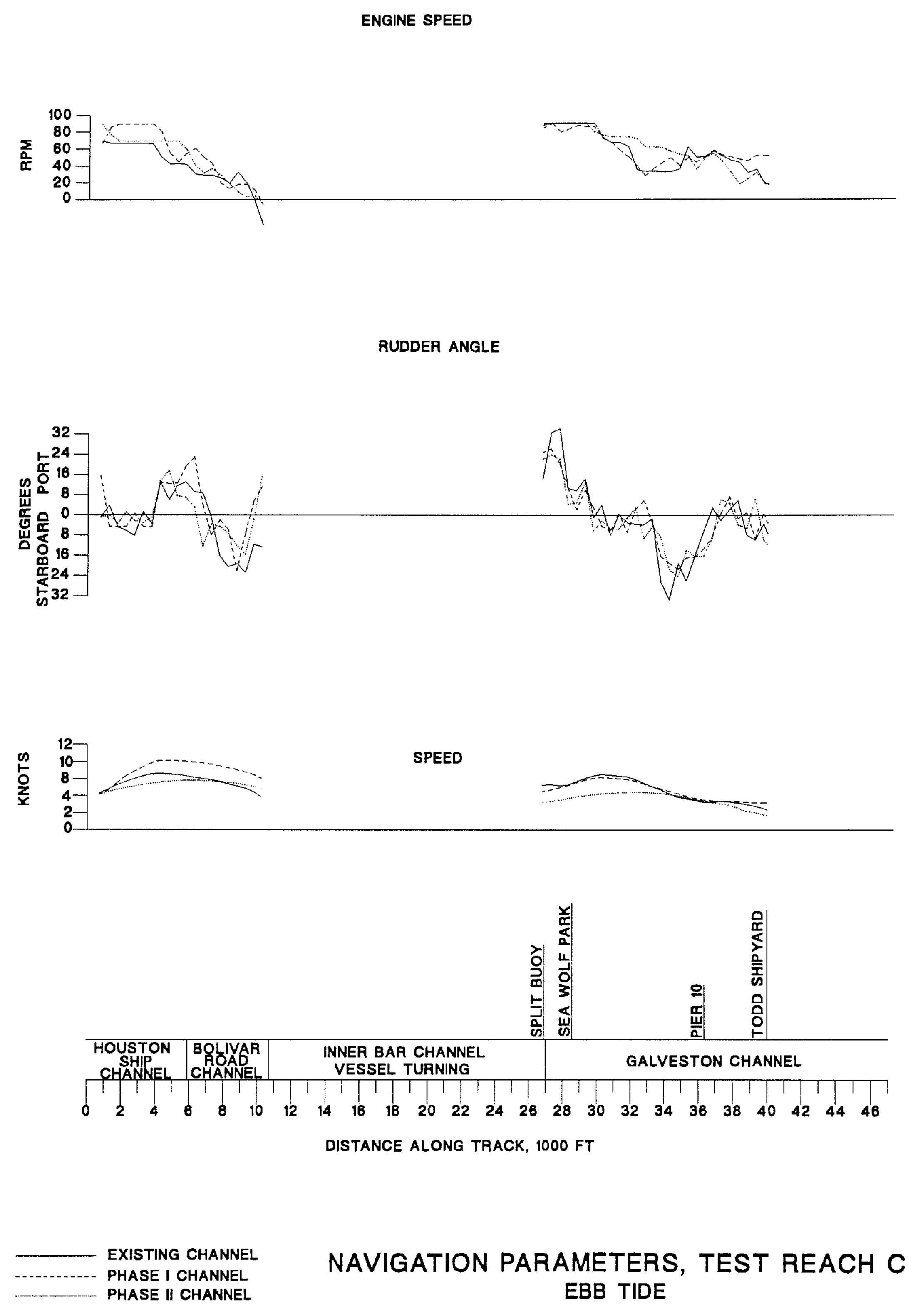
SHIP TRACK PLOTS, TEST REACH C
PHASE I CONDITIONS, EBB TIDE



SHIP TRACK PLOTS, TEST REACH C
PHASE II CONDITIONS, EBB TIDE

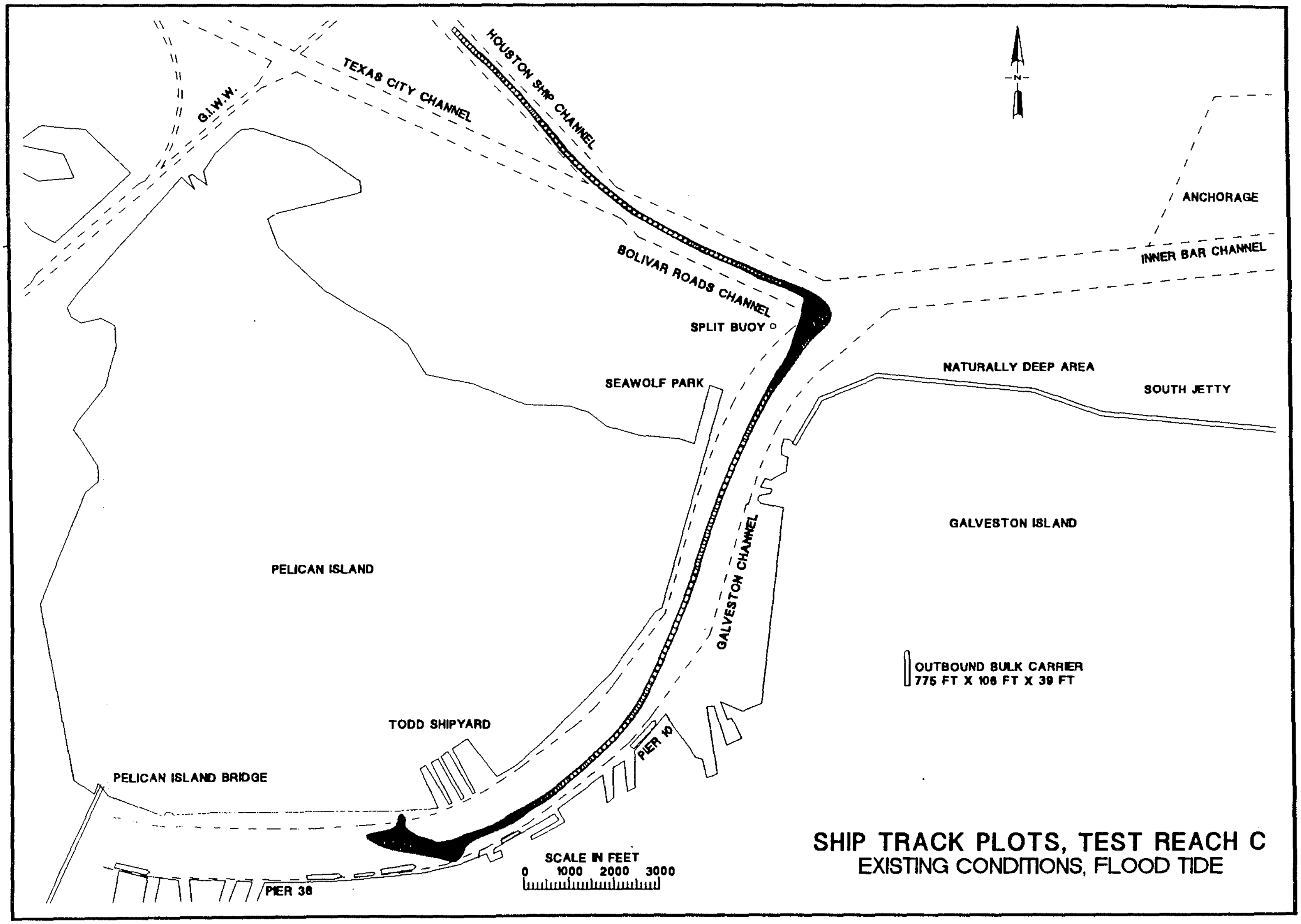


NAVIGATION PARAMETERS, TEST REACH C
EBB TIDE

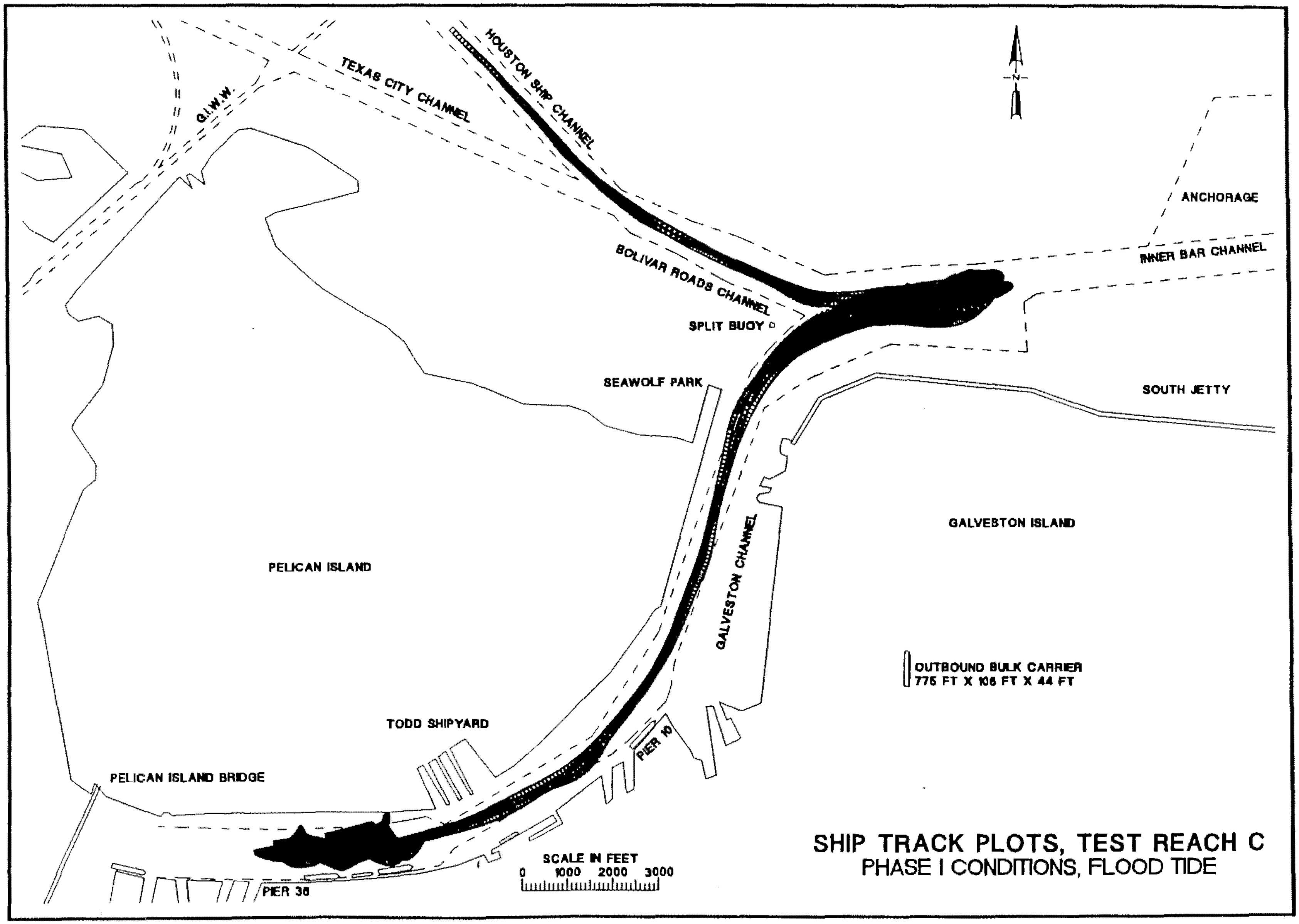


NAVIGATION PARAMETERS, TEST REACH C
EBB TIDE

Plate 82

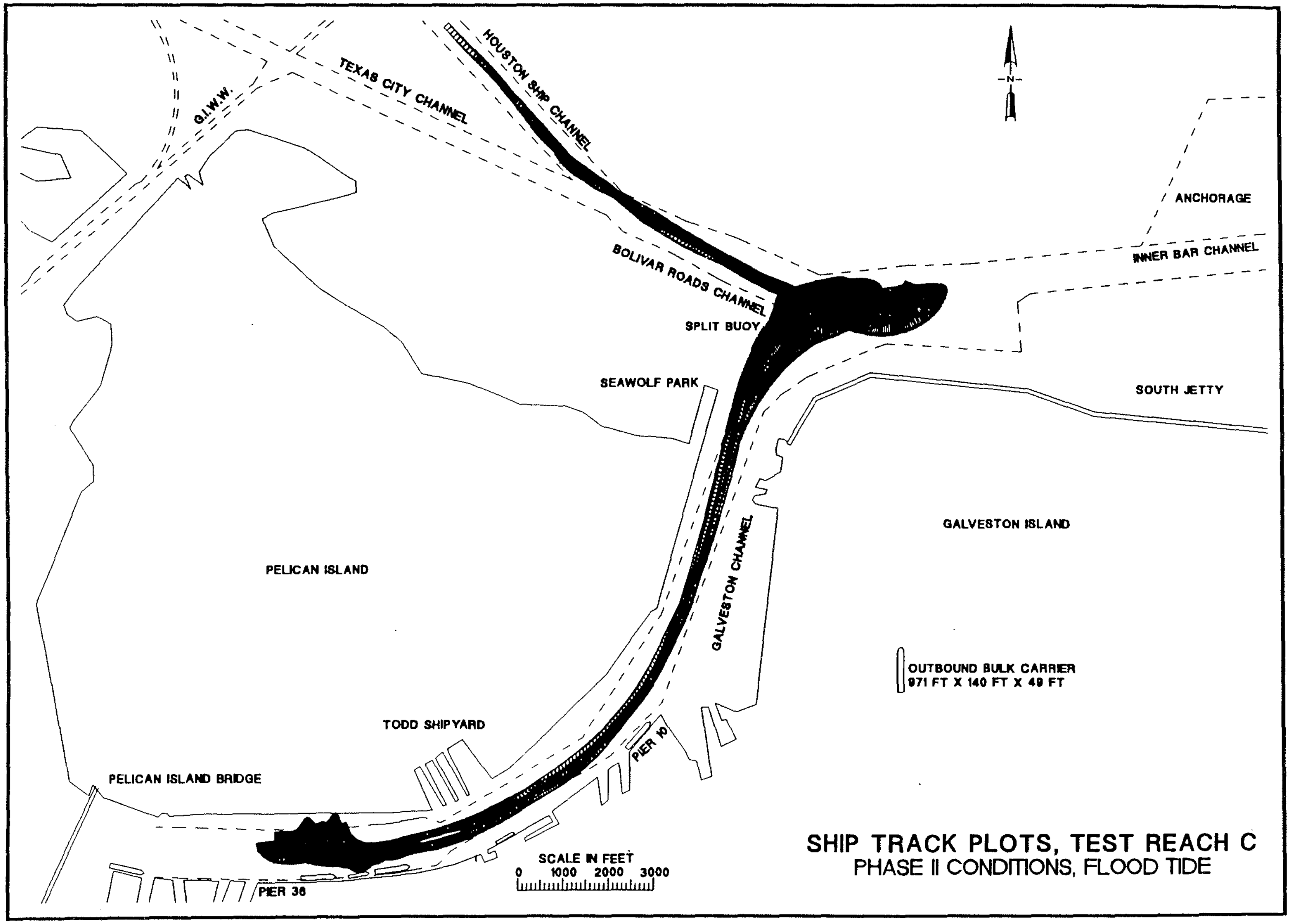


SHIP TRACK PLOTS, TEST REACH C
EXISTING CONDITIONS, FLOOD TIDE



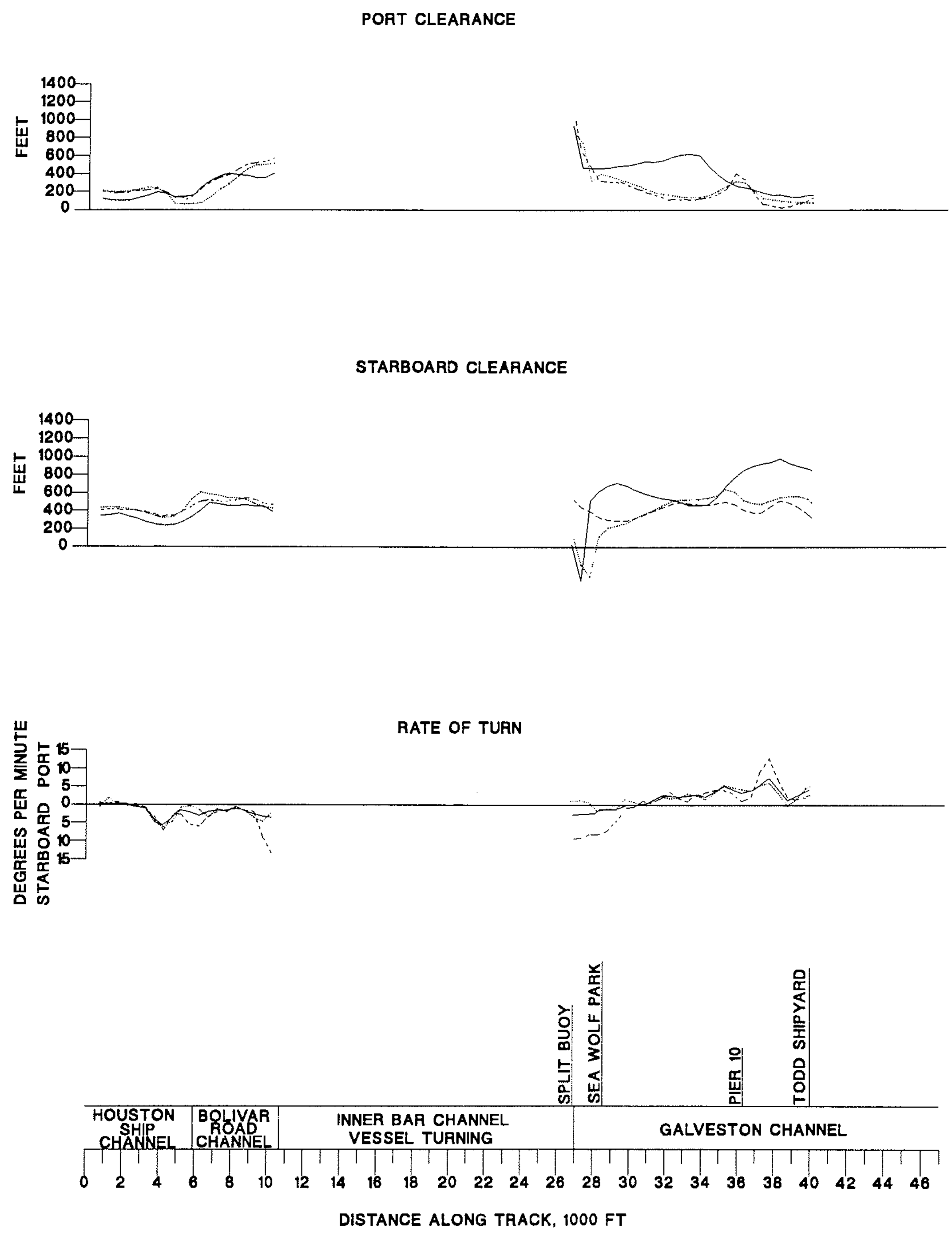
SHIP TRACK PLOTS, TEST REACH C
PHASE I CONDITIONS, FLOOD TIDE

Plate 83

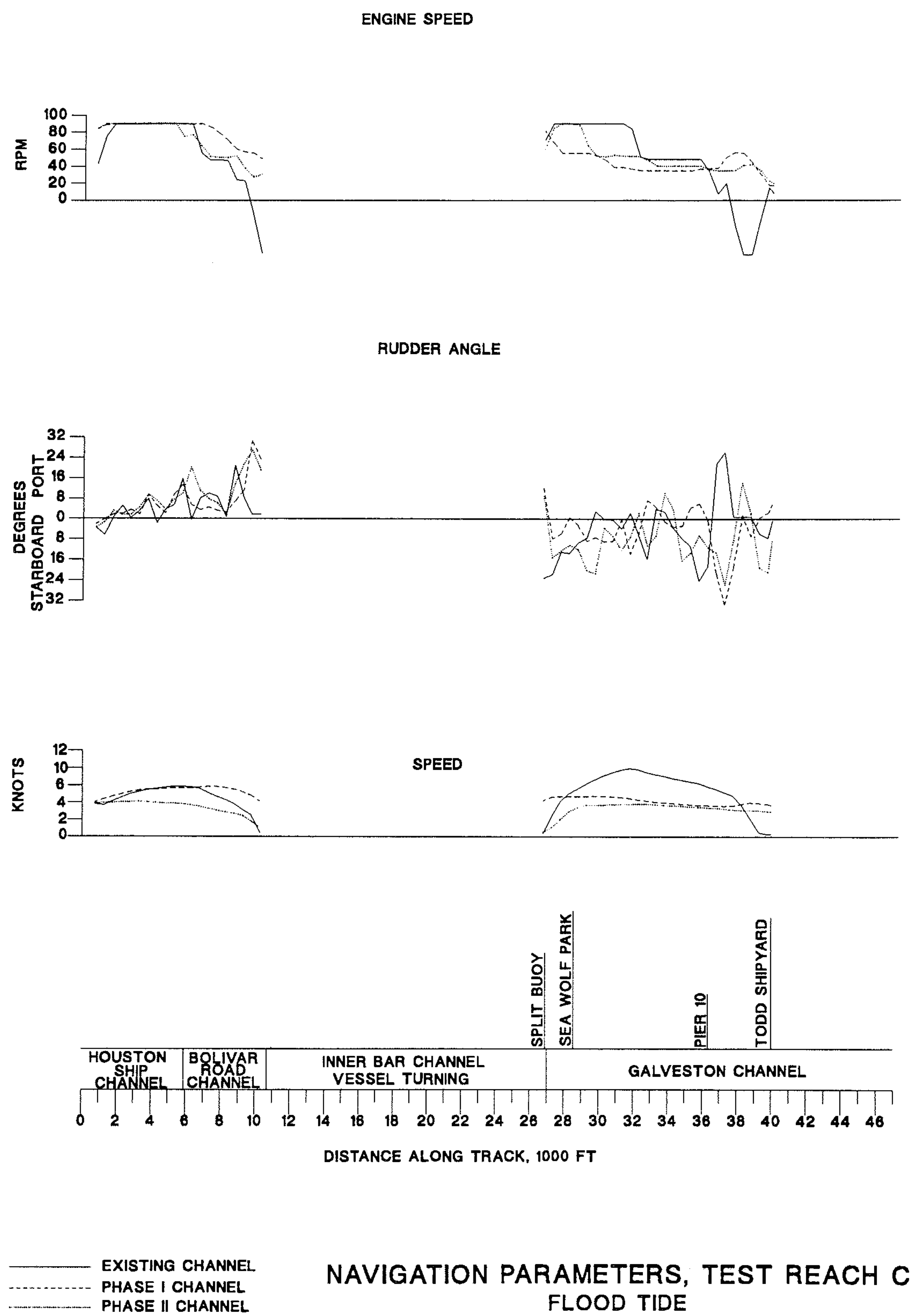


SHIP TRACK PLOTS, TEST REACH C
PHASE II CONDITIONS, FLOOD TIDE

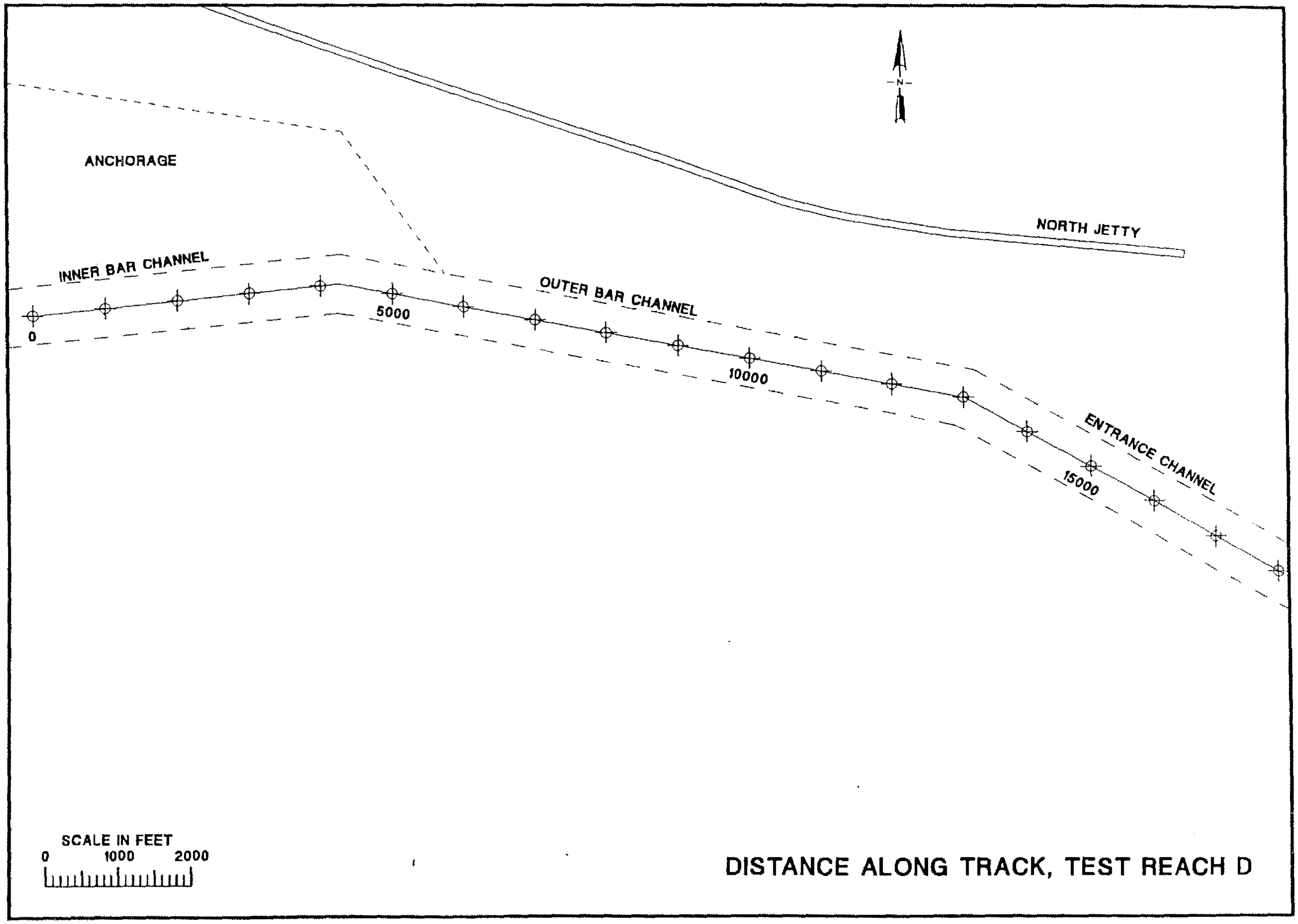
Plate 84



NAVIGATION PARAMETERS, TEST REACH C
FLOOD TIDE

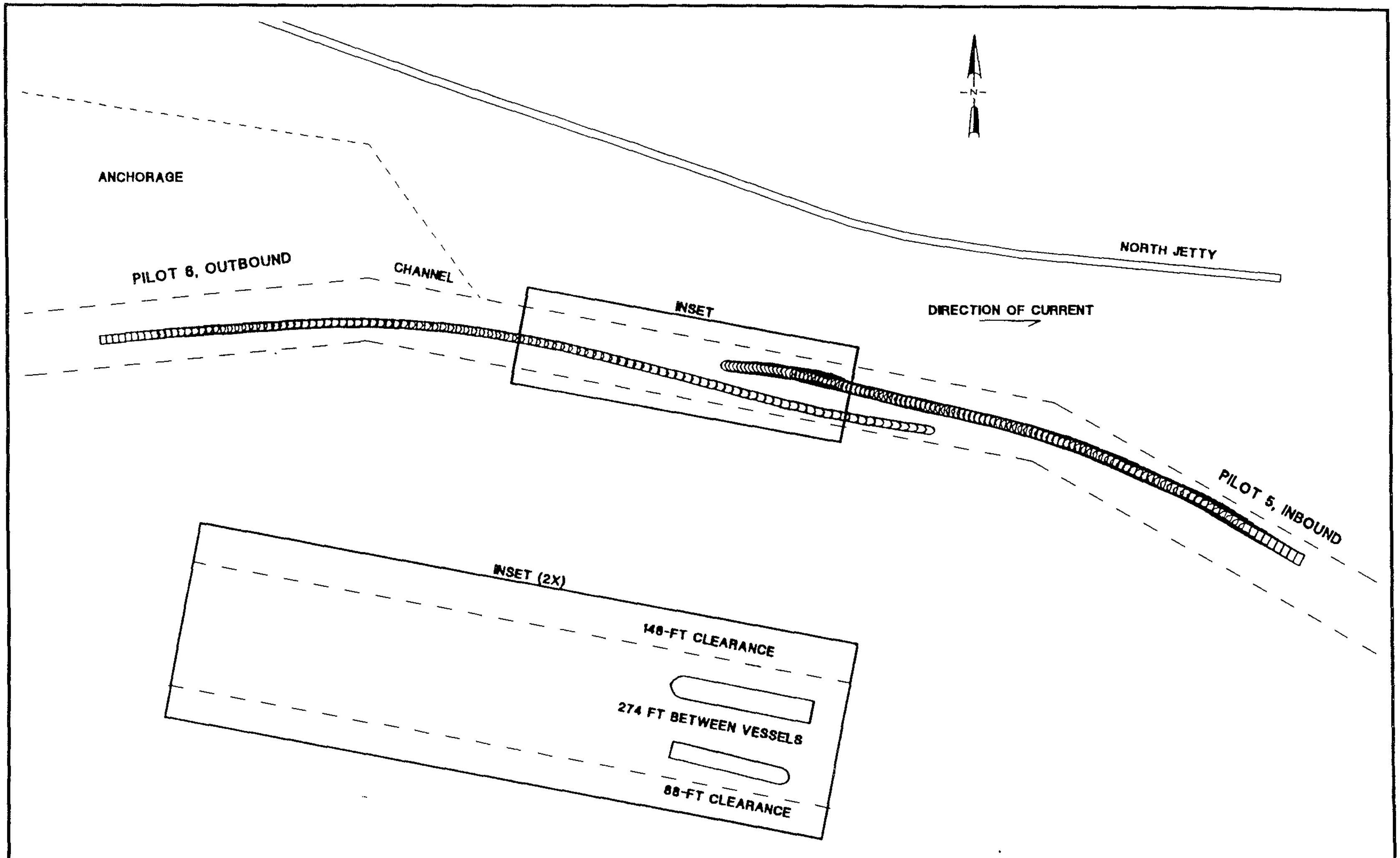


NAVIGATION PARAMETERS, TEST REACH C
FLOOD TIDE

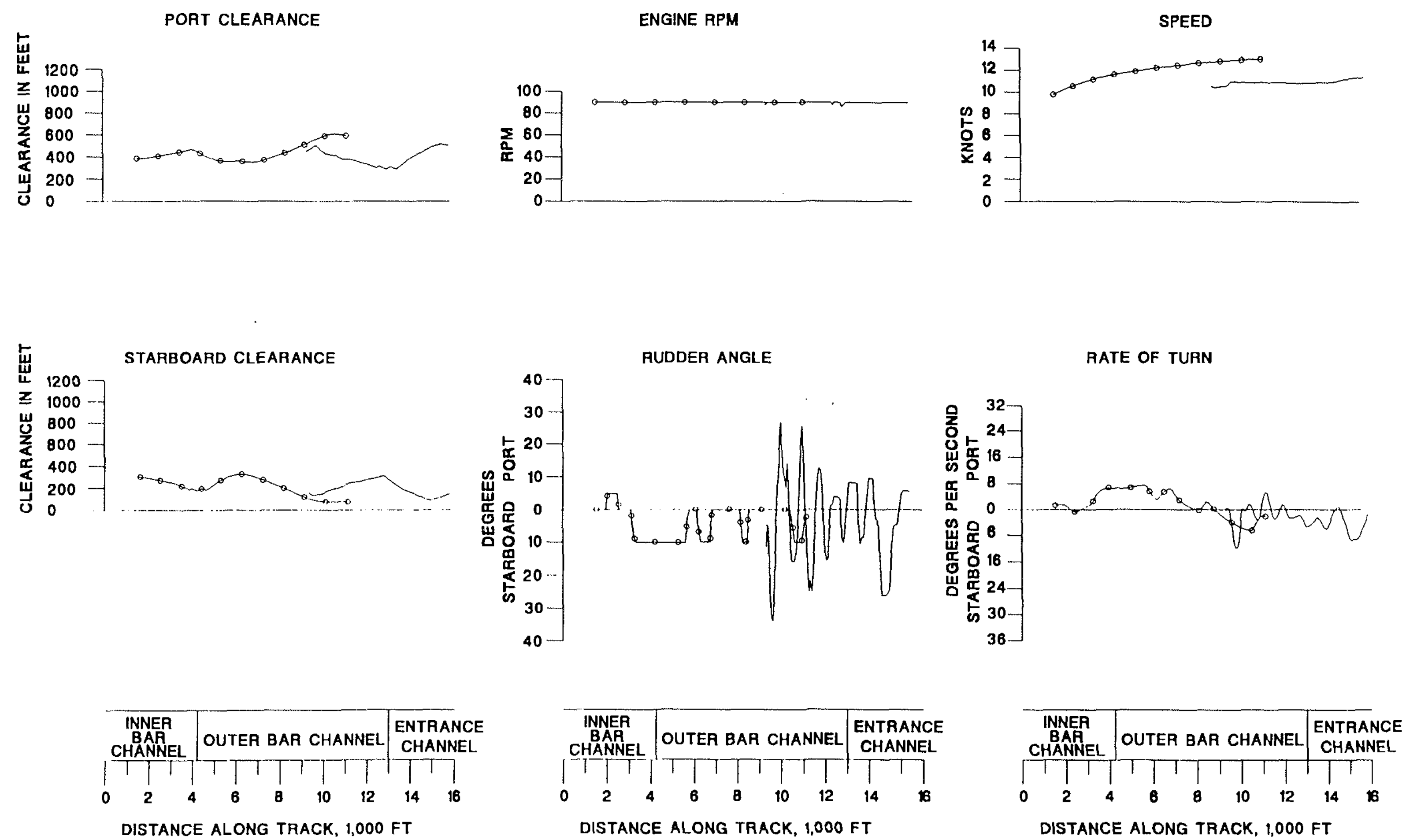


DISTANCE ALONG TRACK, TEST REACH D

Plate 88



SHIP TRACK PLOTS, TEST REACH D
EXISTING CONDITIONS, EBB TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



PILOT 5 INBOUND

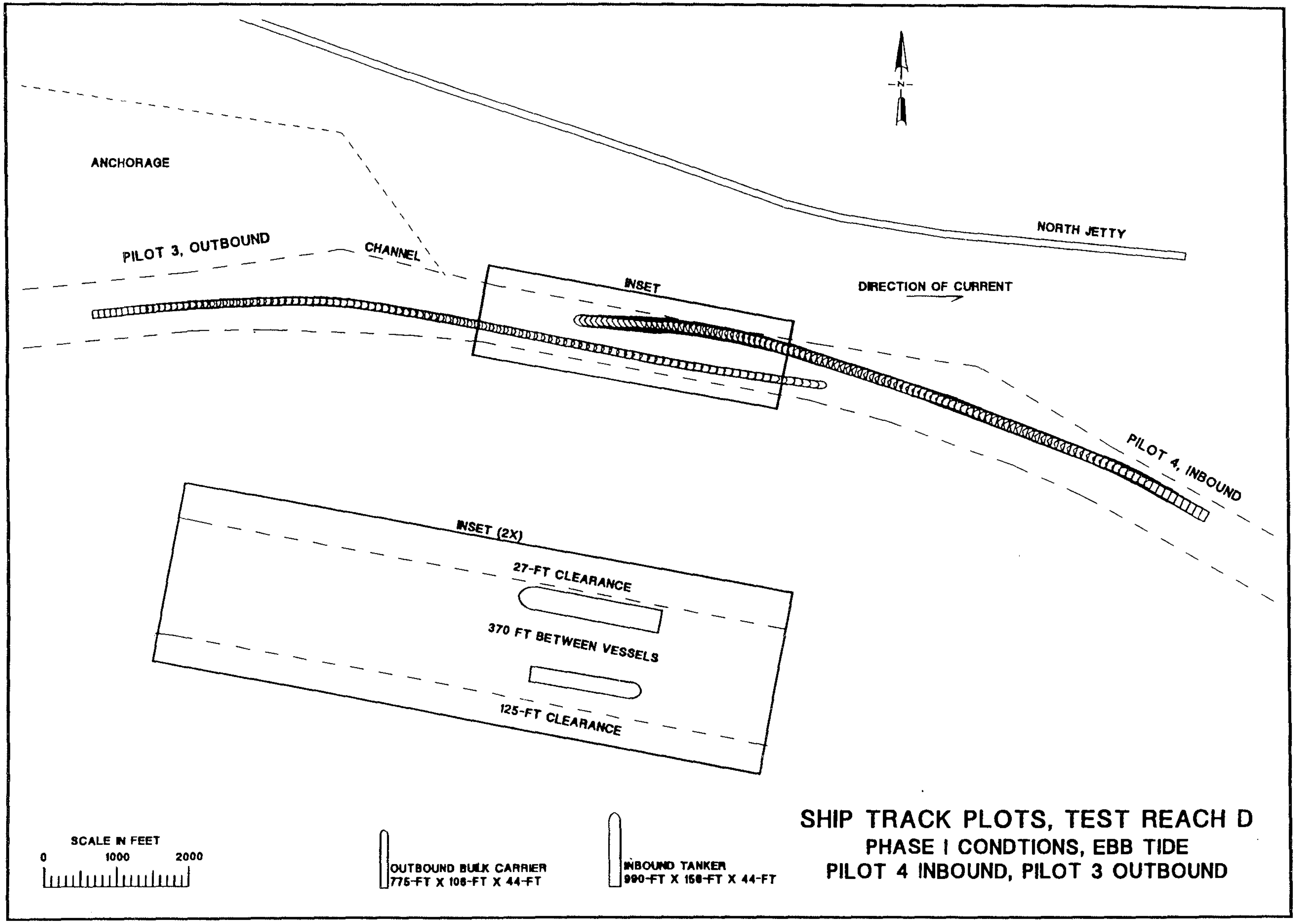
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D

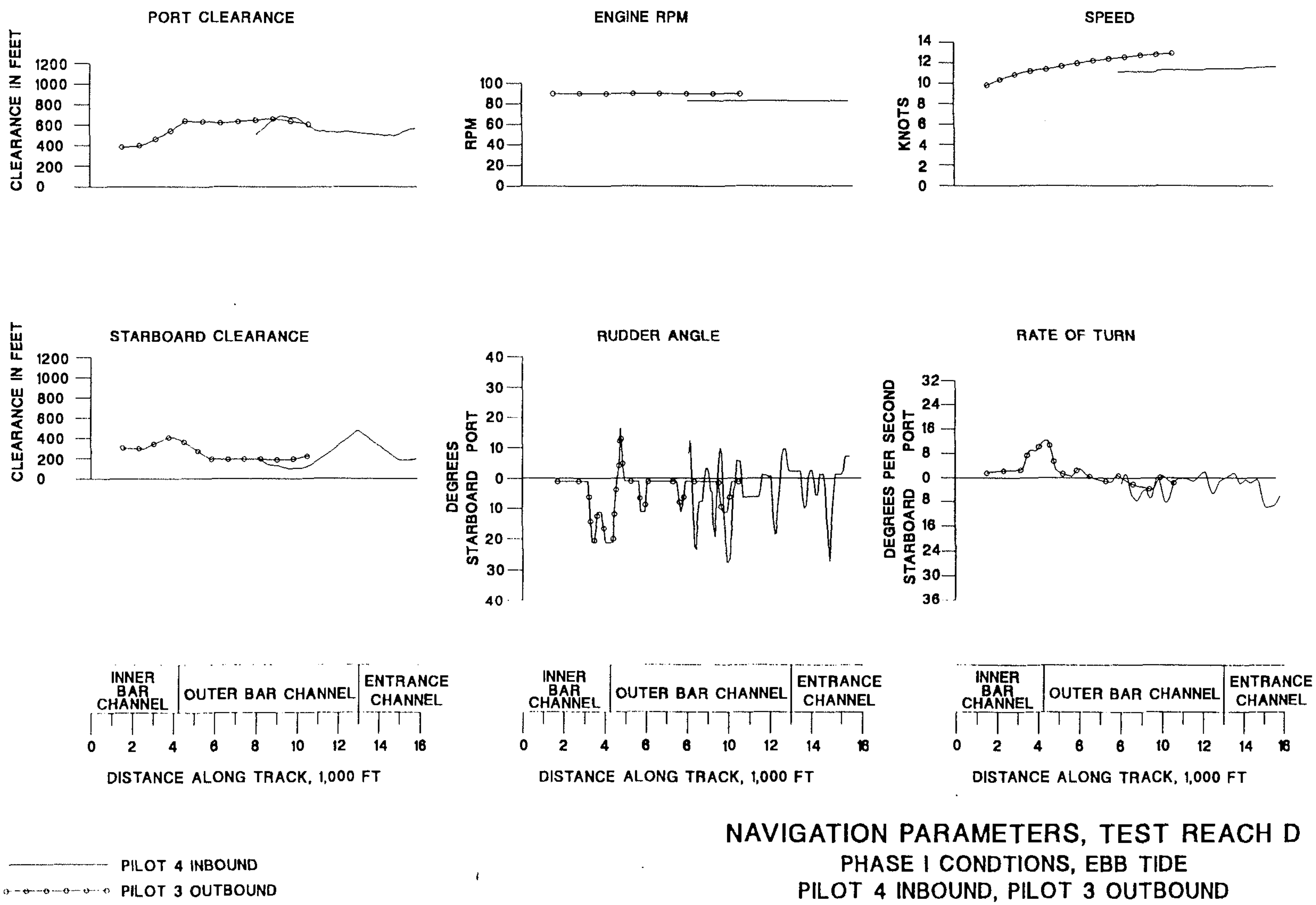
EXISTING CONDITIONS, EBB TIDE

PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 90



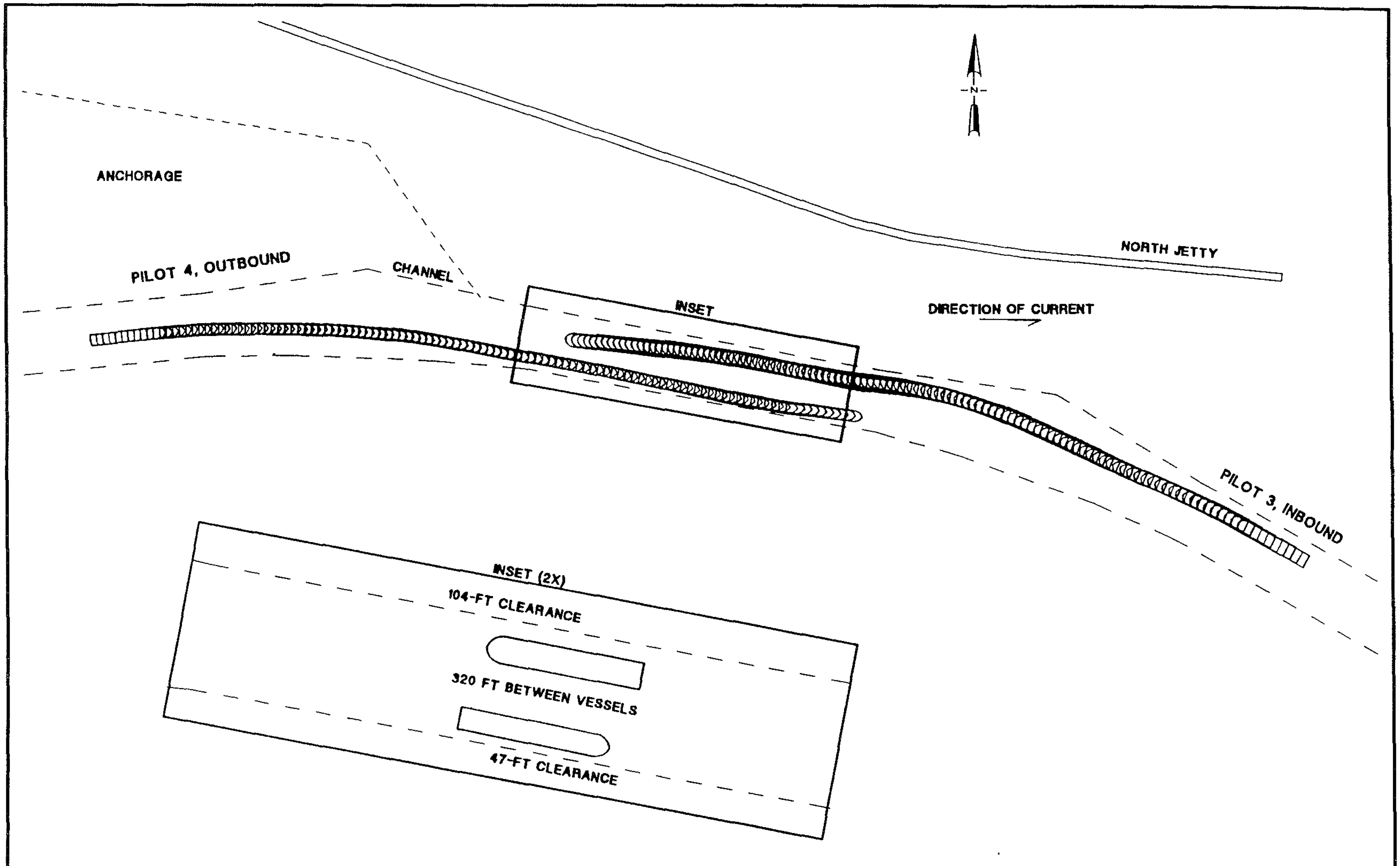
SHIP TRACK PLOTS, TEST REACH D
PHASE I CONDTIONS, EBB TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



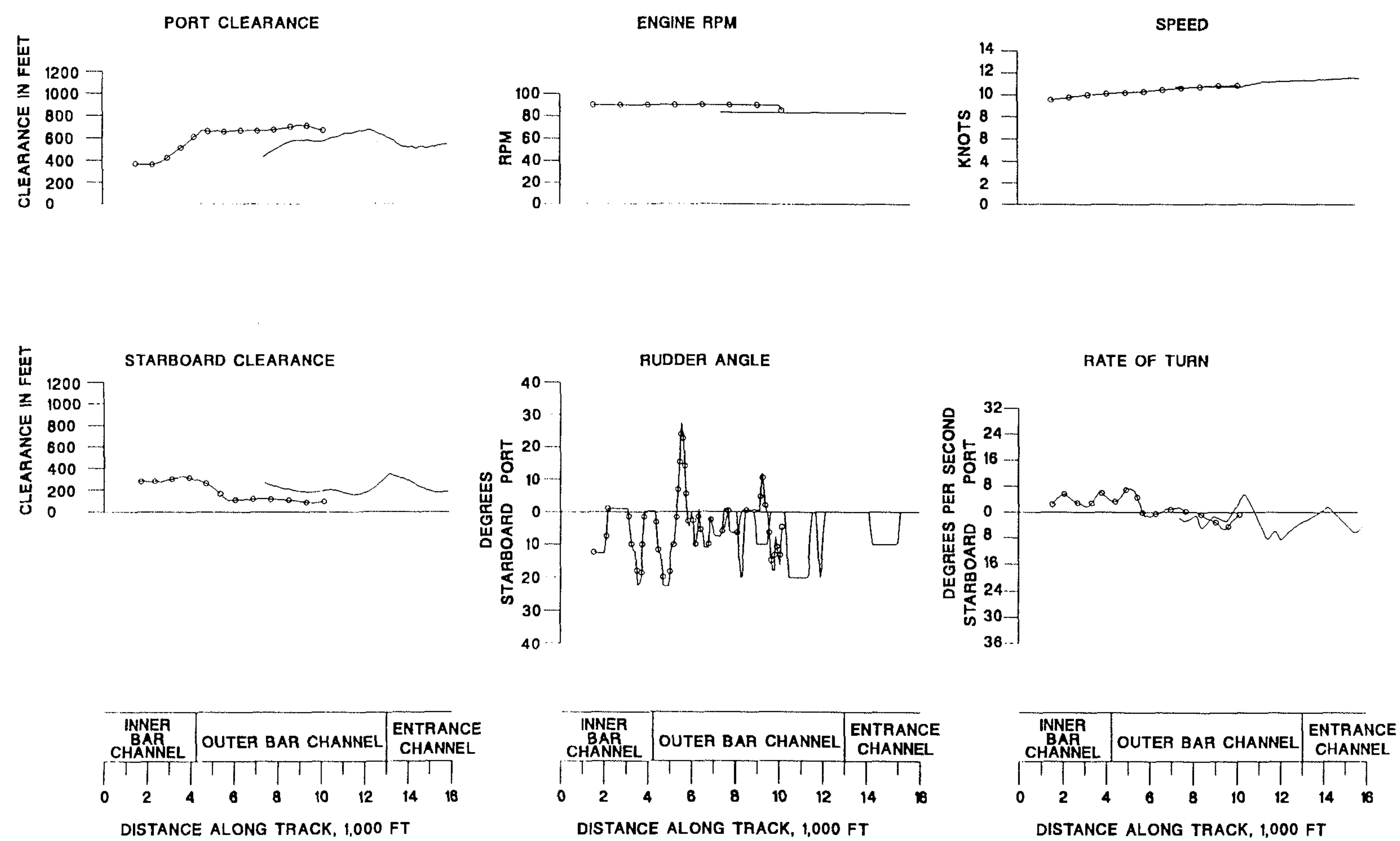
NAVIGATION PARAMETERS, TEST REACH D

PHASE I CONDTIONS, EBB TIDE

PILOT 4 INBOUND, PILOT 3 OUTBOUND



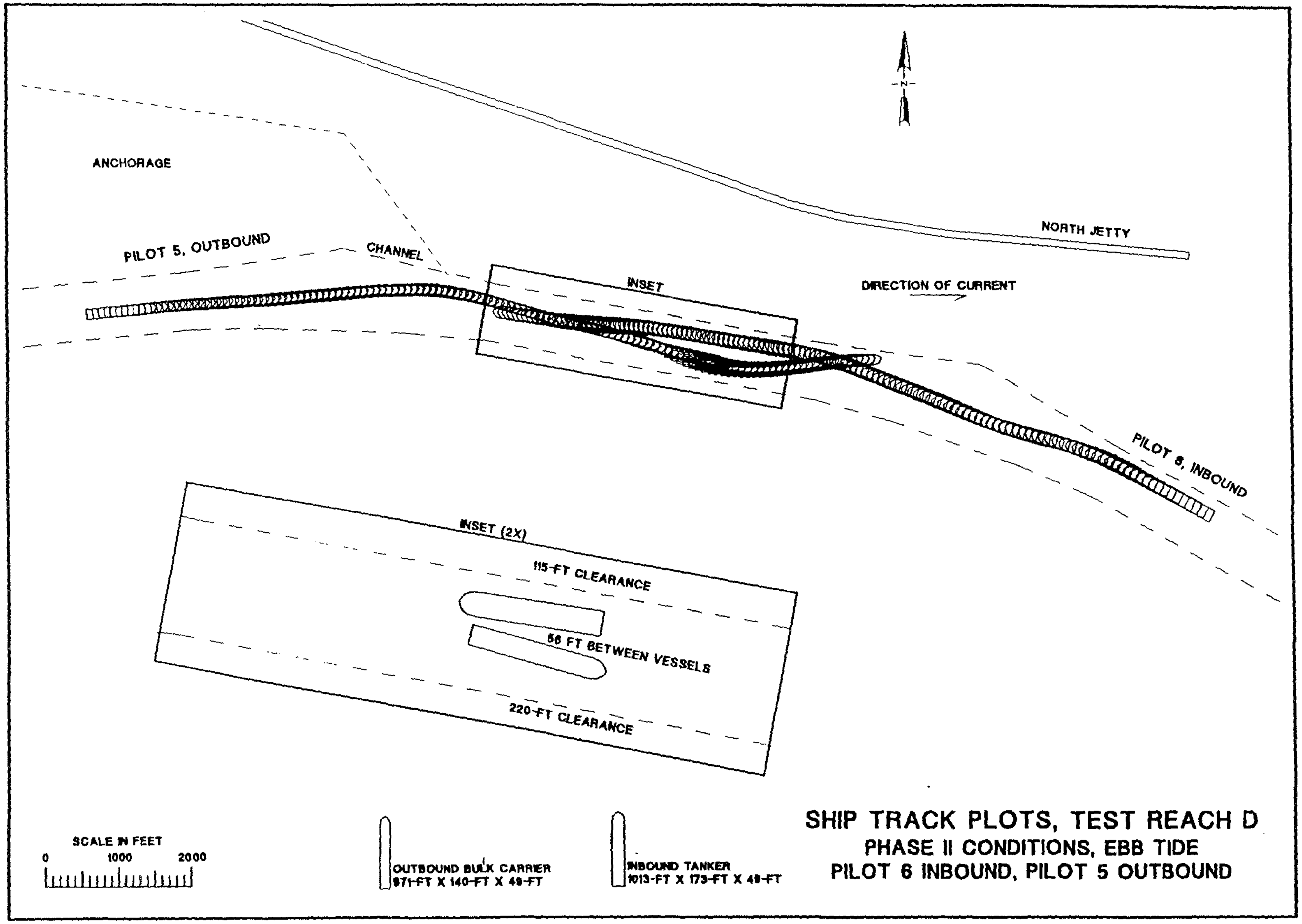
SHIP TRACK PLOTS, TEST REACH D
PHASE II CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



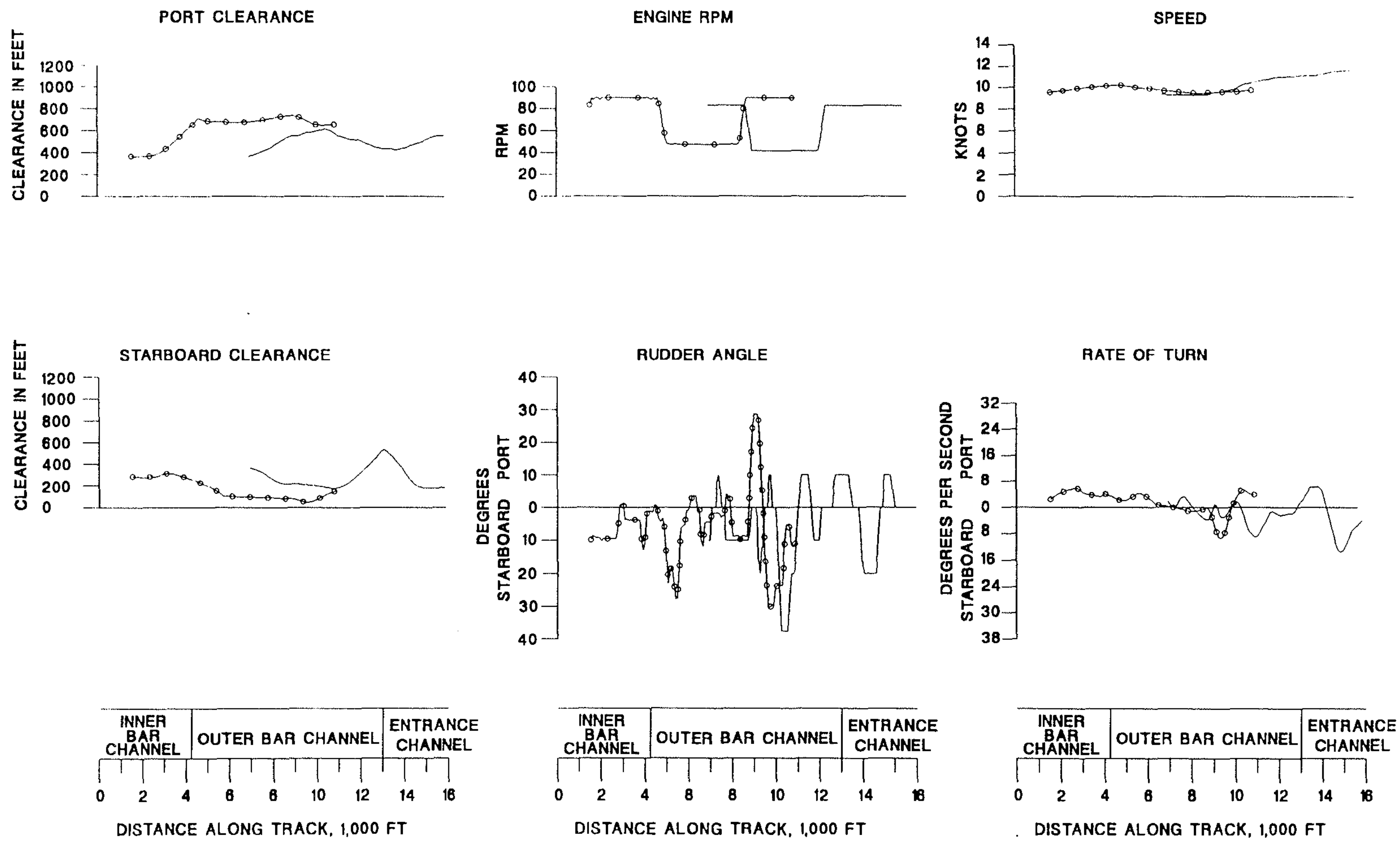
PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D
PHASE II CONDITIONS, EBB TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 94

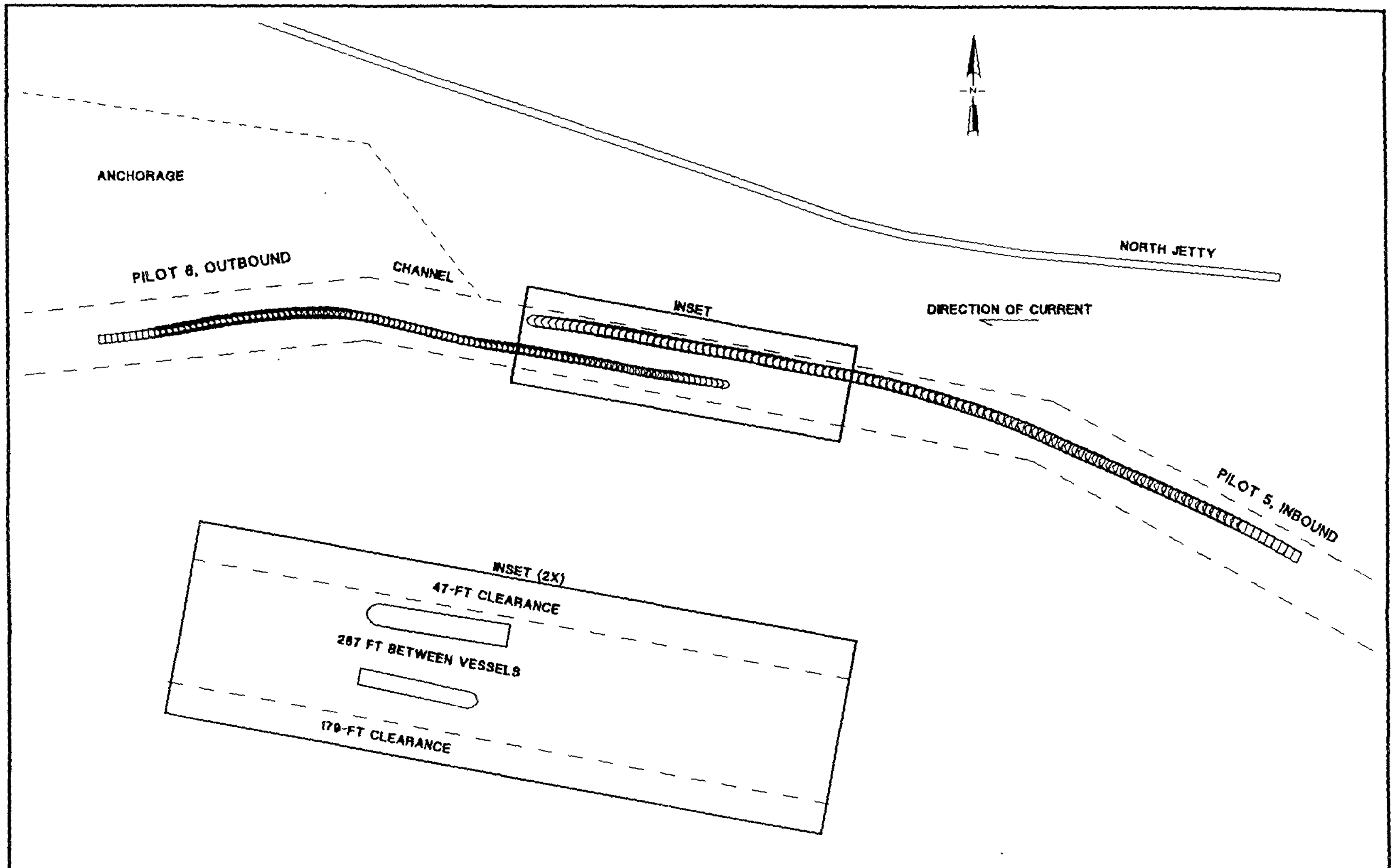


SHIP TRACK PLOTS, TEST REACH D
PHASE II CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

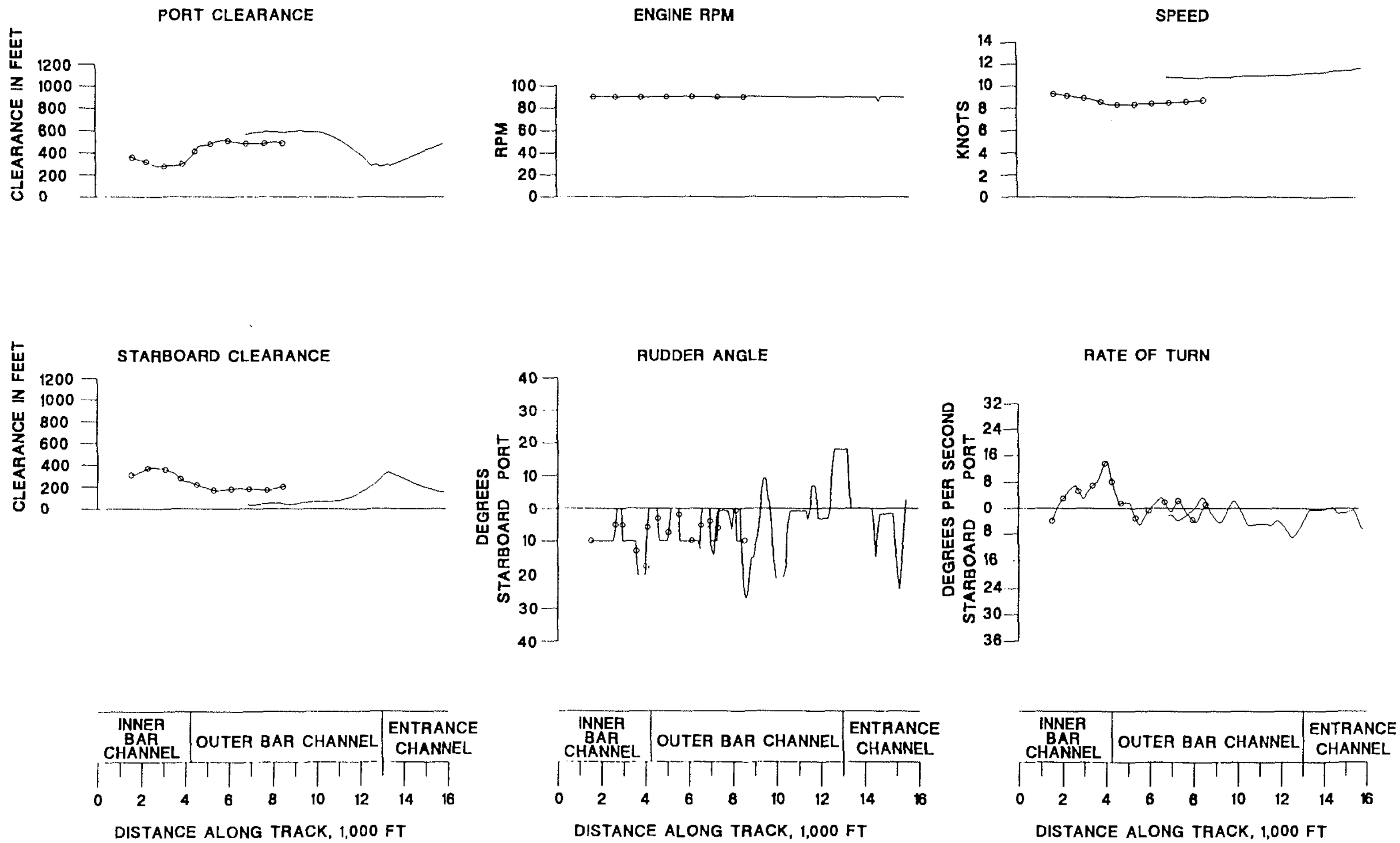


PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D
PHASE II CONDITIONS, EBB TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND

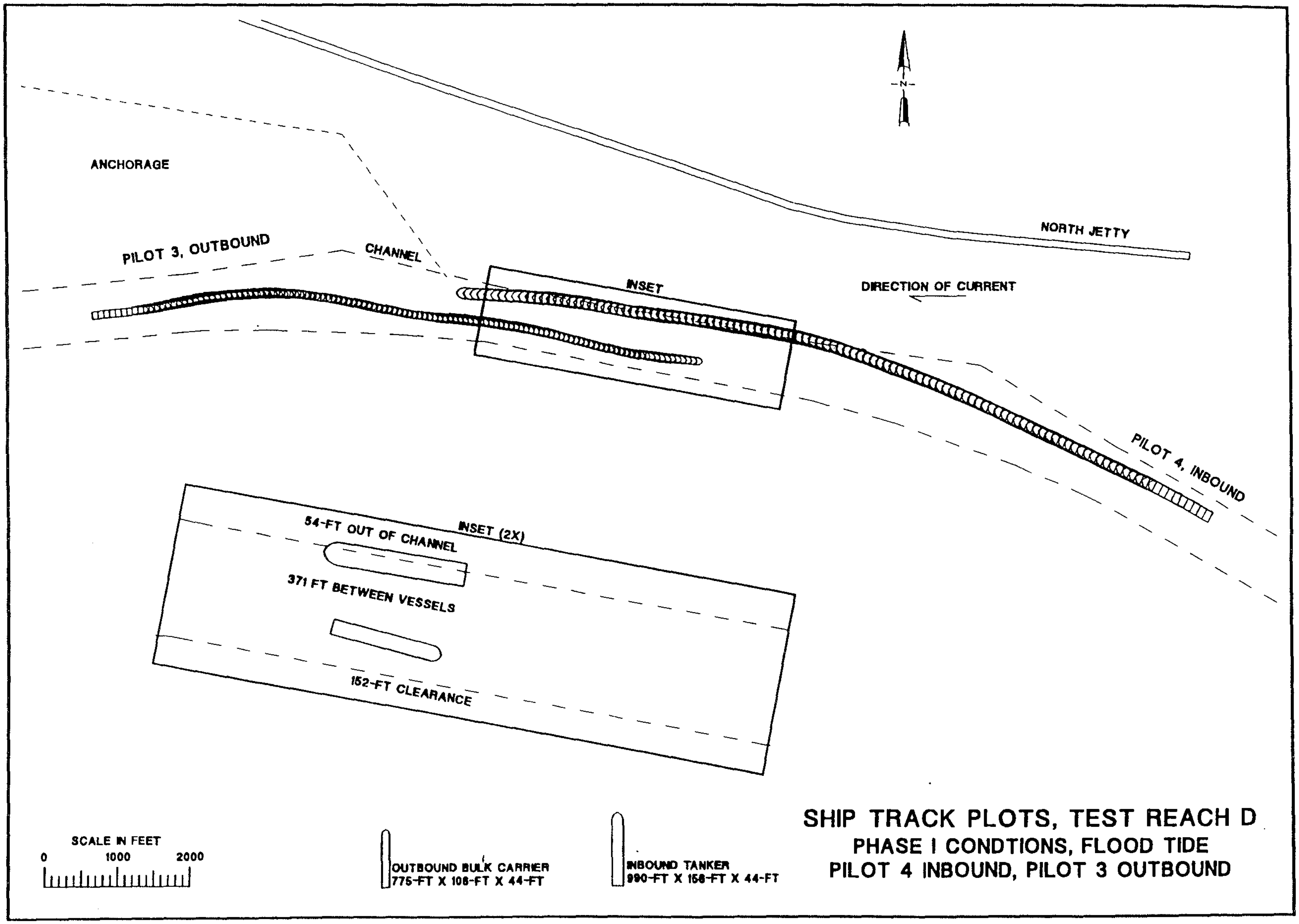


SHIP TRACK PLOTS, TEST REACH D
EXISTING CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



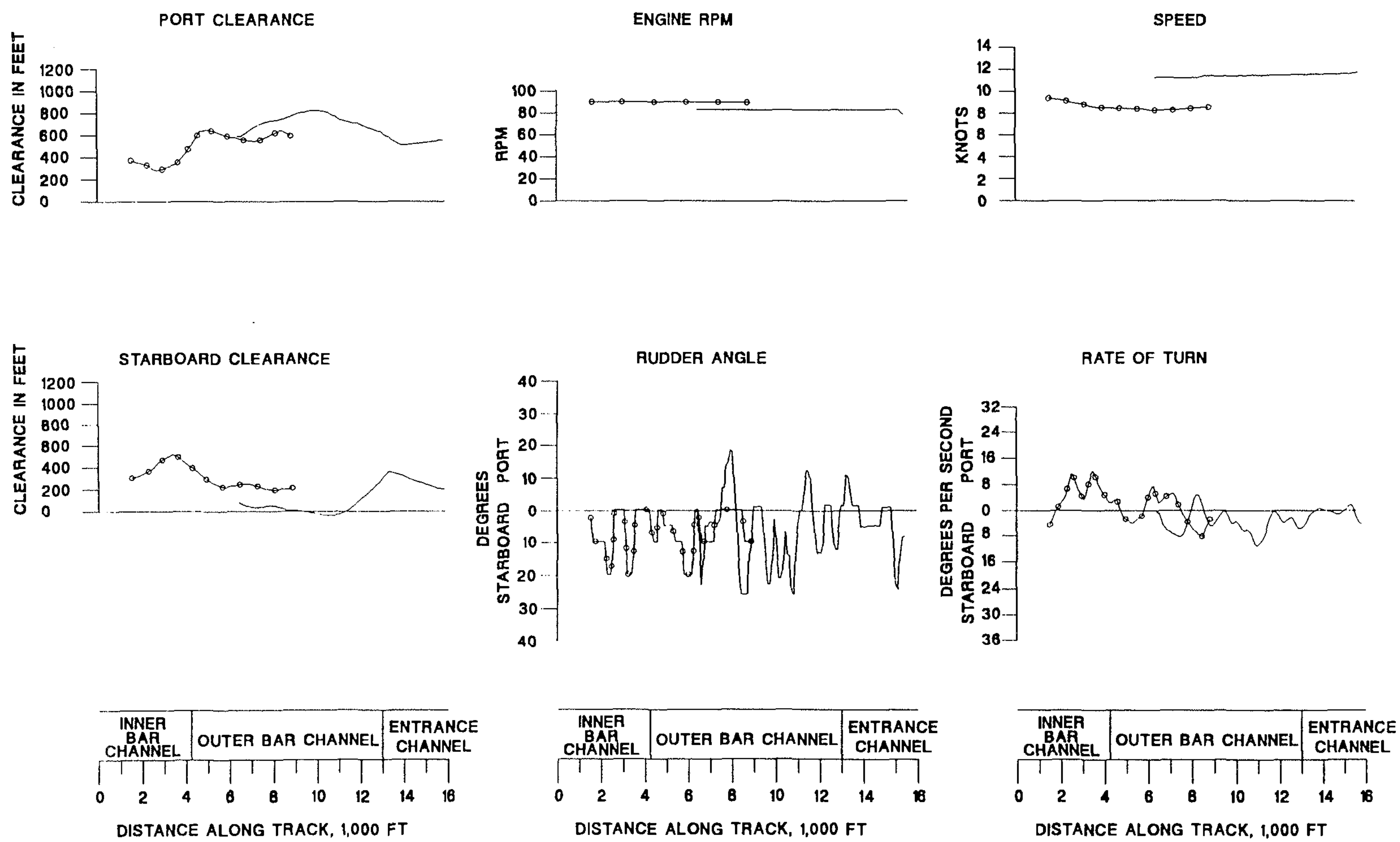
PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D
EXISTING CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



SHIP TRACK PLOTS, TEST REACH D
PHASE I CONDTIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND

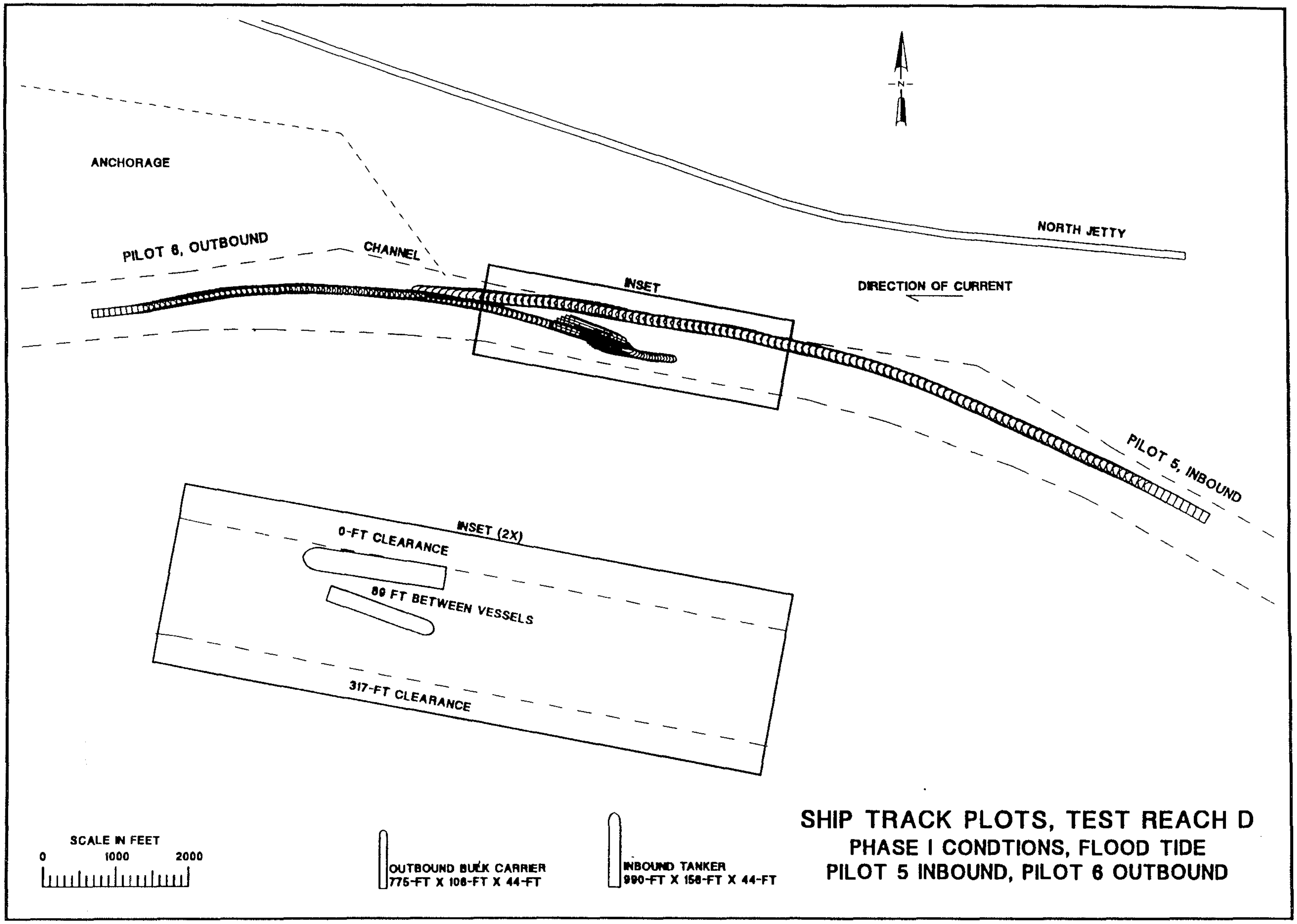
Plate 98



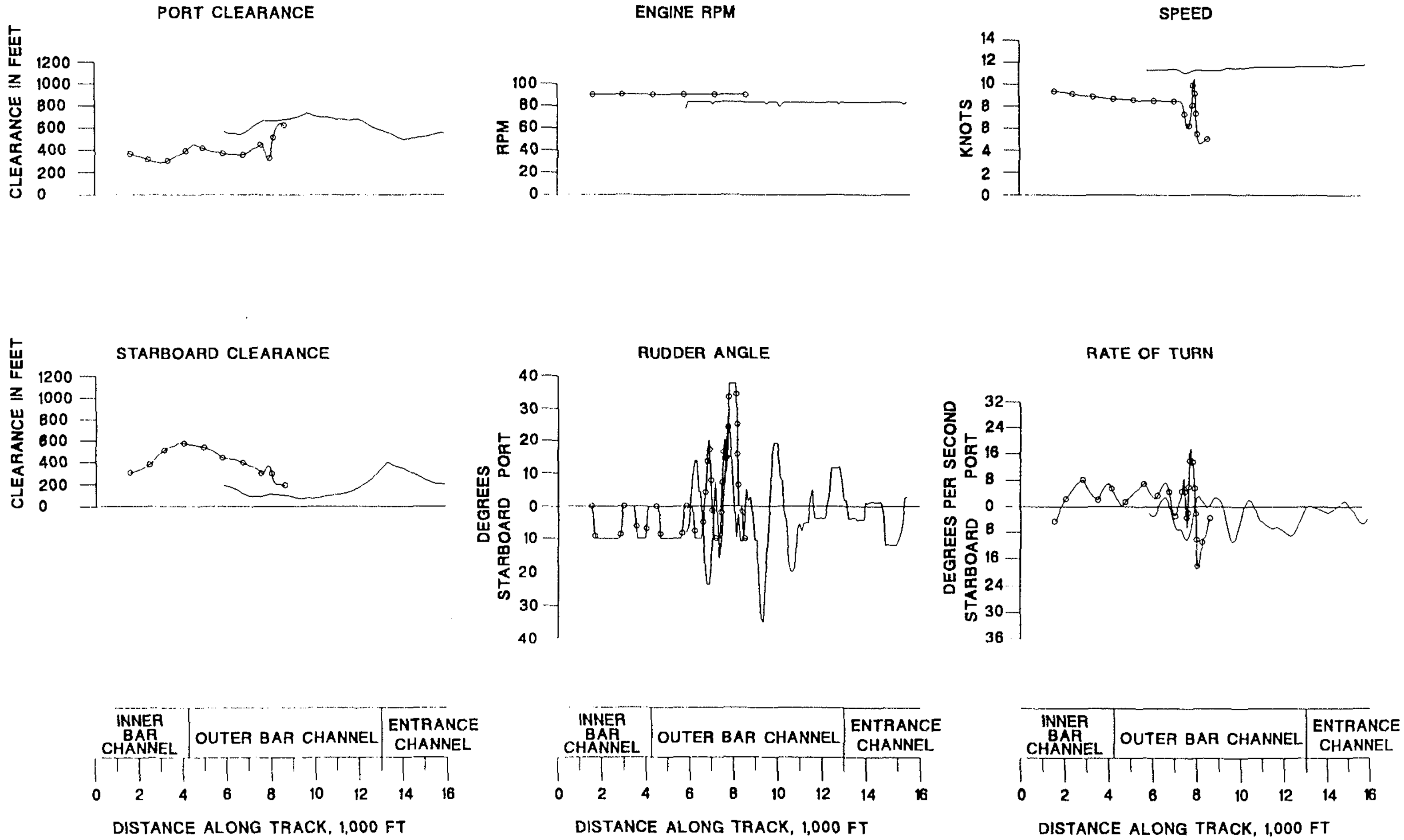
PILOT 4 INBOUND

PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D
PHASE I CONDTIONS, FLOOD TIDE
PILOT 4 INBOUND, PILOT 3 OUTBOUND



SHIP TRACK PLOTS, TEST REACH D
PHASE I CONDTIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



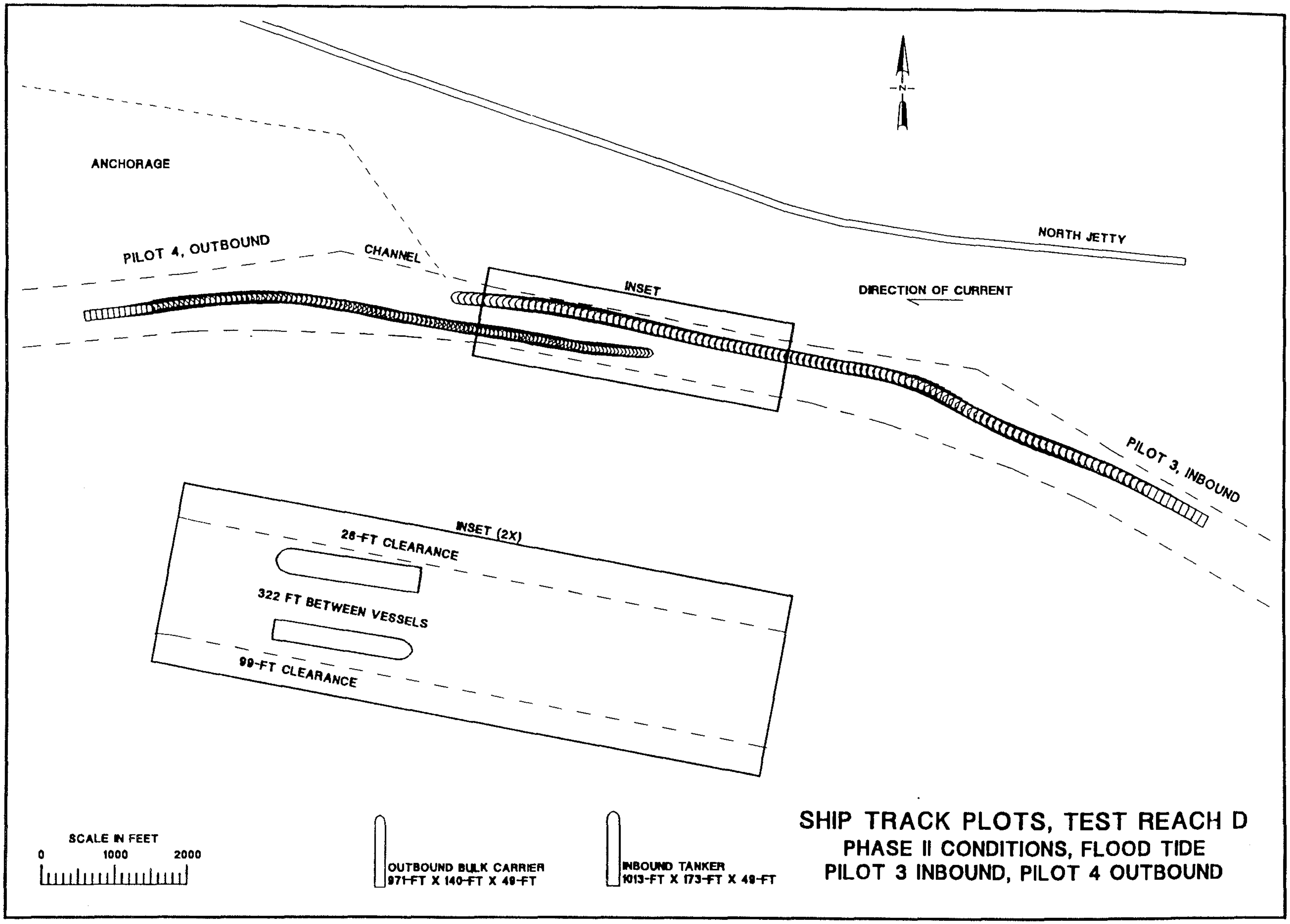
PILOT 5 INBOUND

PILOT 6 OUTBOUND

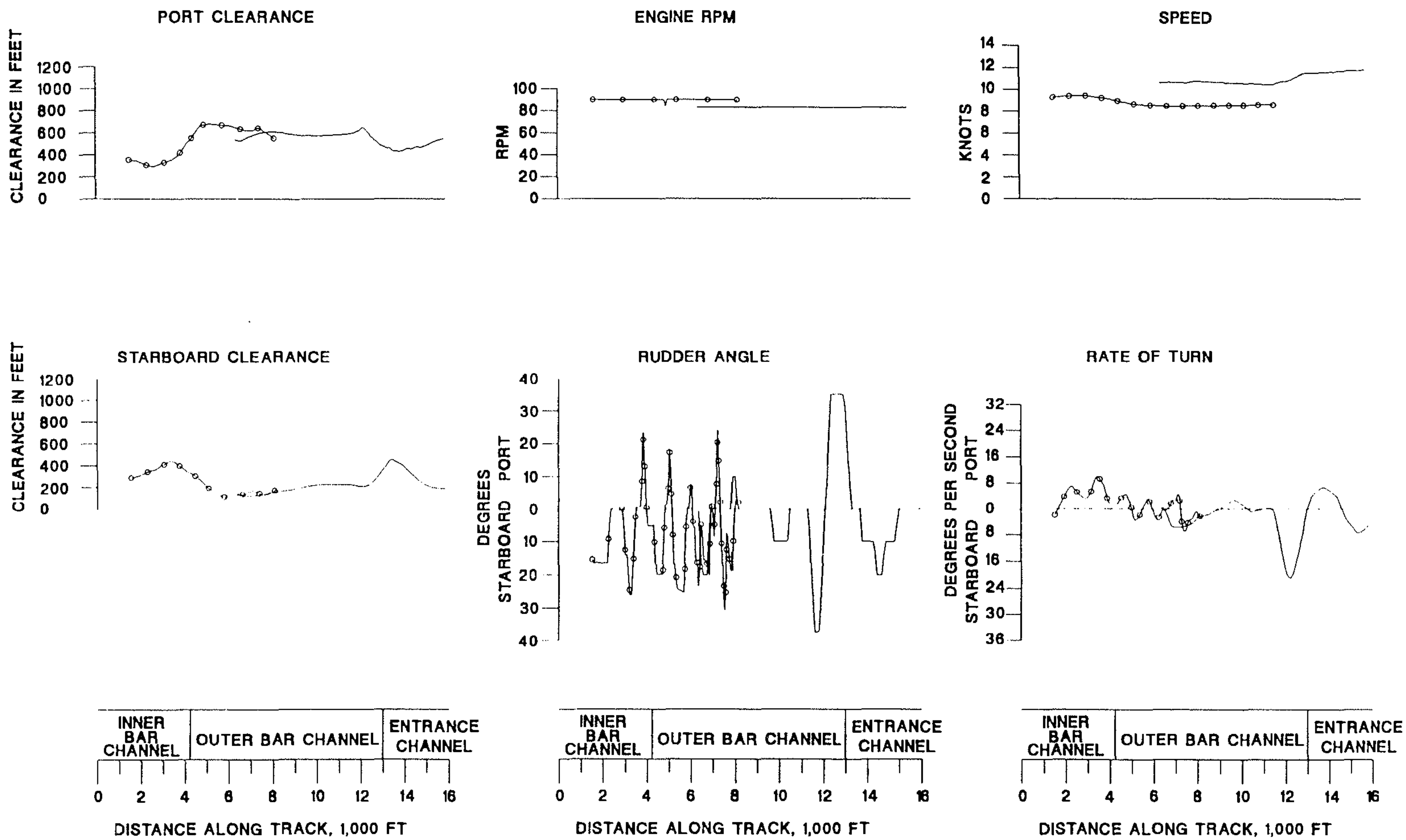
NAVIGATION PARAMETERS, TEST REACH D

PHASE I CONDTIONS, FLOOD TIDE

PILOT 5 INBOUND, PILOT 6 OUTBOUND



SHIP TRACK PLOTS, TEST REACH D
PHASE II CONDITIONS, FLOOD TIDE
PILOT 3 INBOUND, PILOT 4 OUTBOUND



———— PILOT 3 INBOUND

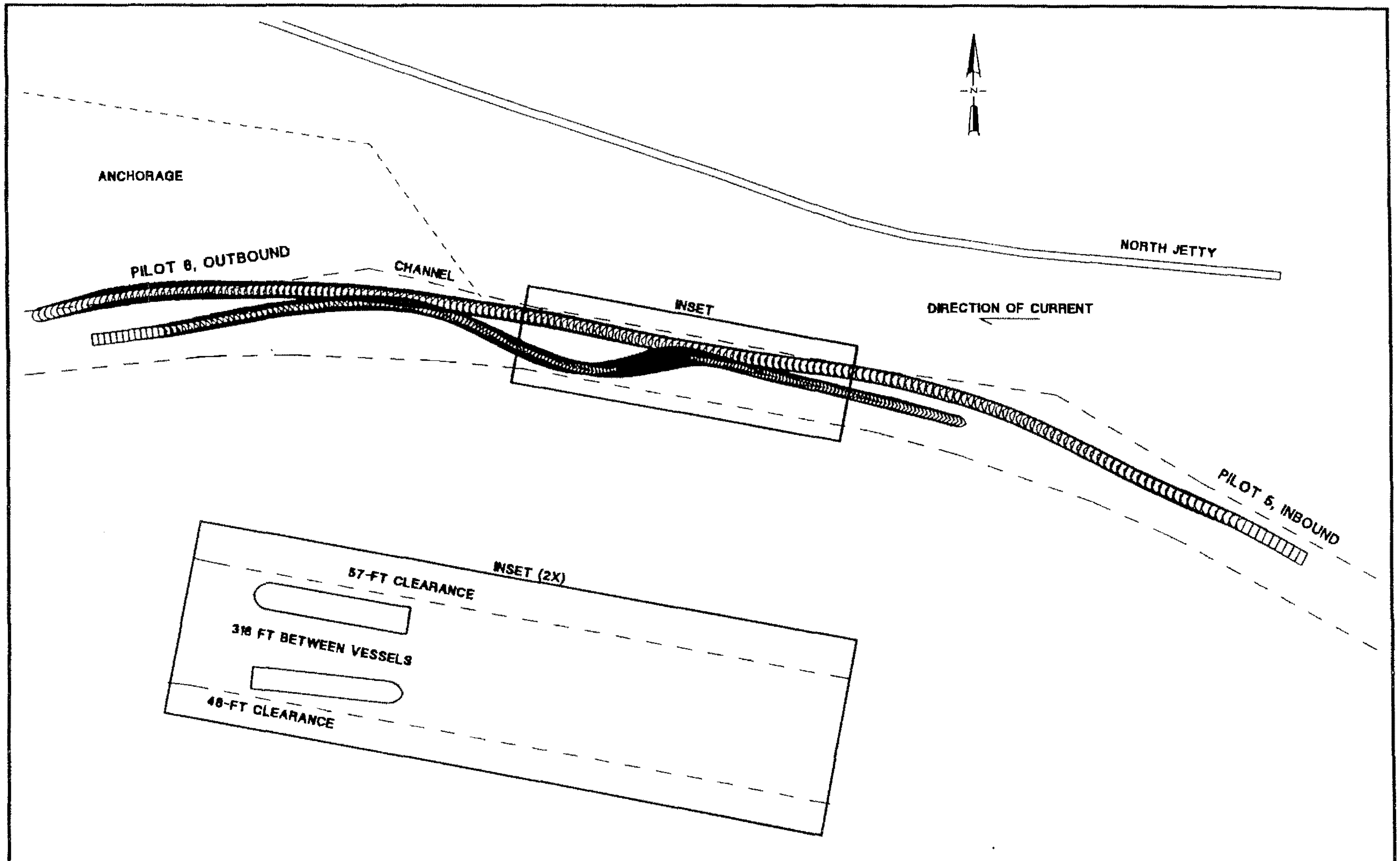
-o-o-o-o-o- PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D

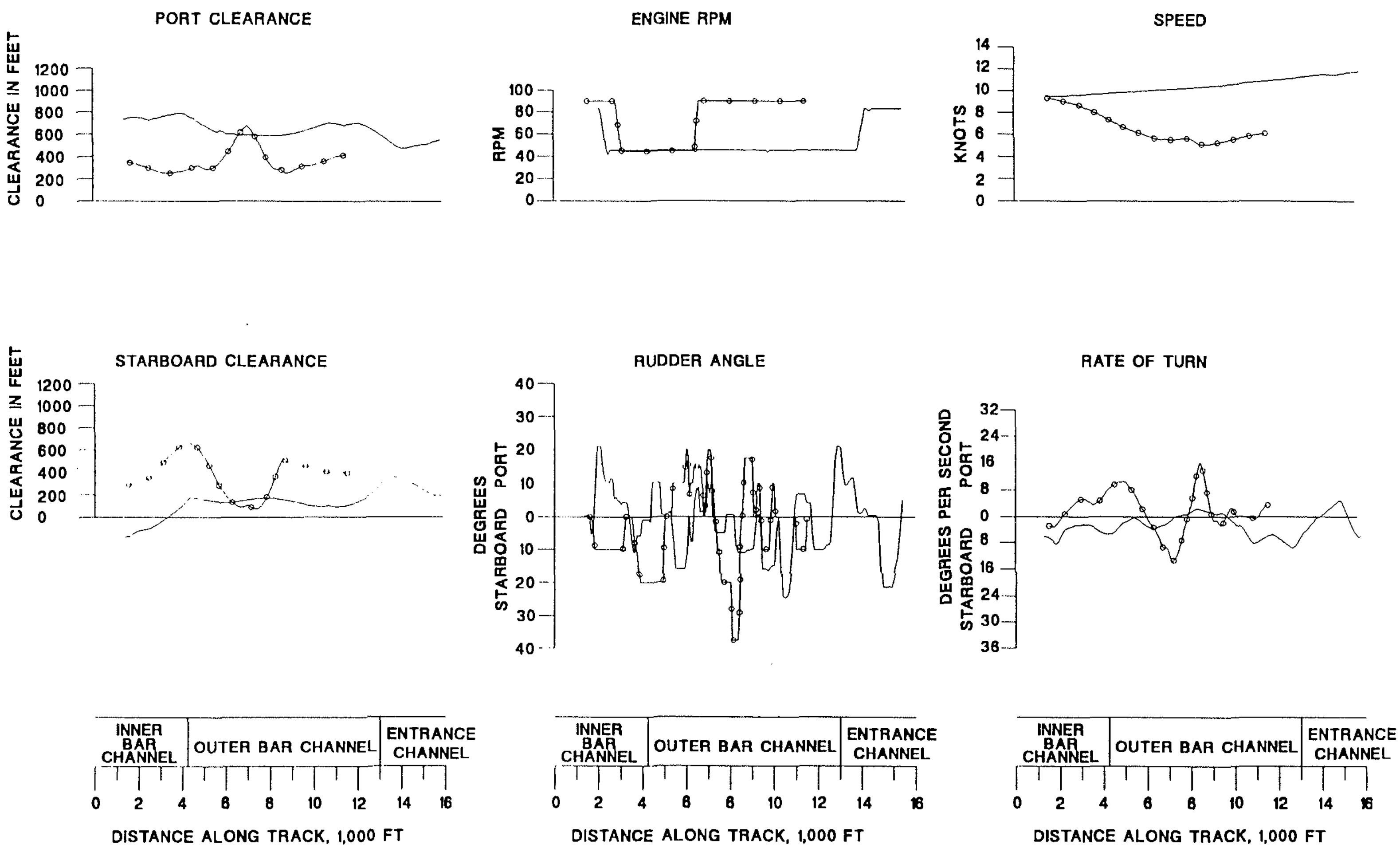
PHASE II CONDITIONS, FLOOD TIDE

PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 104

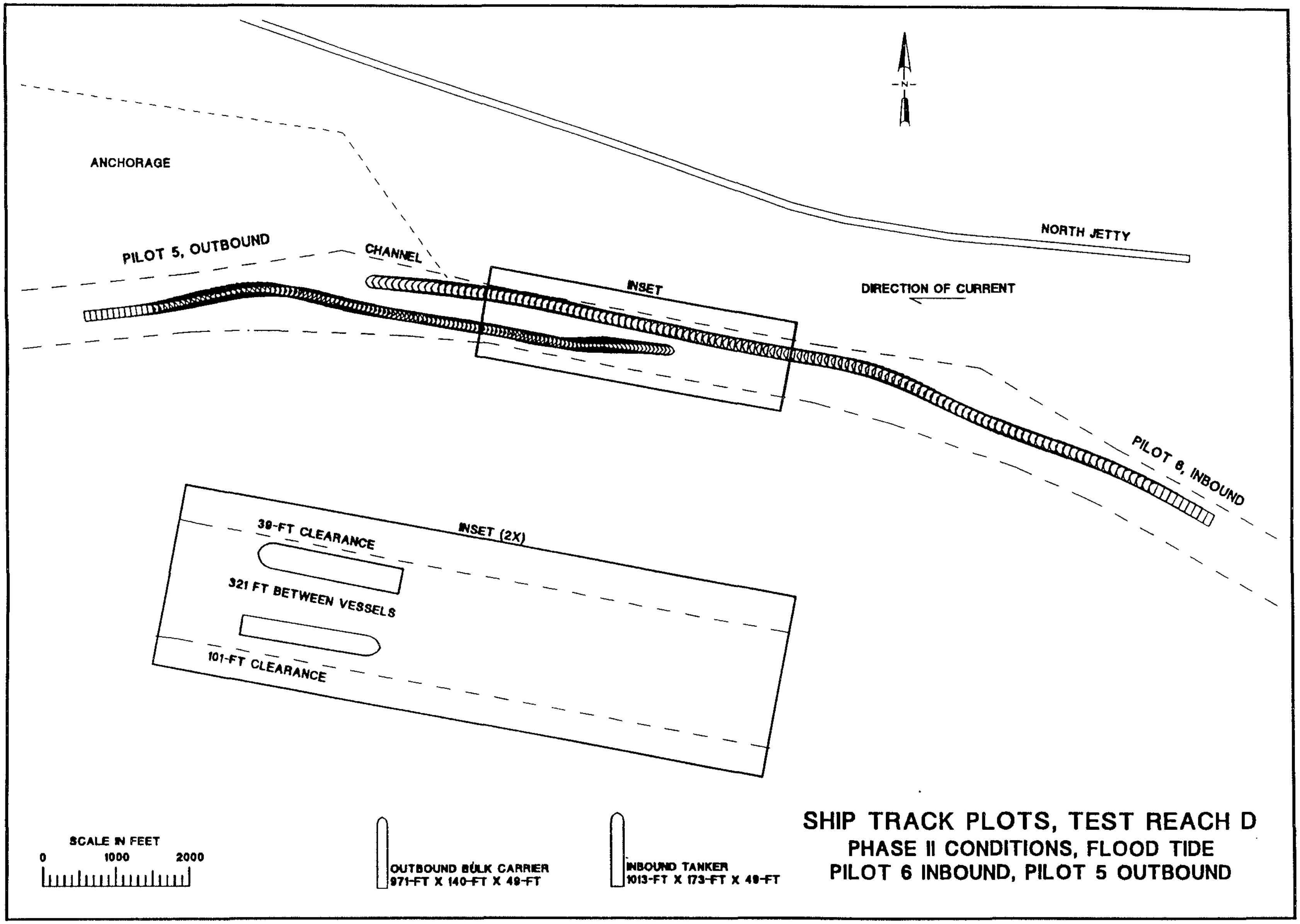


SHIP TRACK PLOTS, TEST REACH D
PHASE II CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND

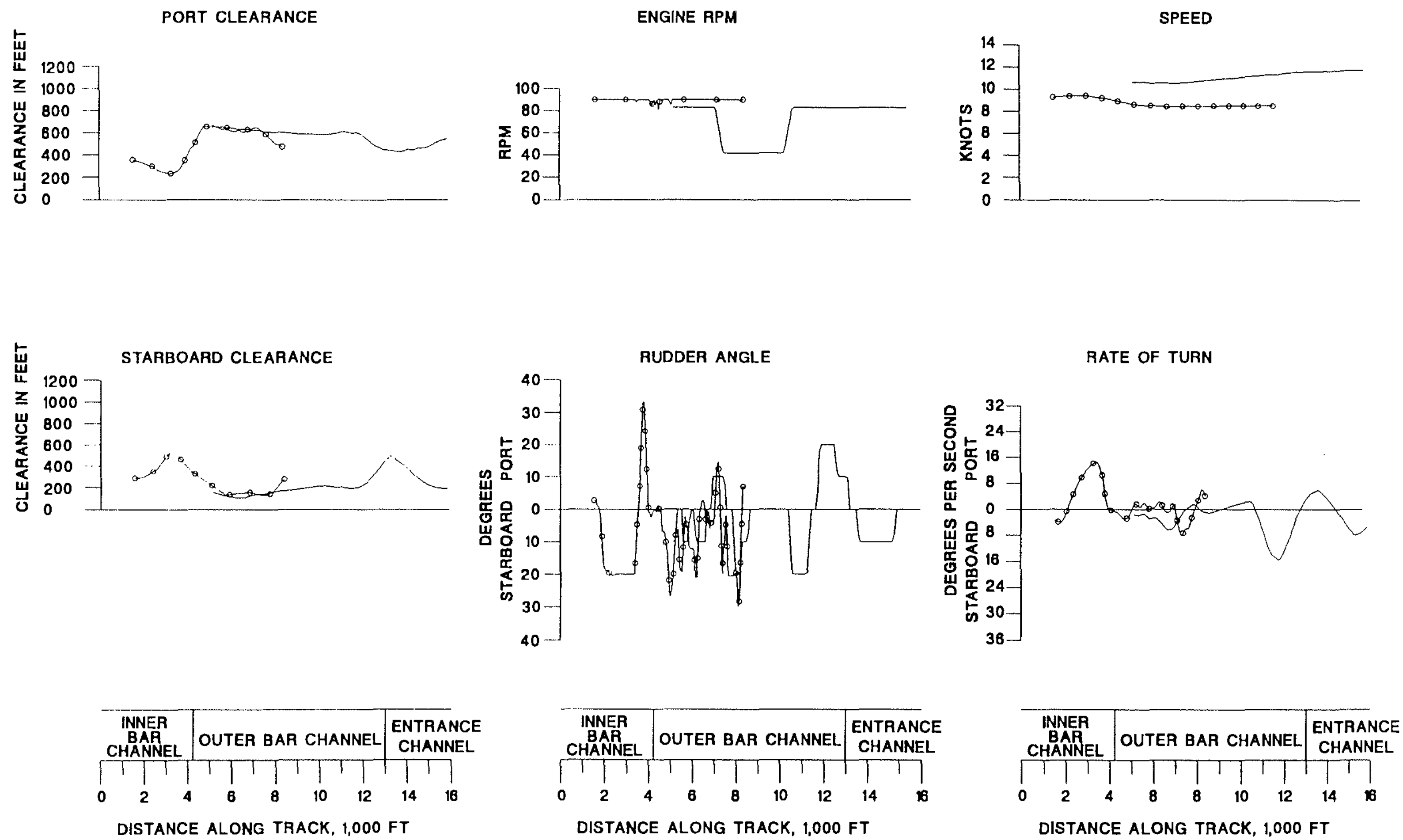


PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH D
PHASE II CONDITIONS, FLOOD TIDE
PILOT 5 INBOUND, PILOT 6 OUTBOUND



SHIP TRACK PLOTS, TEST REACH D
PHASE II CONDITIONS, FLOOD TIDE
PILOT 6 INBOUND, PILOT 5 OUTBOUND



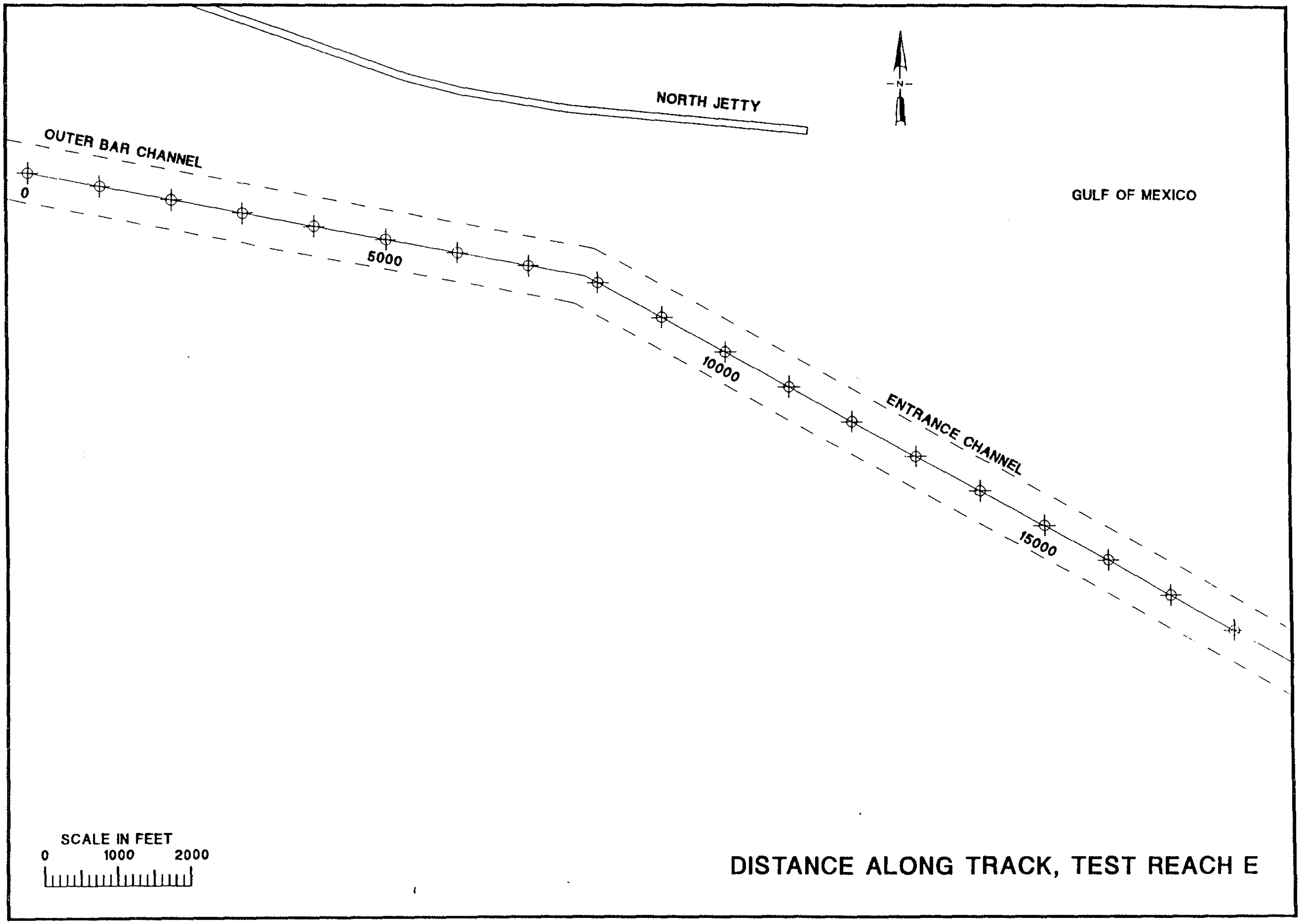
PILOT 6 INBOUND

PILOT 5 OUTBOUND

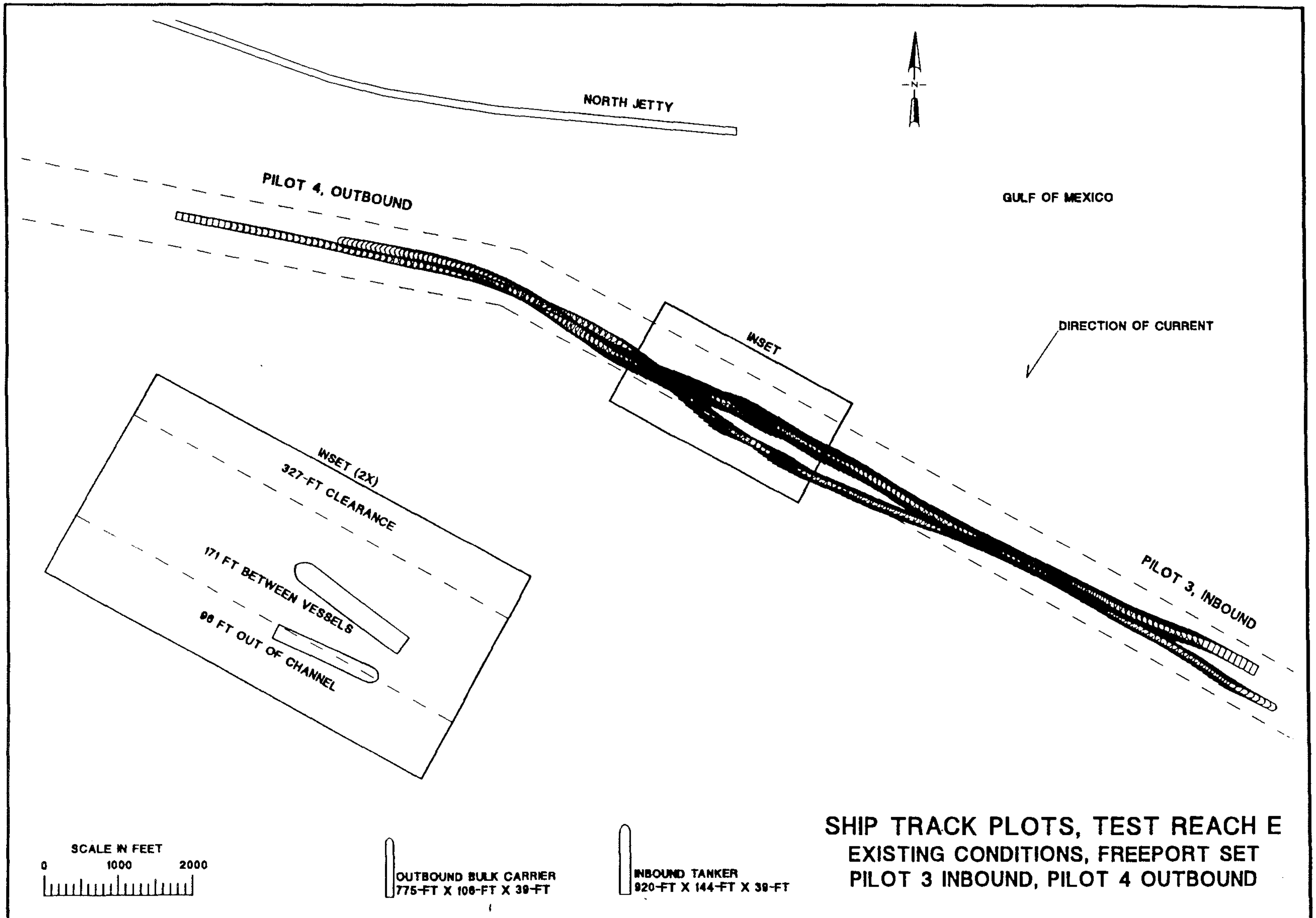
NAVIGATION PARAMETERS, TEST REACH D

PHASE II CONDITIONS, FLOOD TIDE

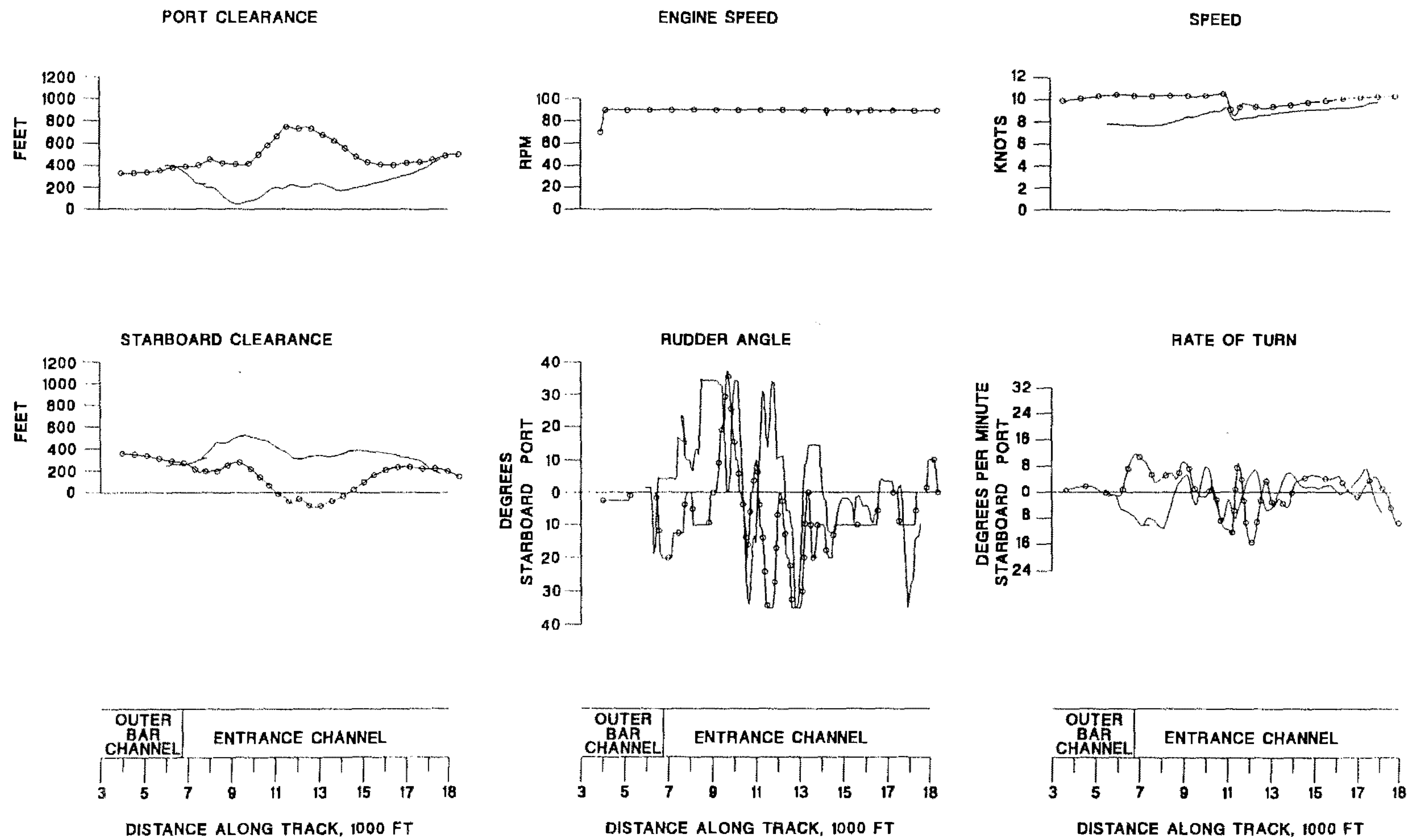
PILOT 6 INBOUND, PILOT 5 OUTBOUND



DISTANCE ALONG TRACK, TEST REACH E

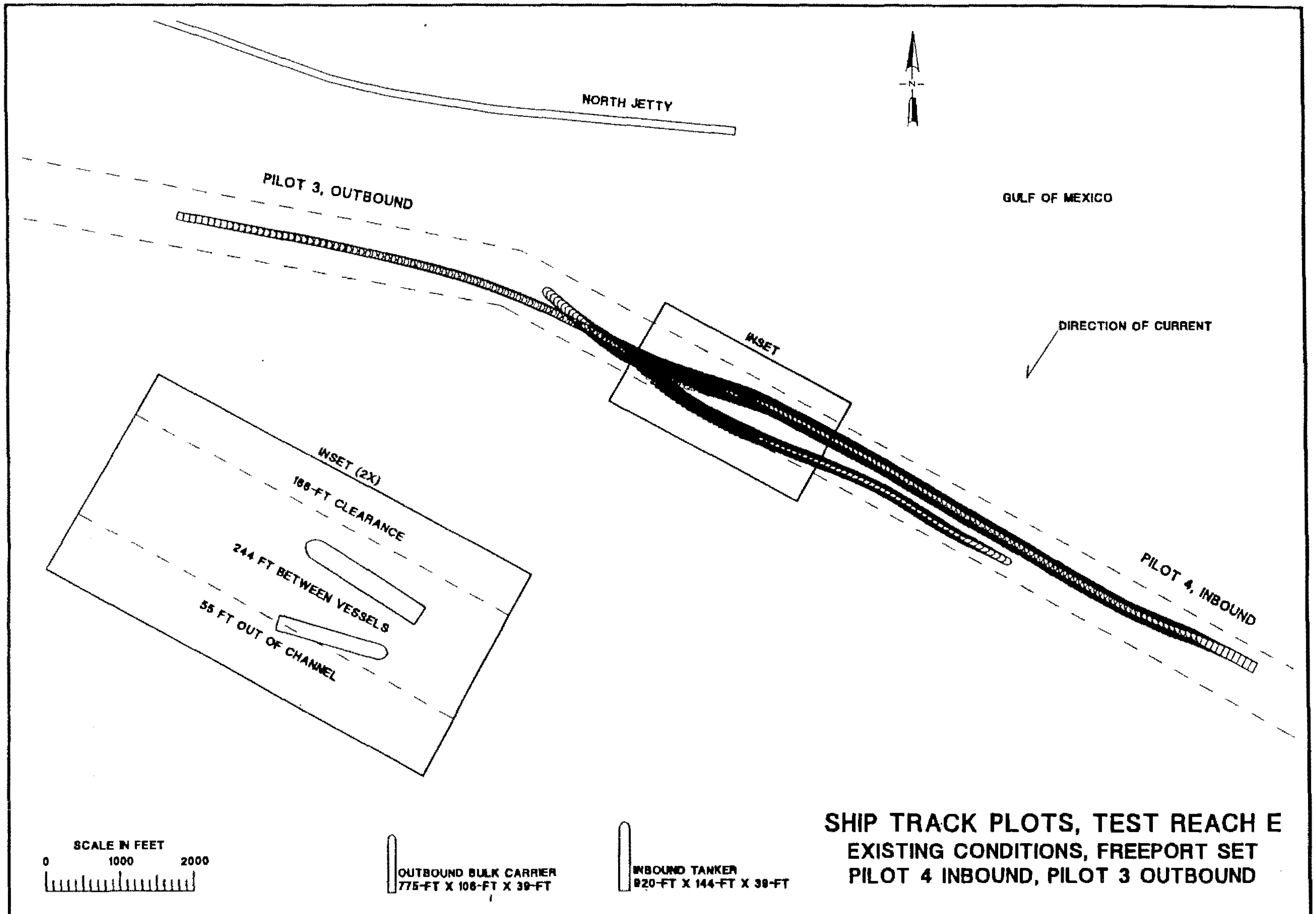


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

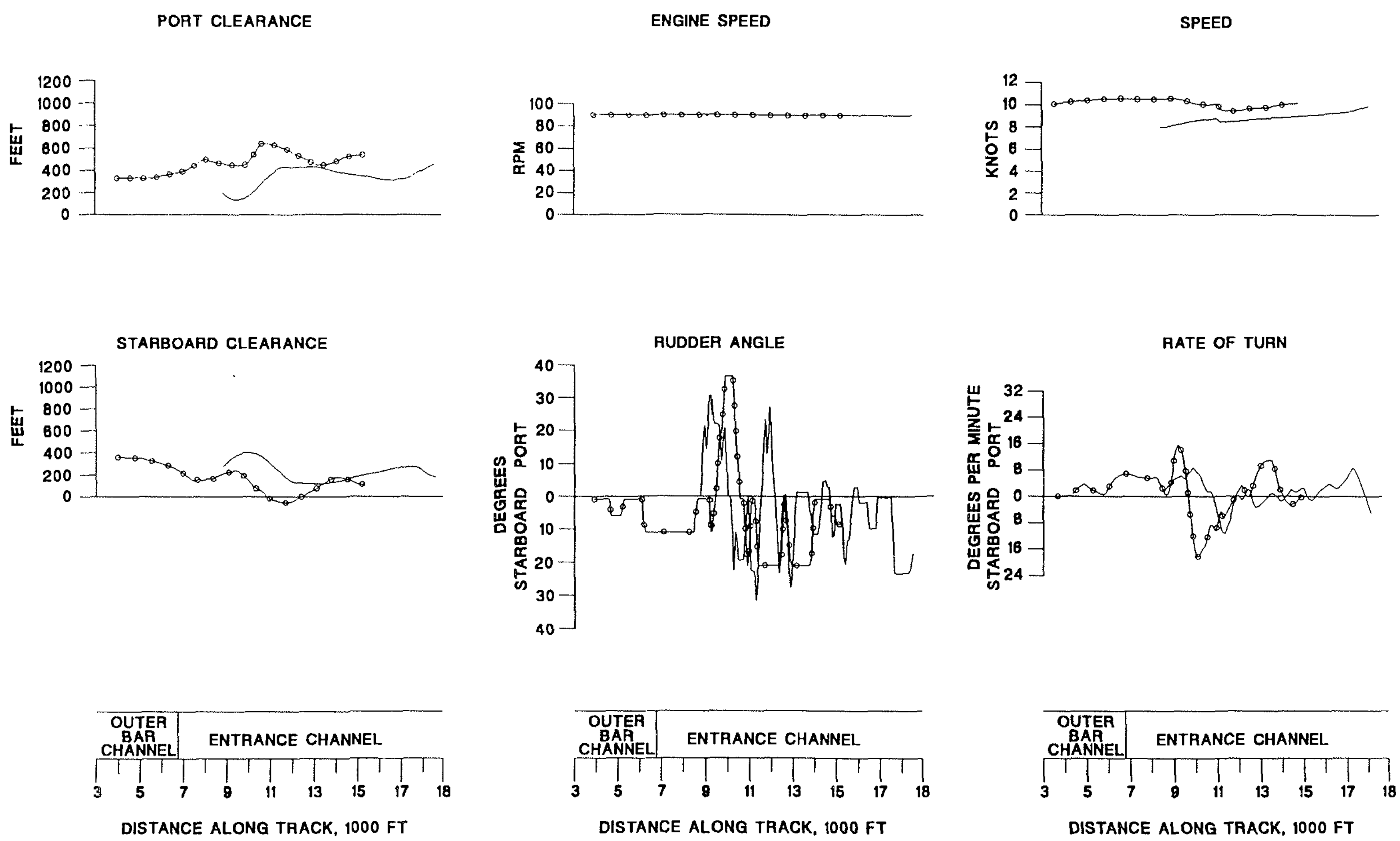


PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

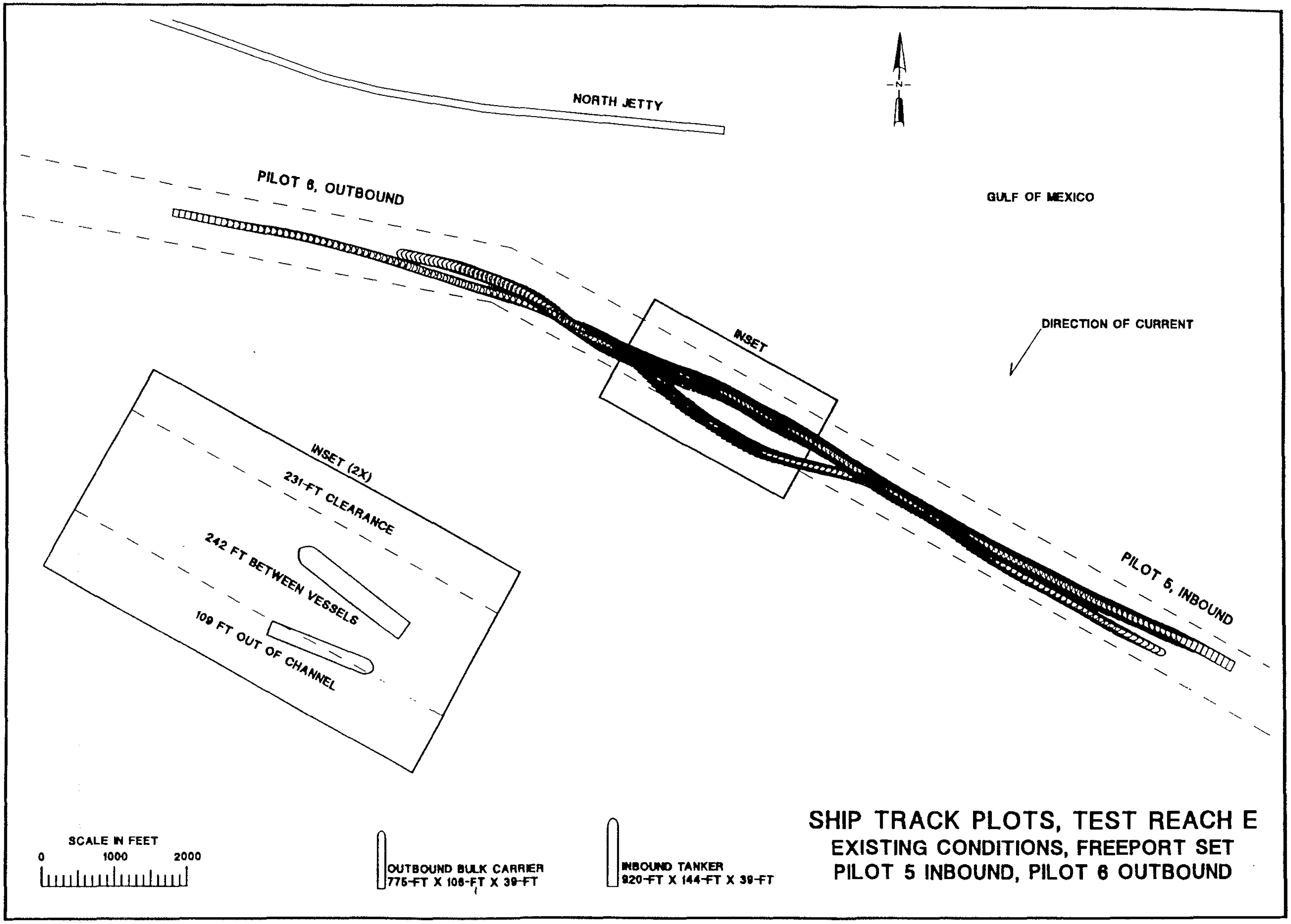


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

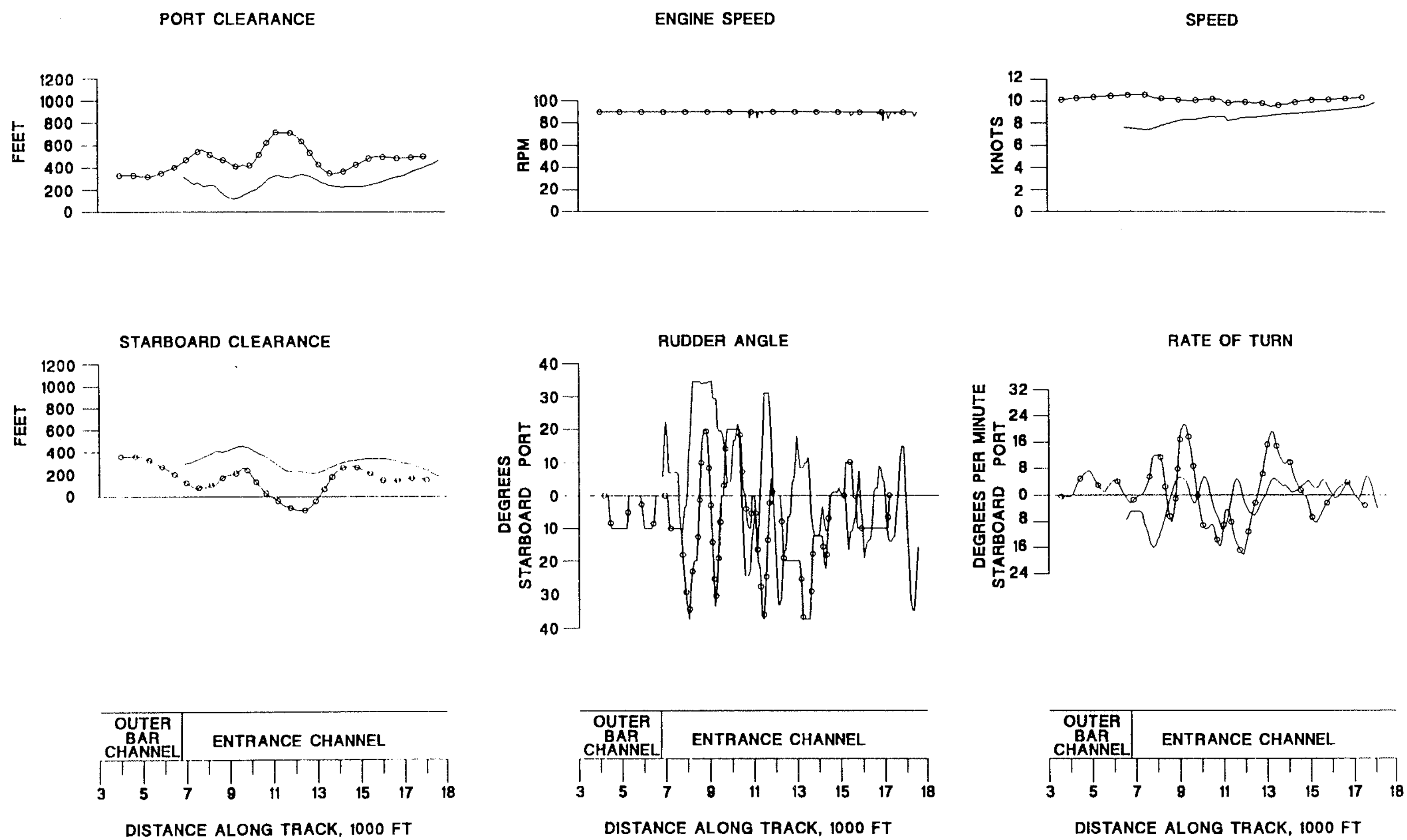


PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

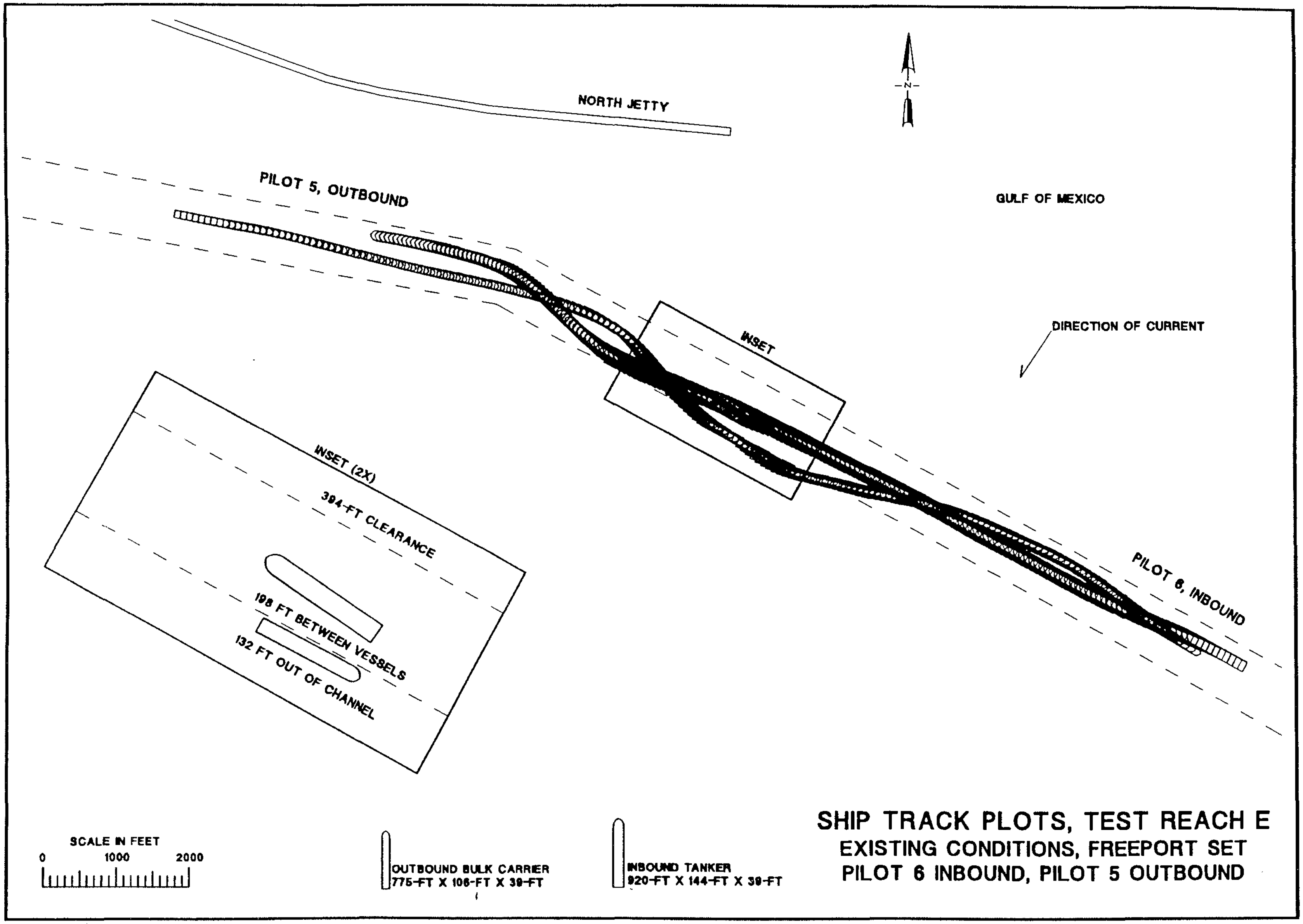


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

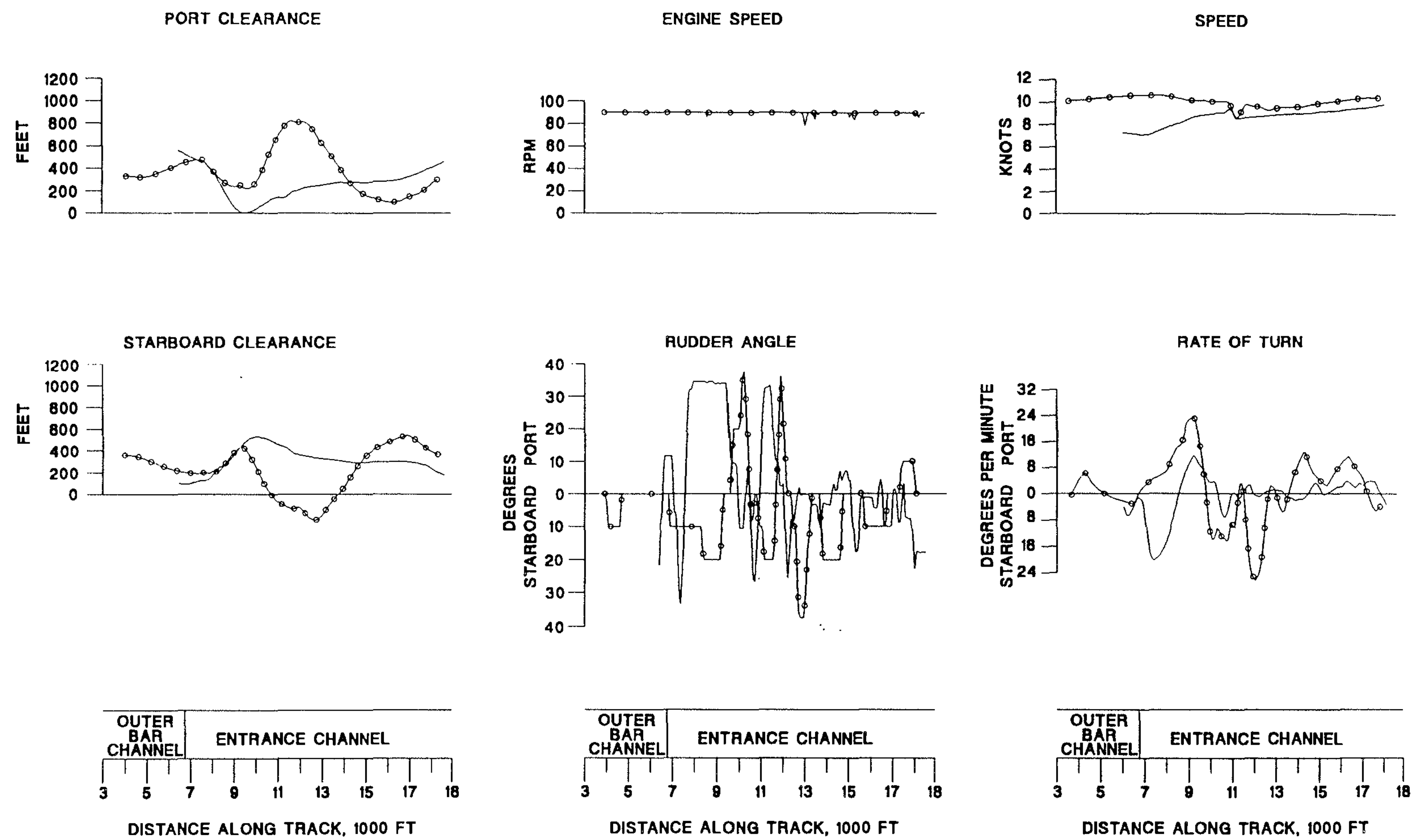


PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

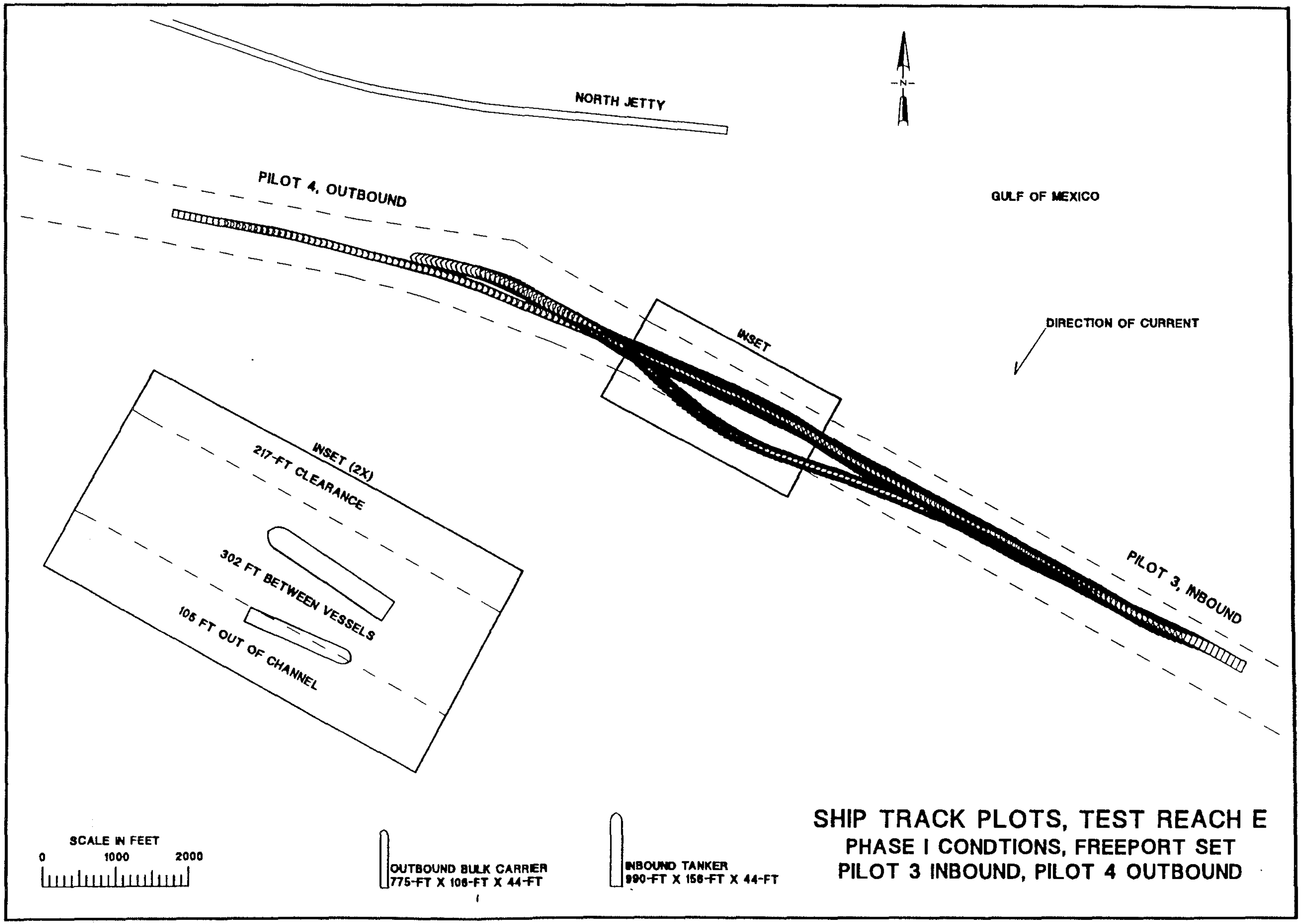


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

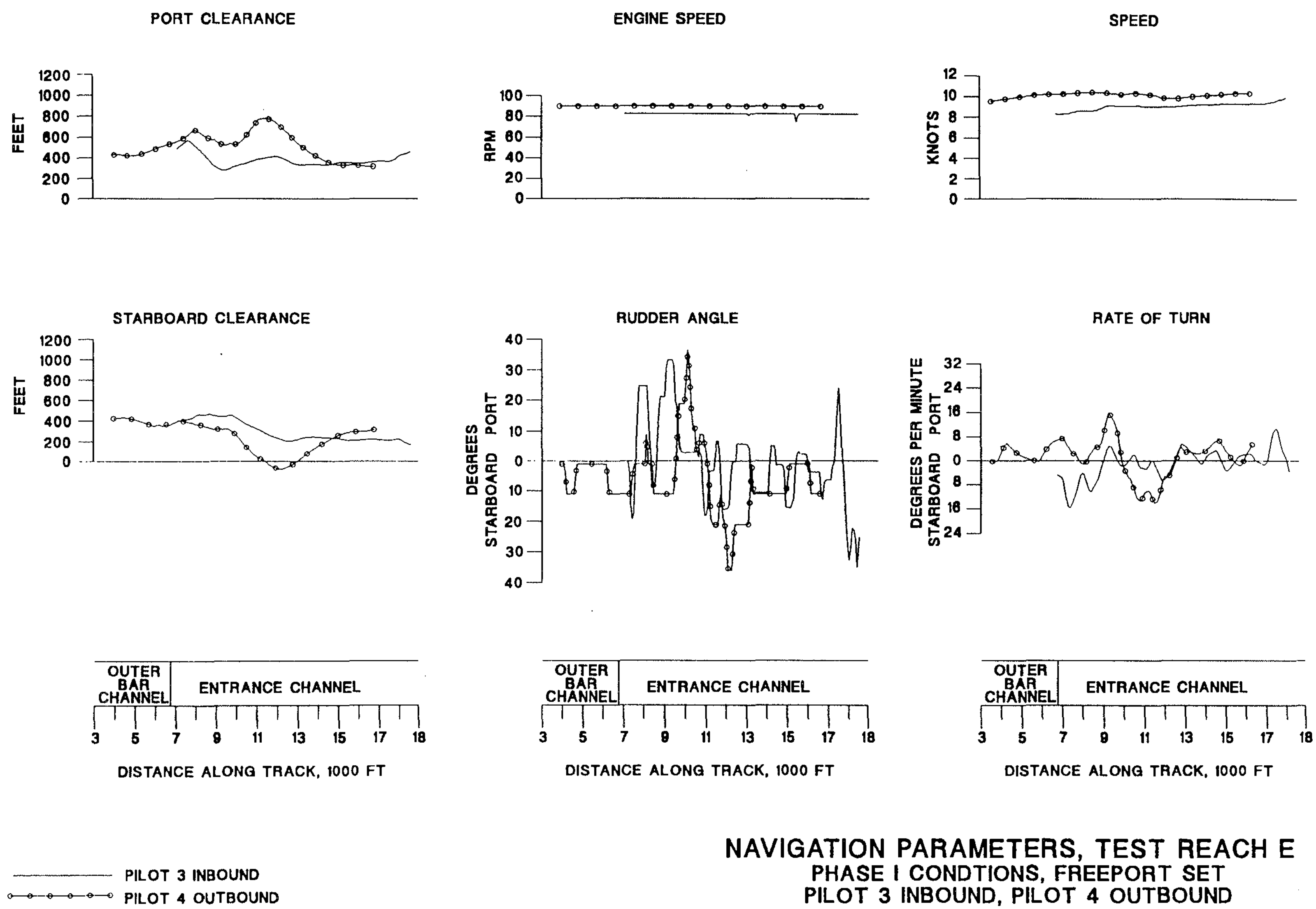


PILOT 6 INBOUND
PILOT 5 OUTBOUND

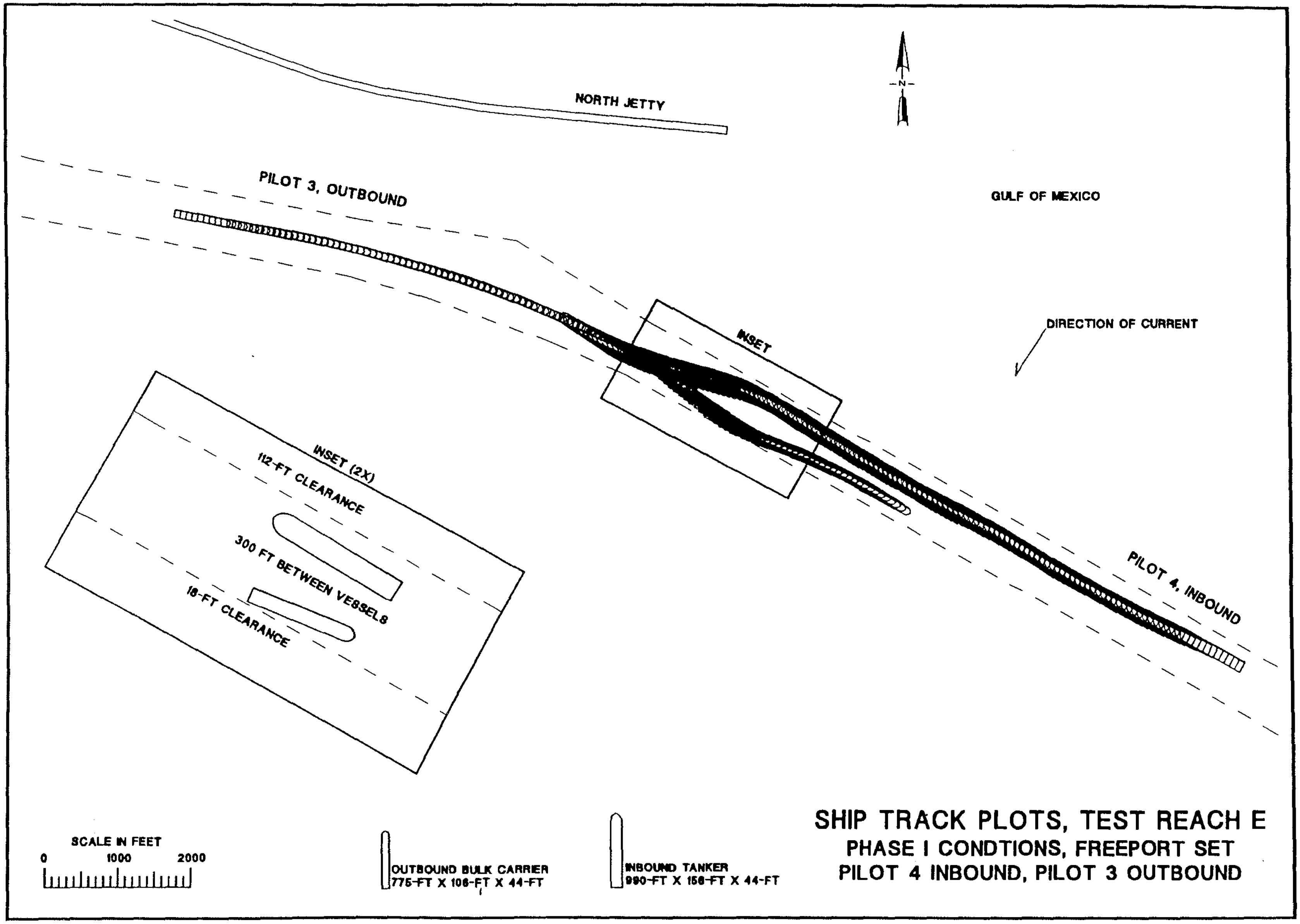
NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



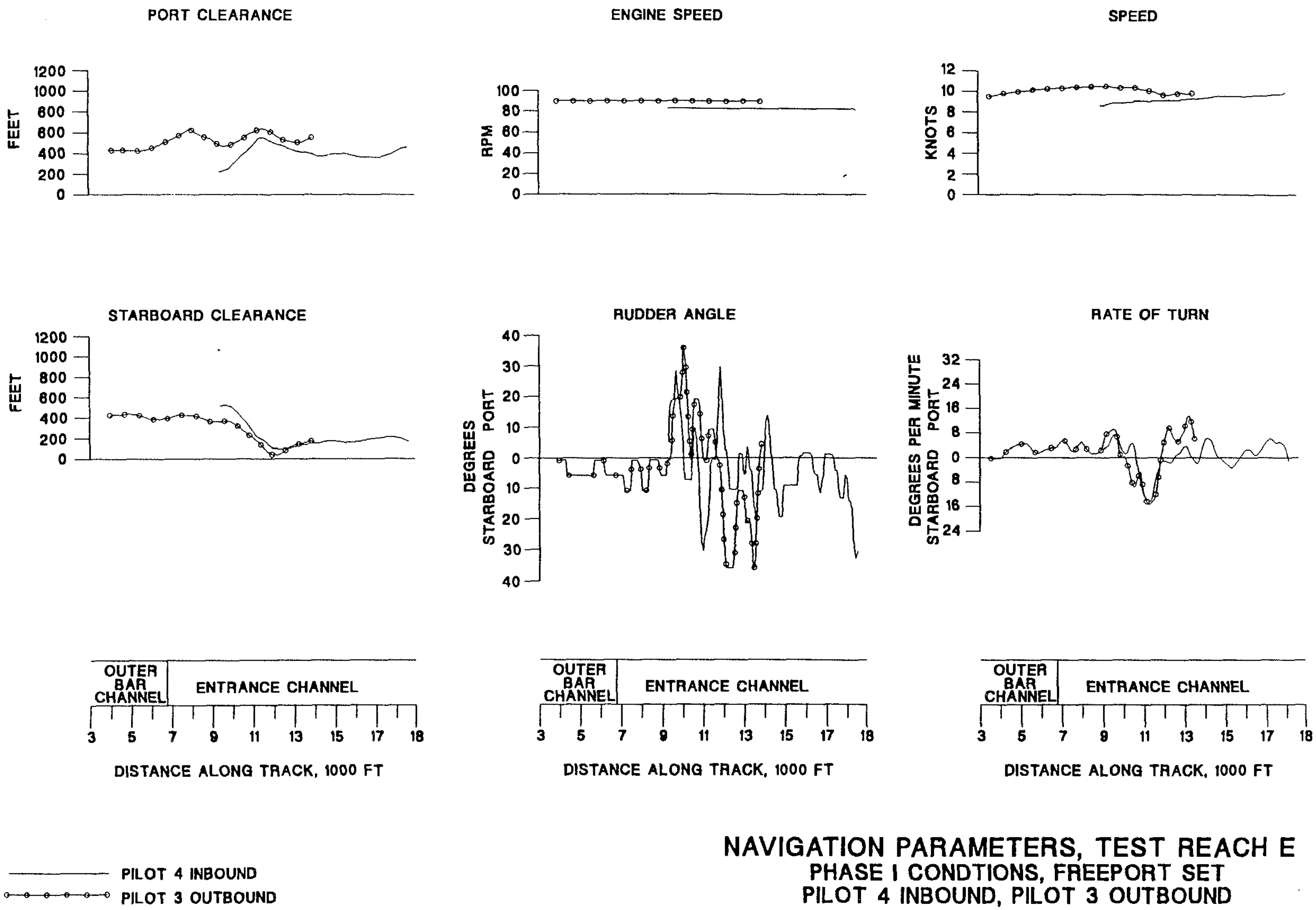
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



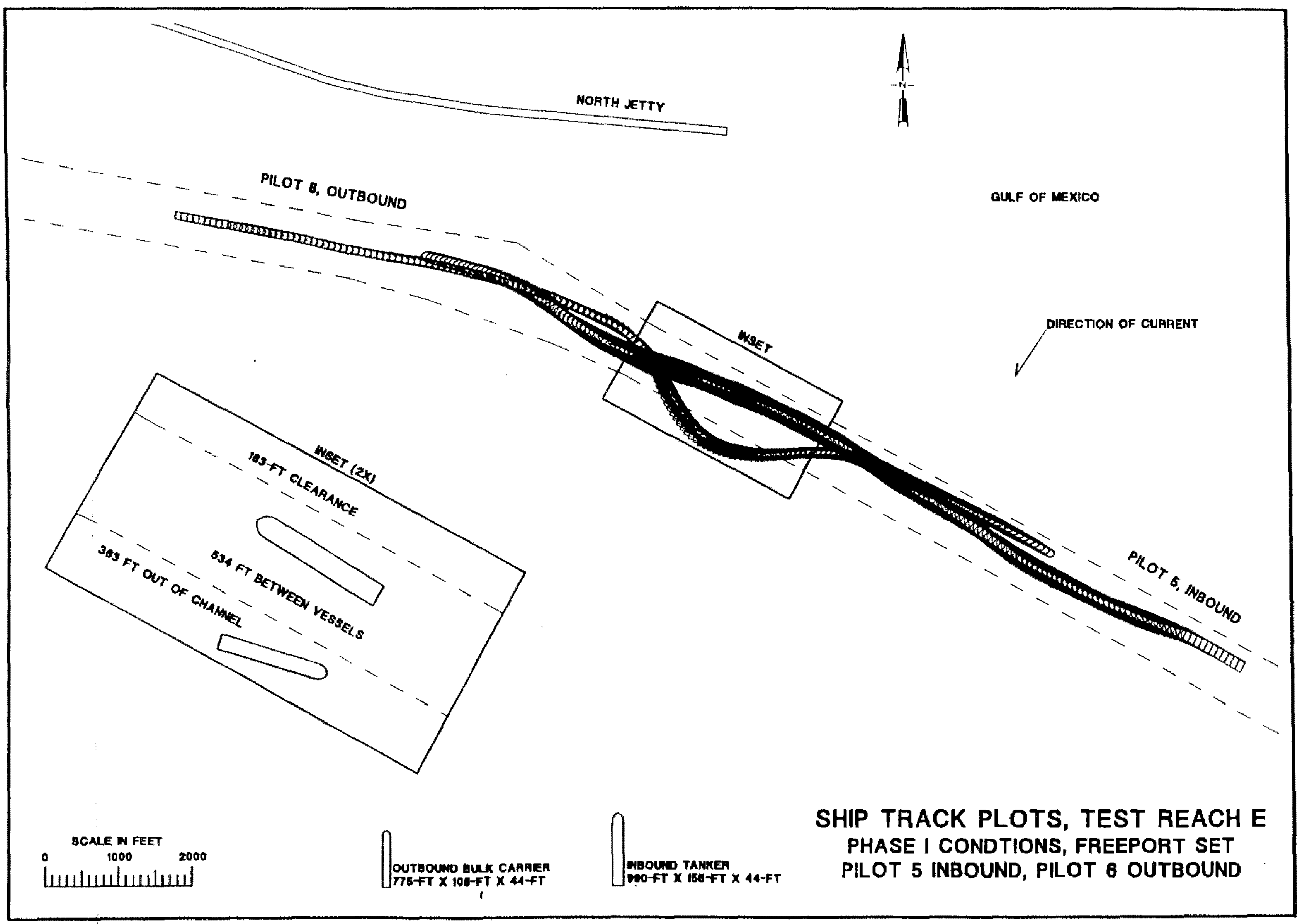
NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

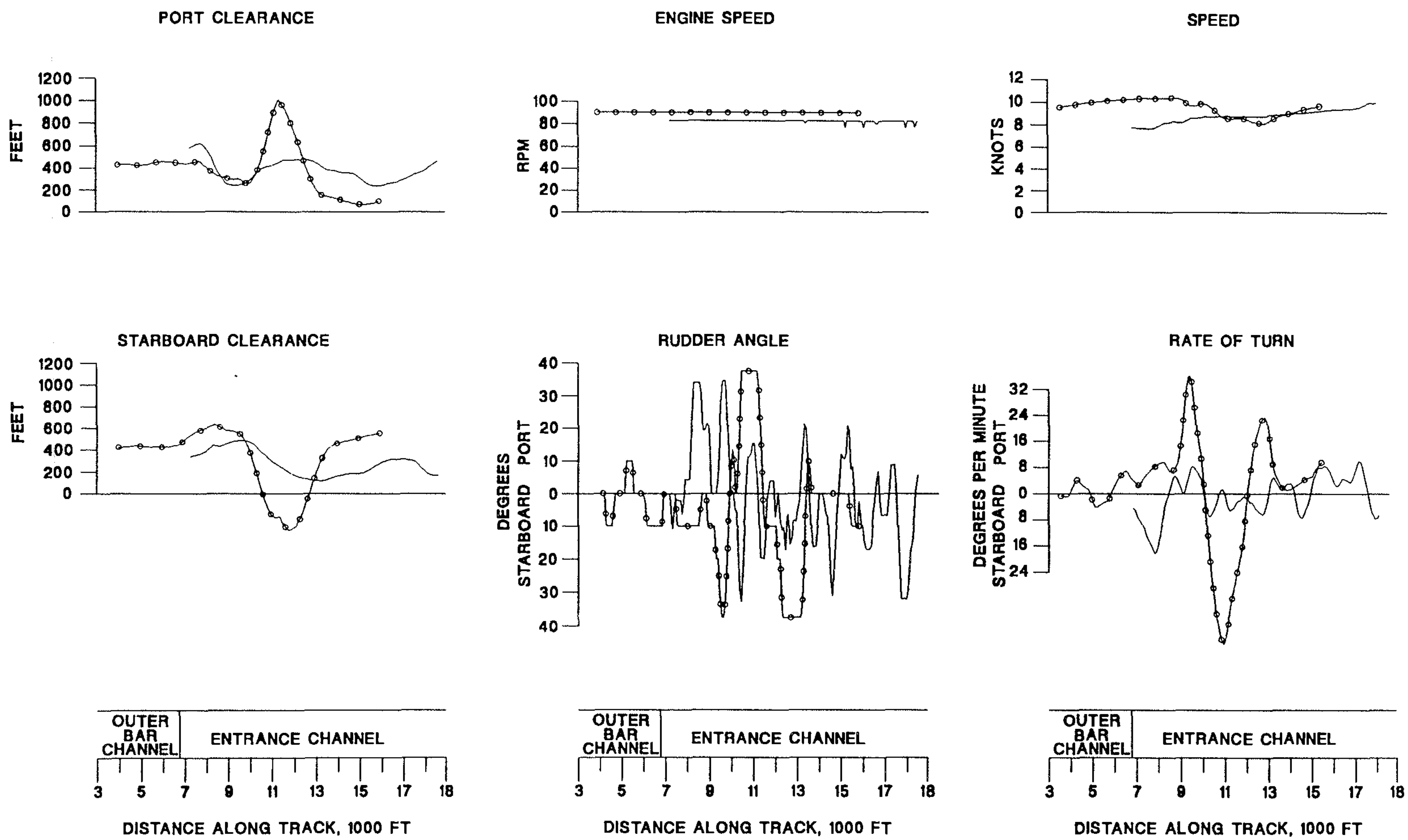


SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



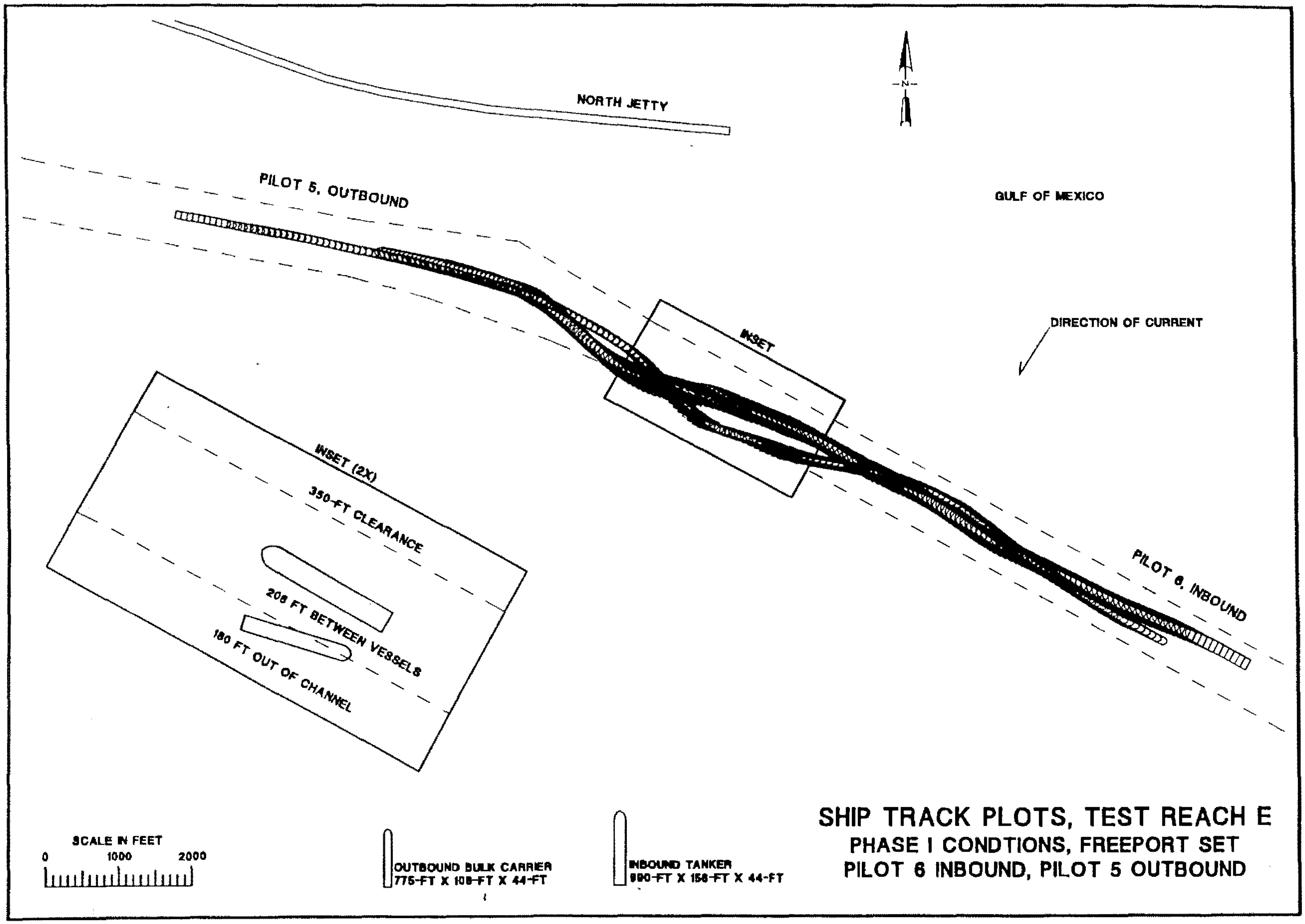
NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND


NORTH JETTY
N
PILOT 6, OUTBOUND
GULF OF MEXICO
DIRECTION OF CURRENT
INSET
INSET (2X)
183-FT CLEARANCE
534 FT BETWEEN VESSELS
383 FT OUT OF CHANNEL
PILOT 5, INBOUND
SCALE IN FEET
0 1000 2000
OUTBOUND BULK CARRIER
775-FT X 106-FT X 44-FT
INBOUND TANKER
990-FT X 156-FT X 44-FT
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



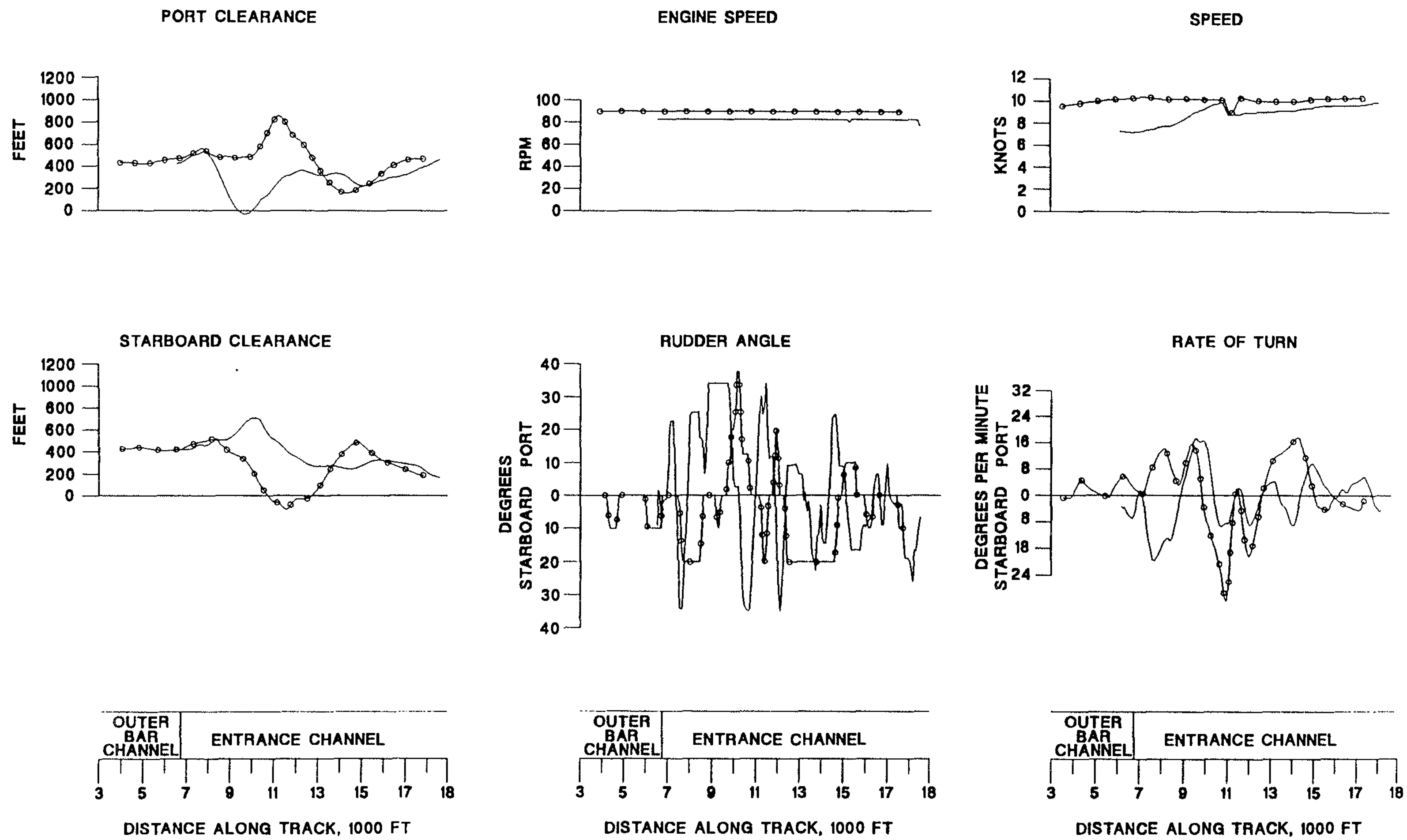
PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



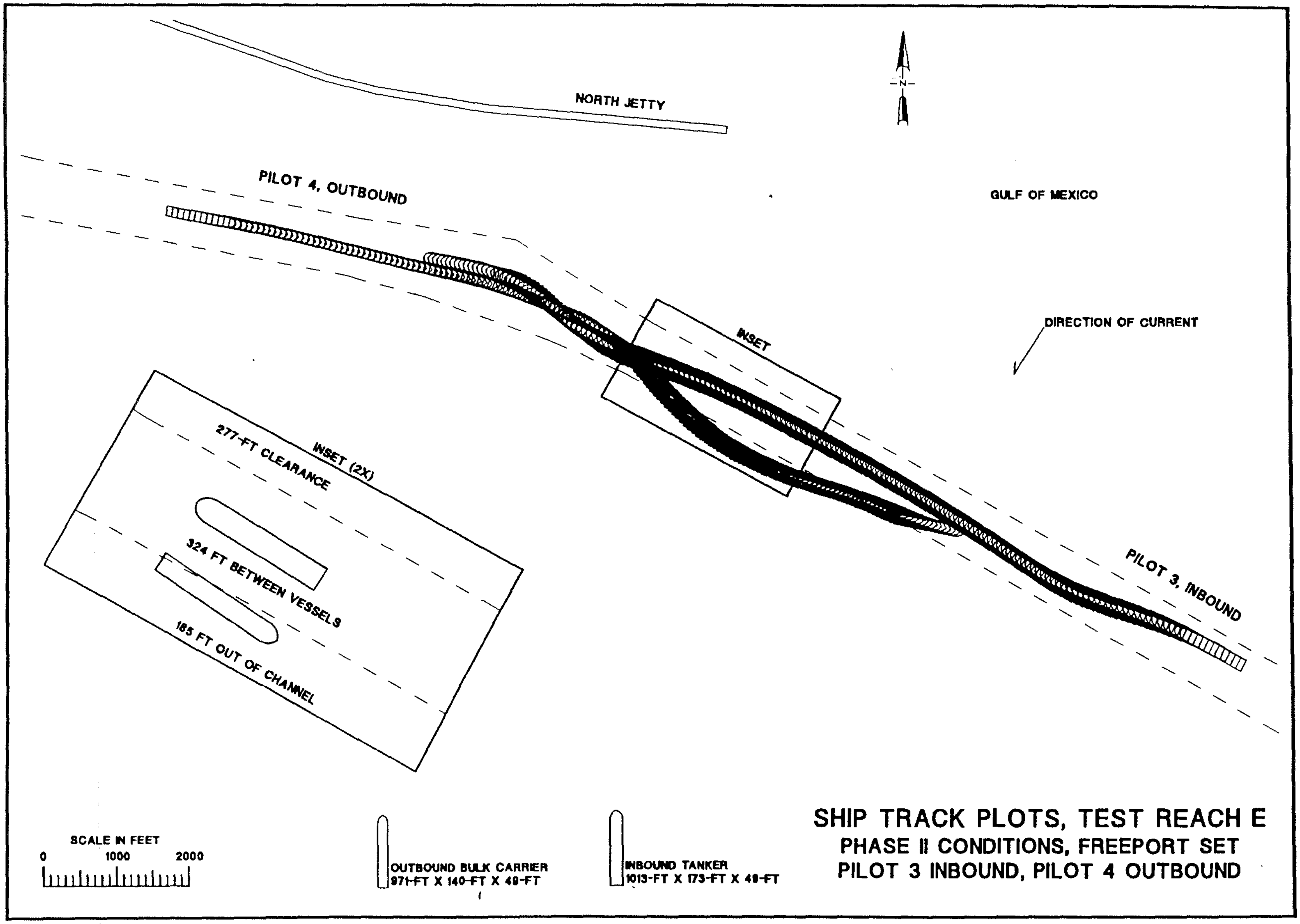
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 123

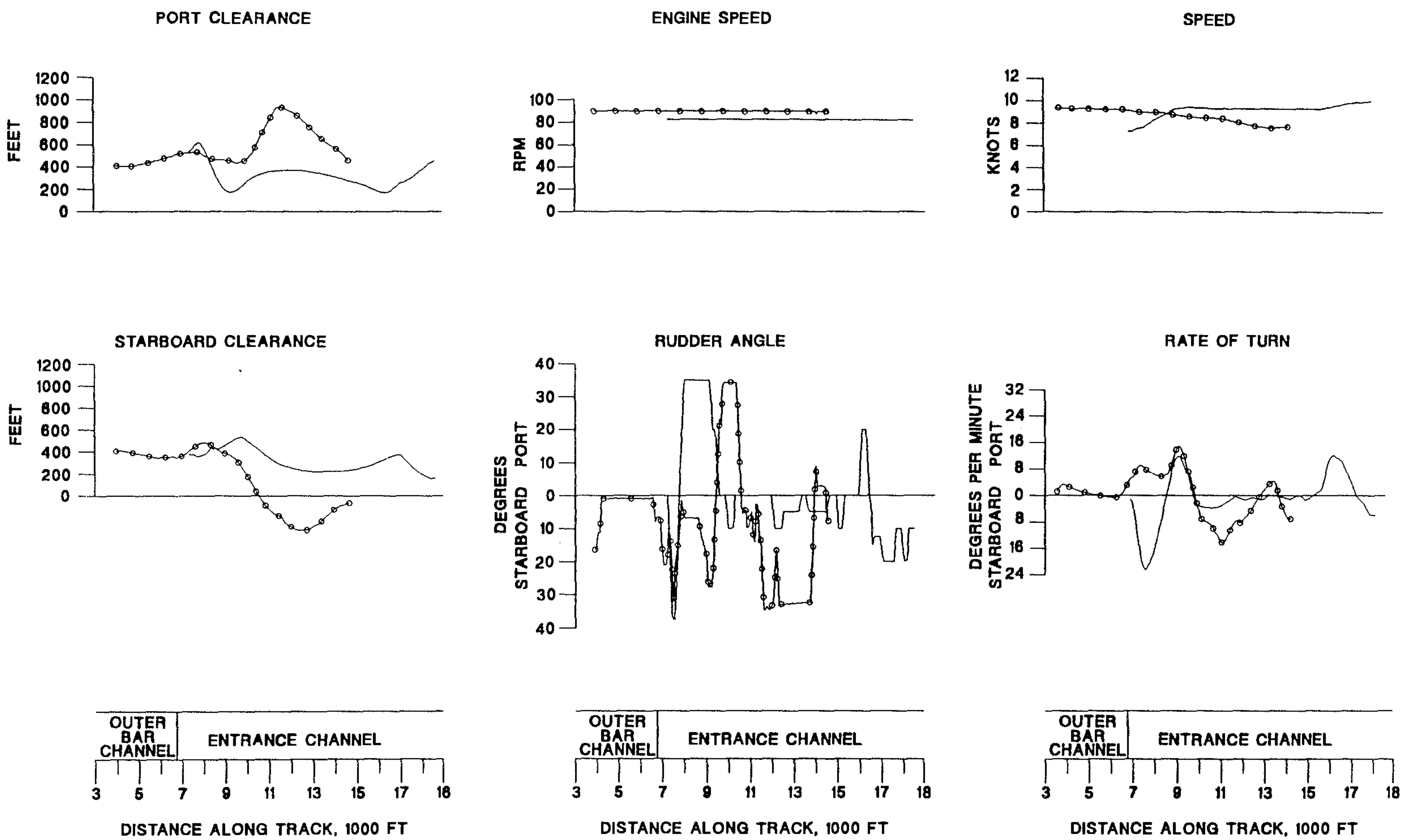


PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

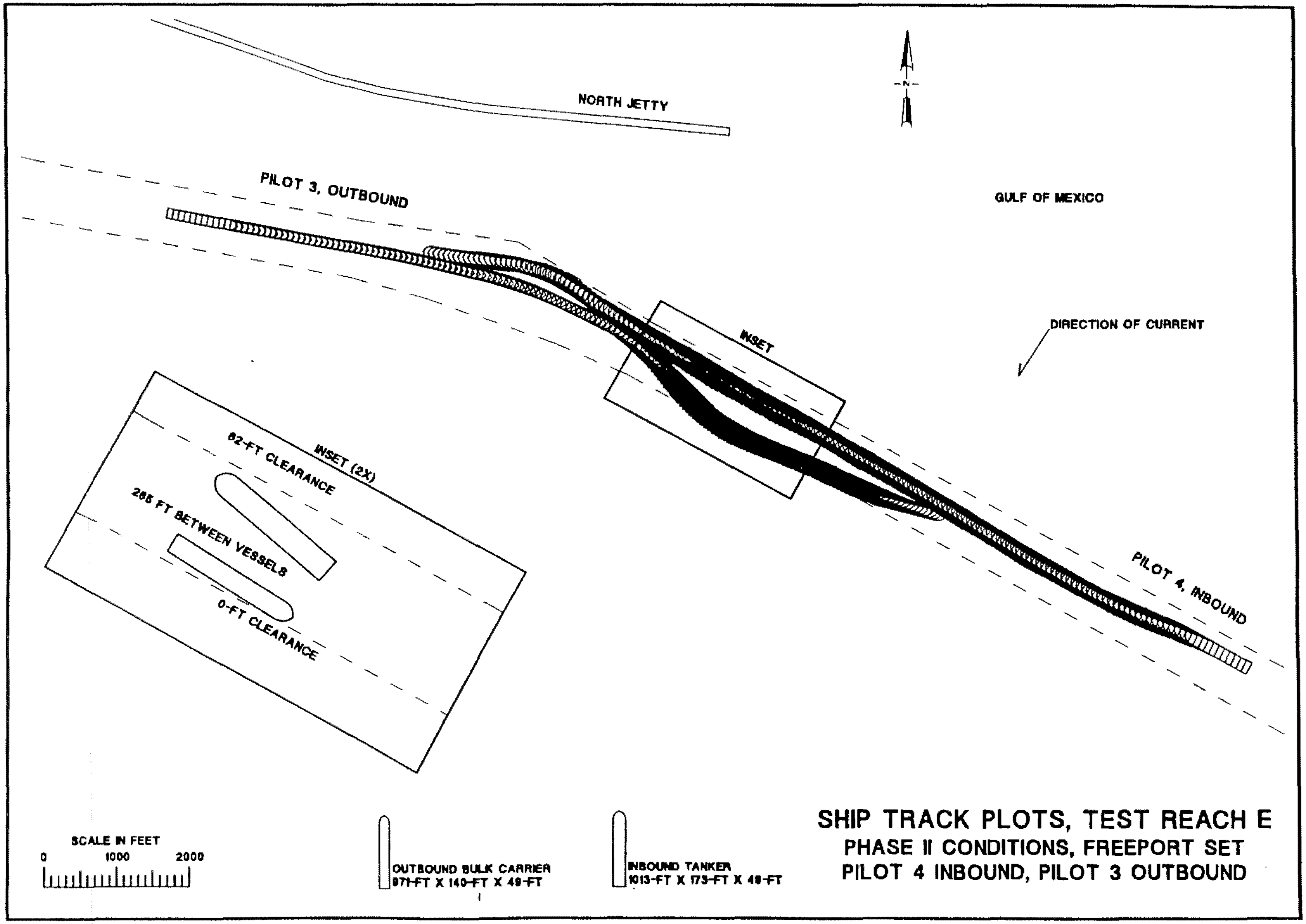


SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

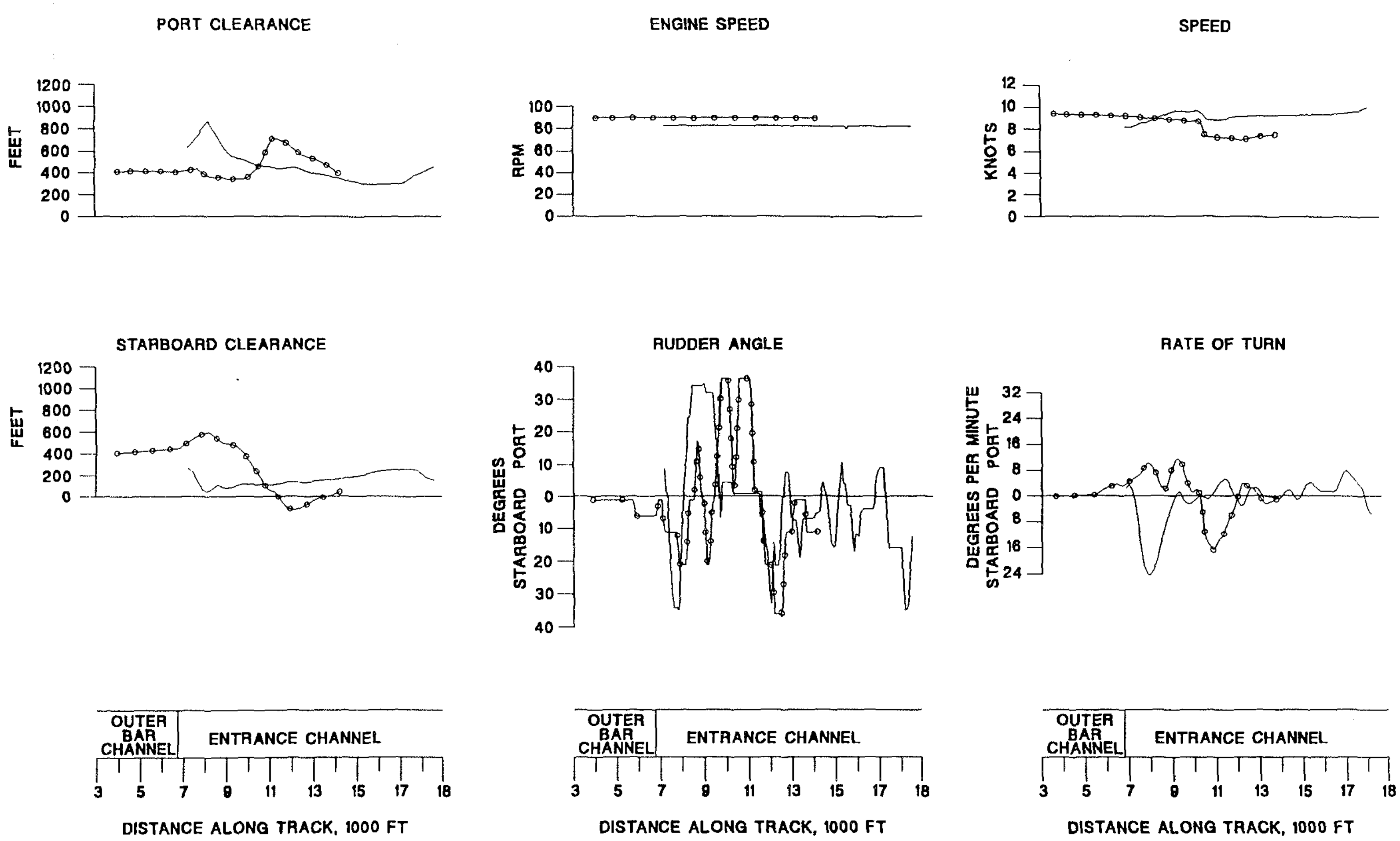


PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

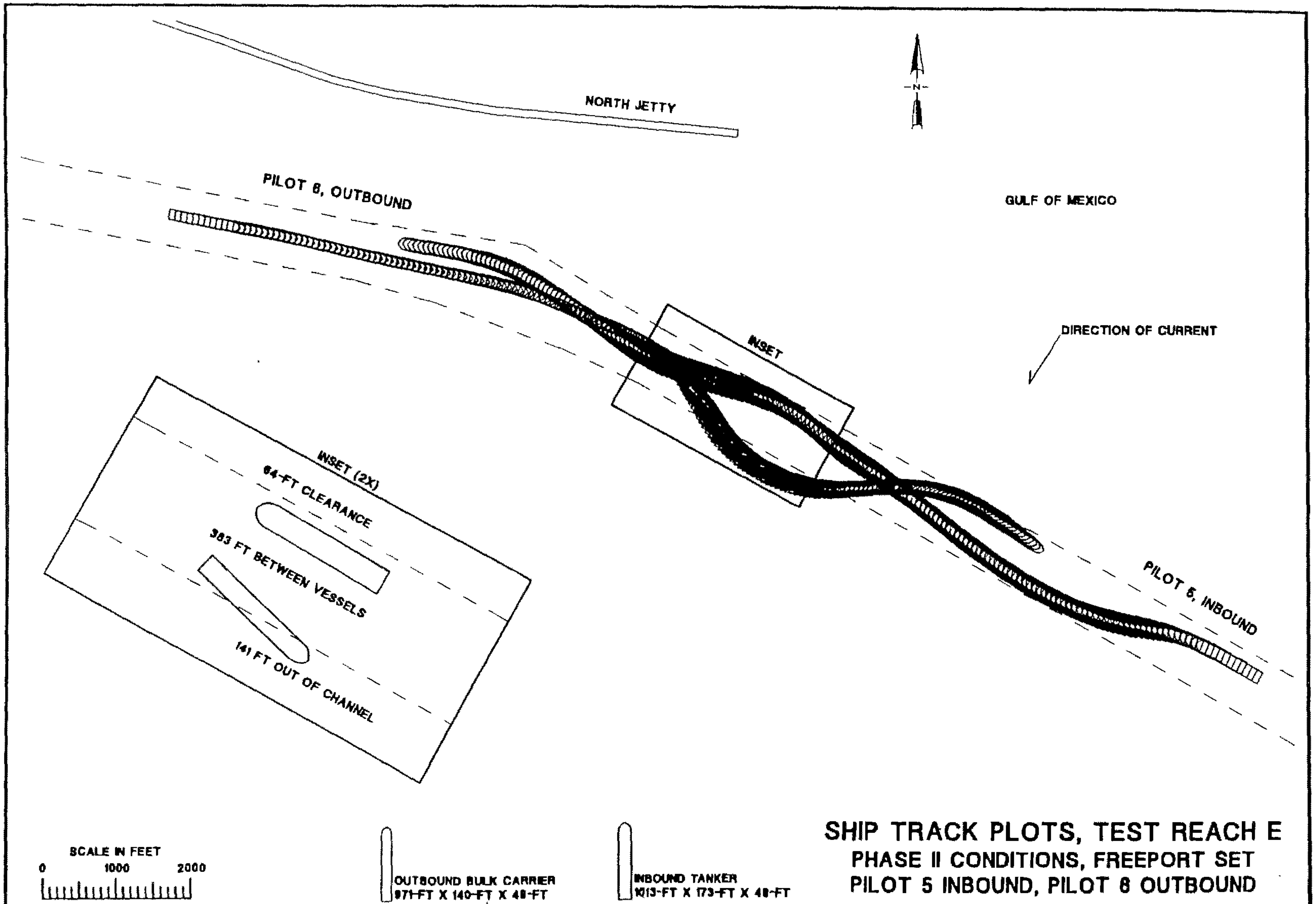


SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

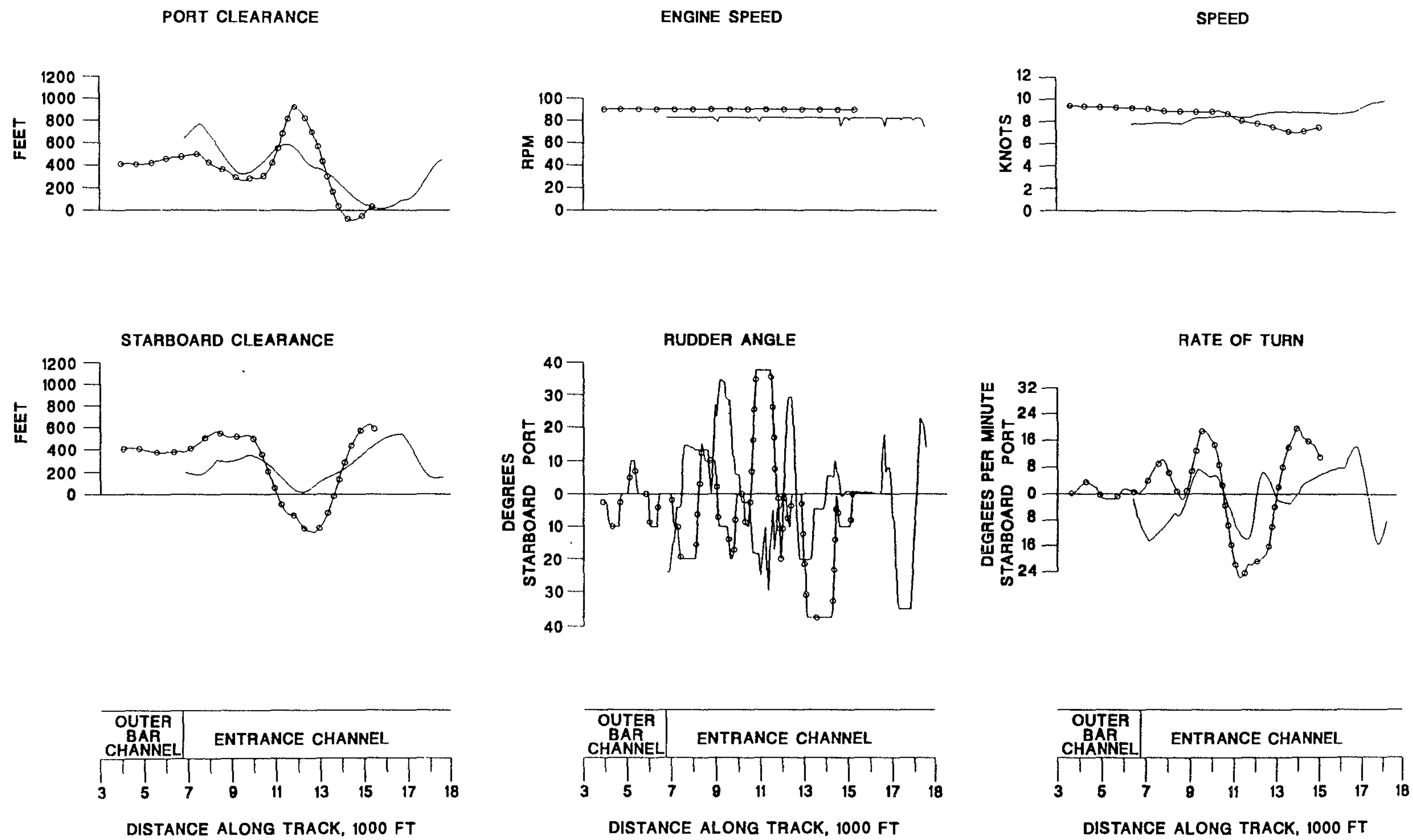


PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



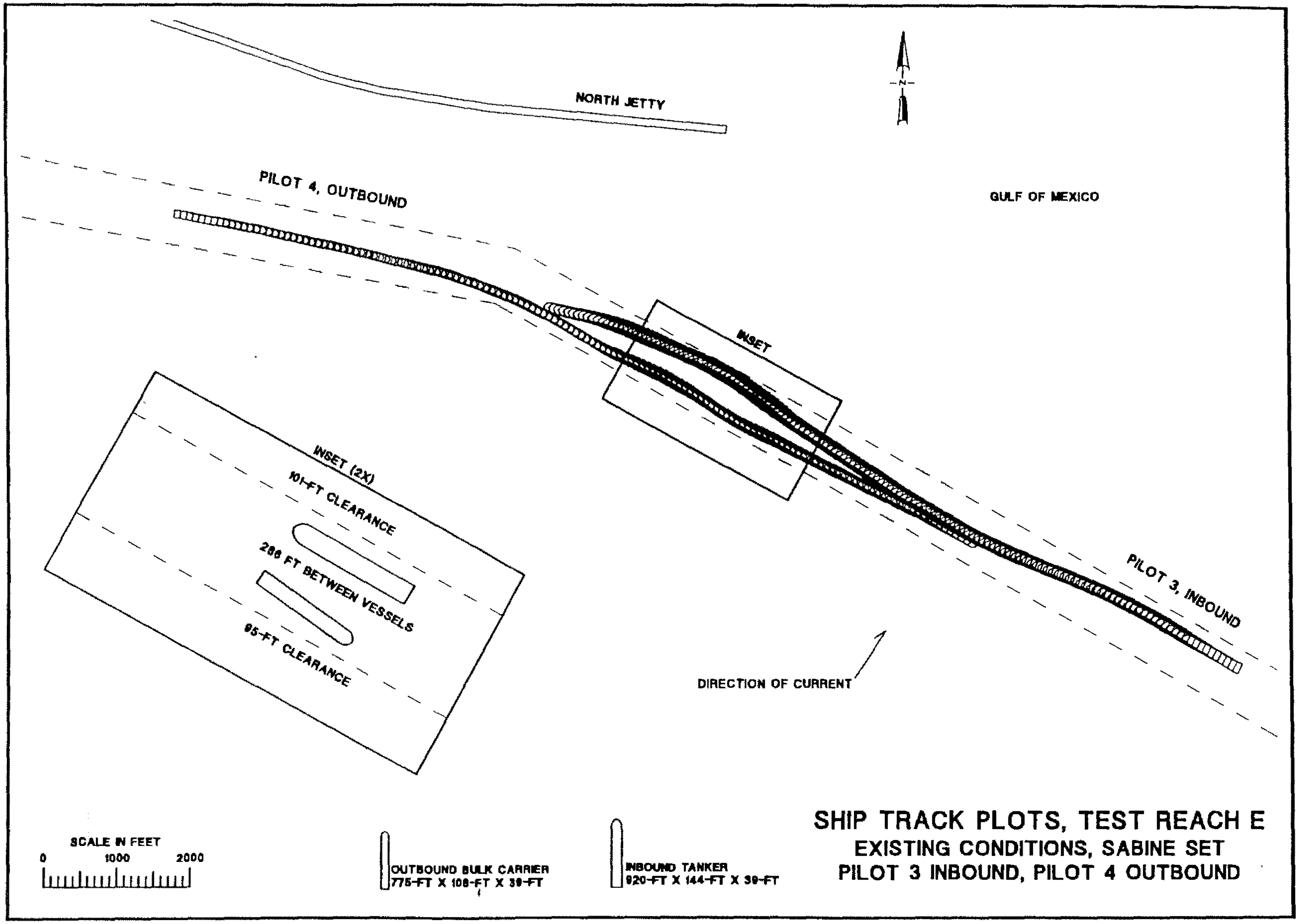
SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 8 OUTBOUND



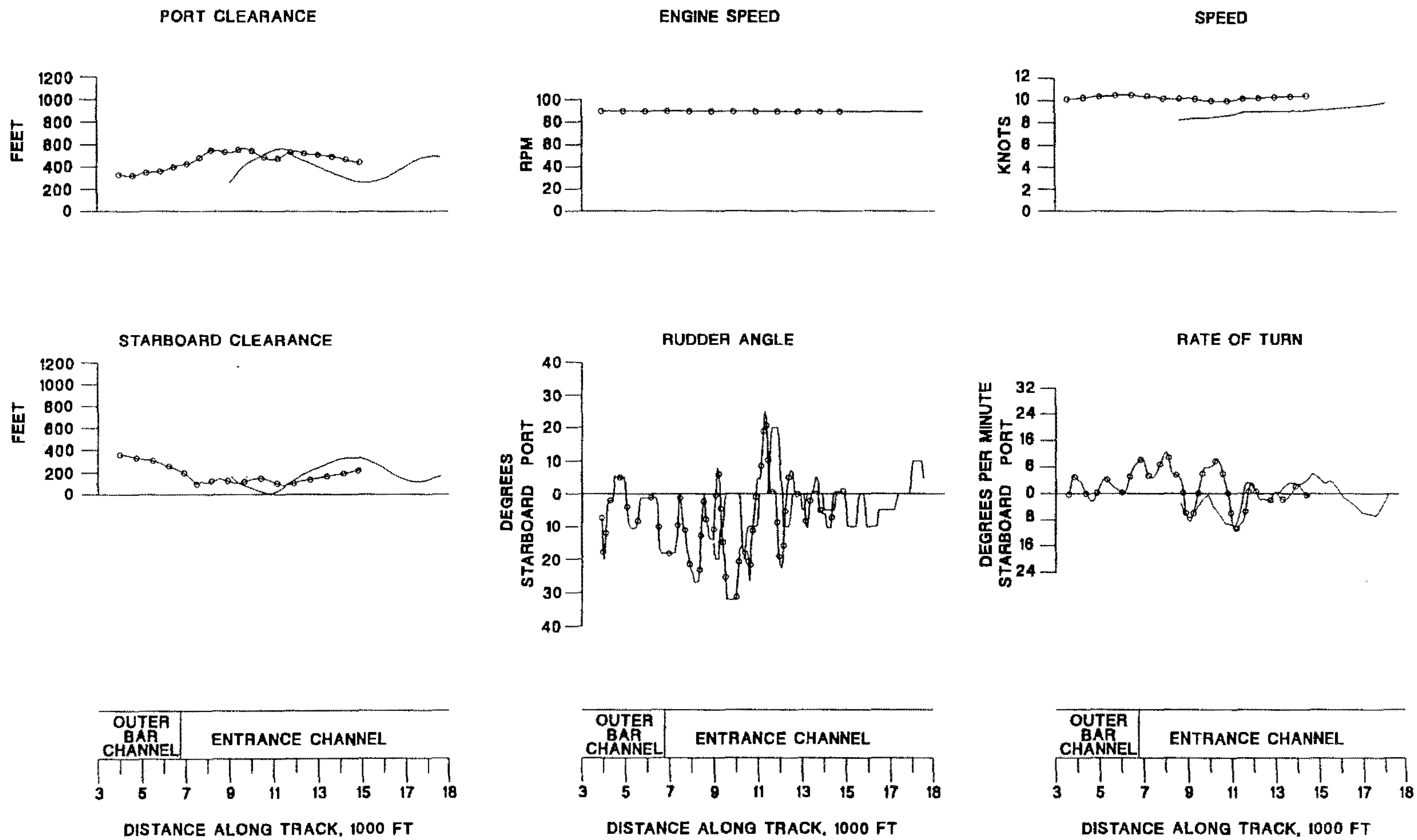
PILOT 5 INBOUND

PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, SABINE SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



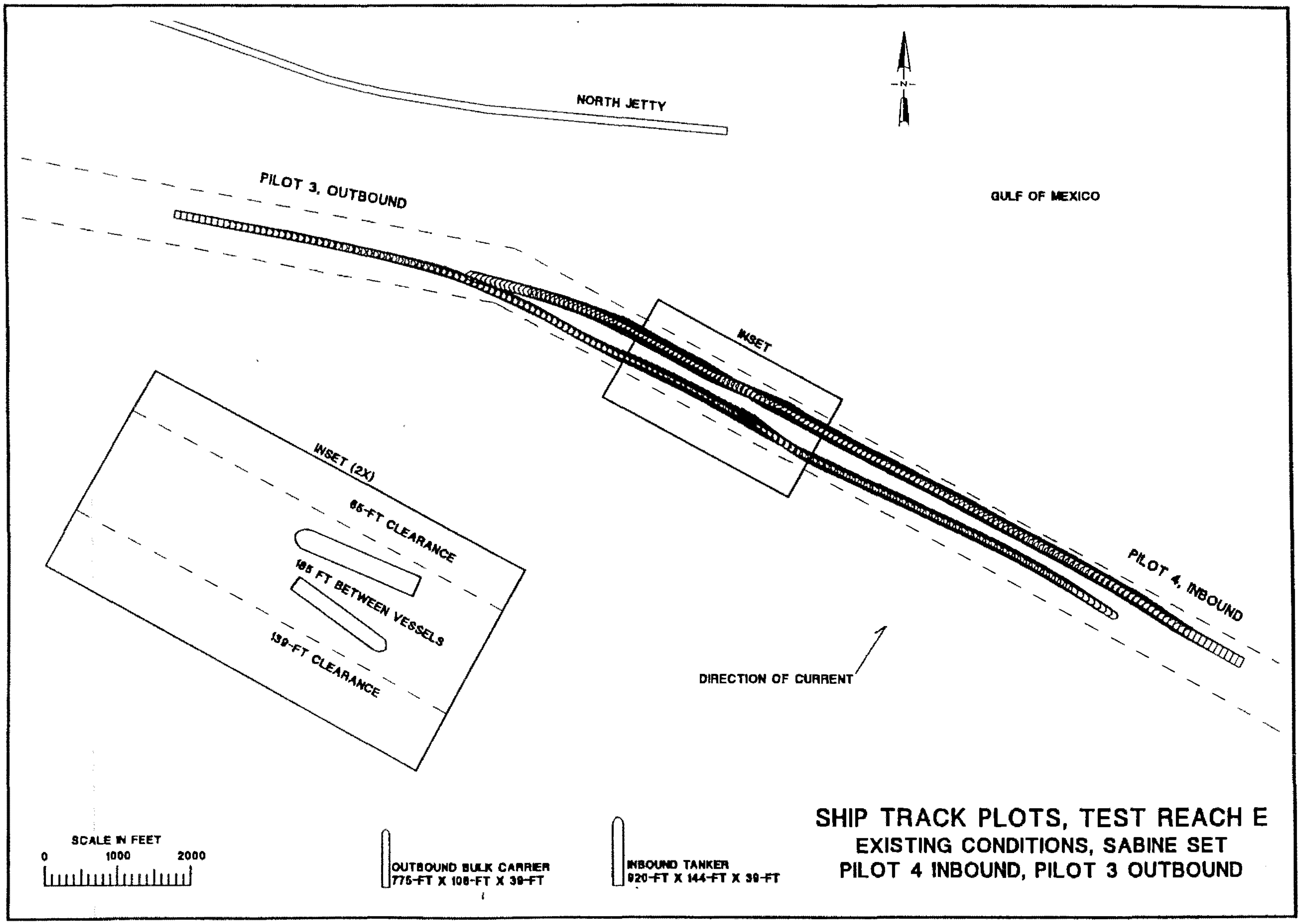
PILOT 3 INBOUND

PILOT 4 OUTBOUND

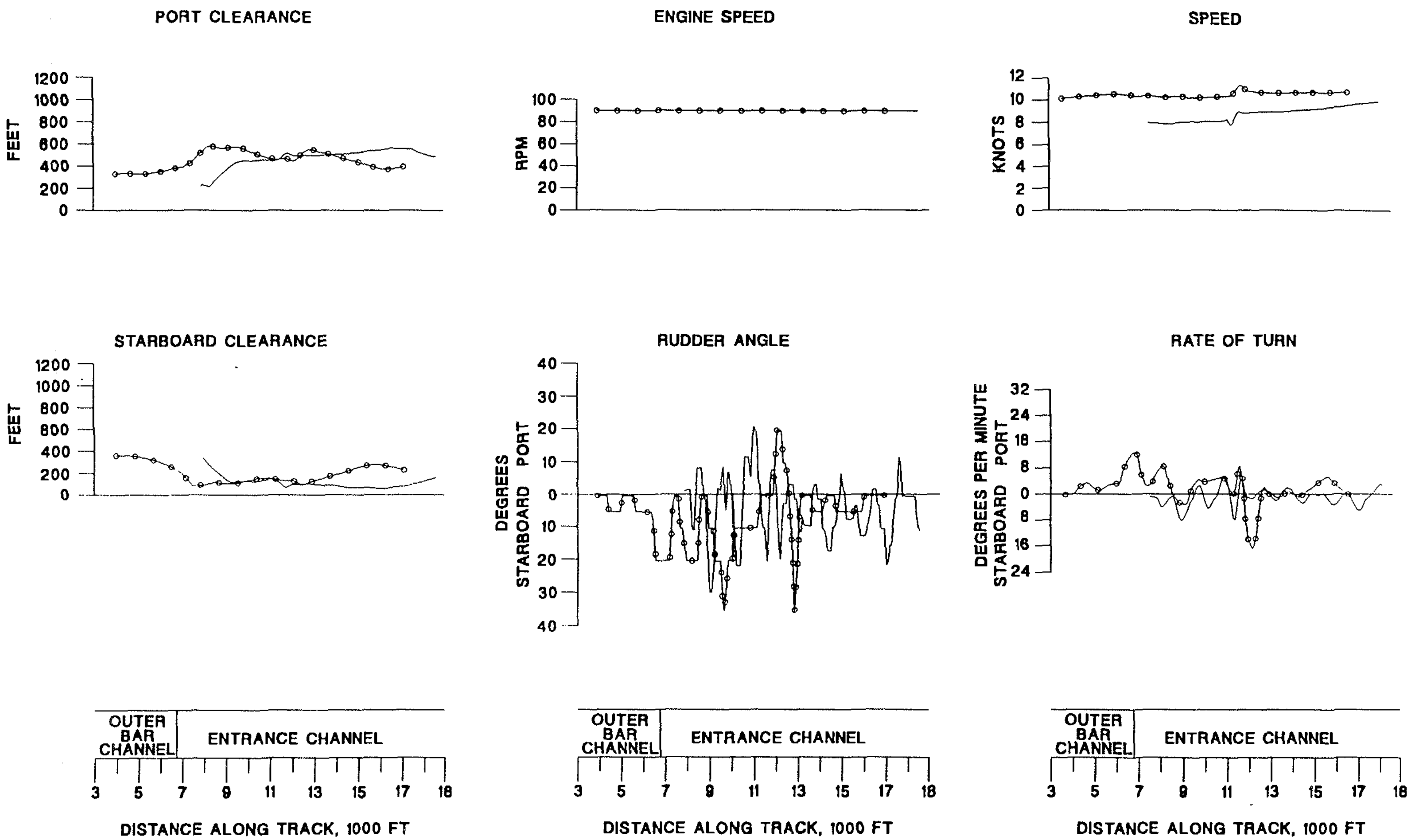
NAVIGATION PARAMETERS, TEST REACH E

EXISTING CONDITIONS, SABINE SET

PILOT 3 INBOUND, PILOT 4 OUTBOUND

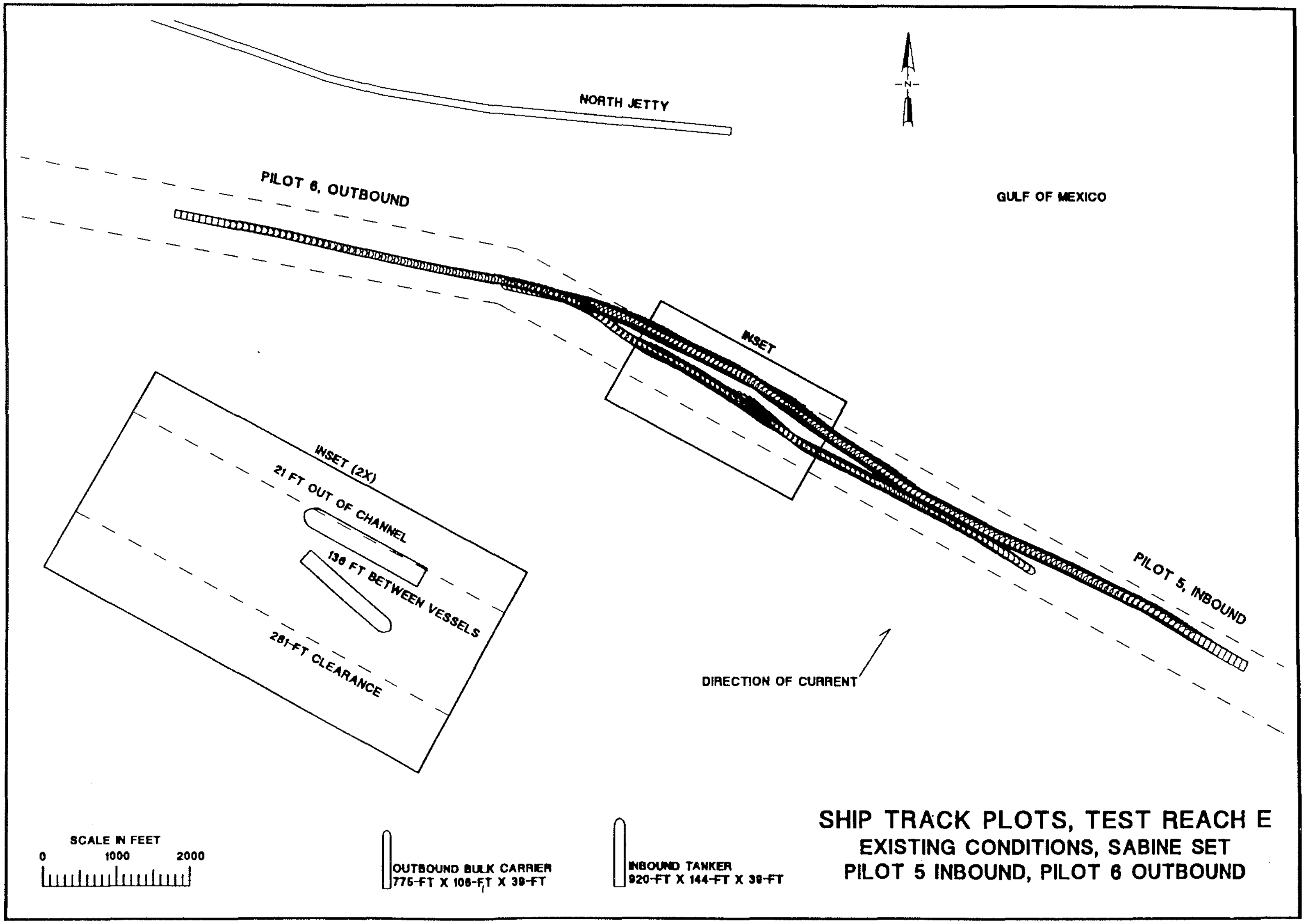


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

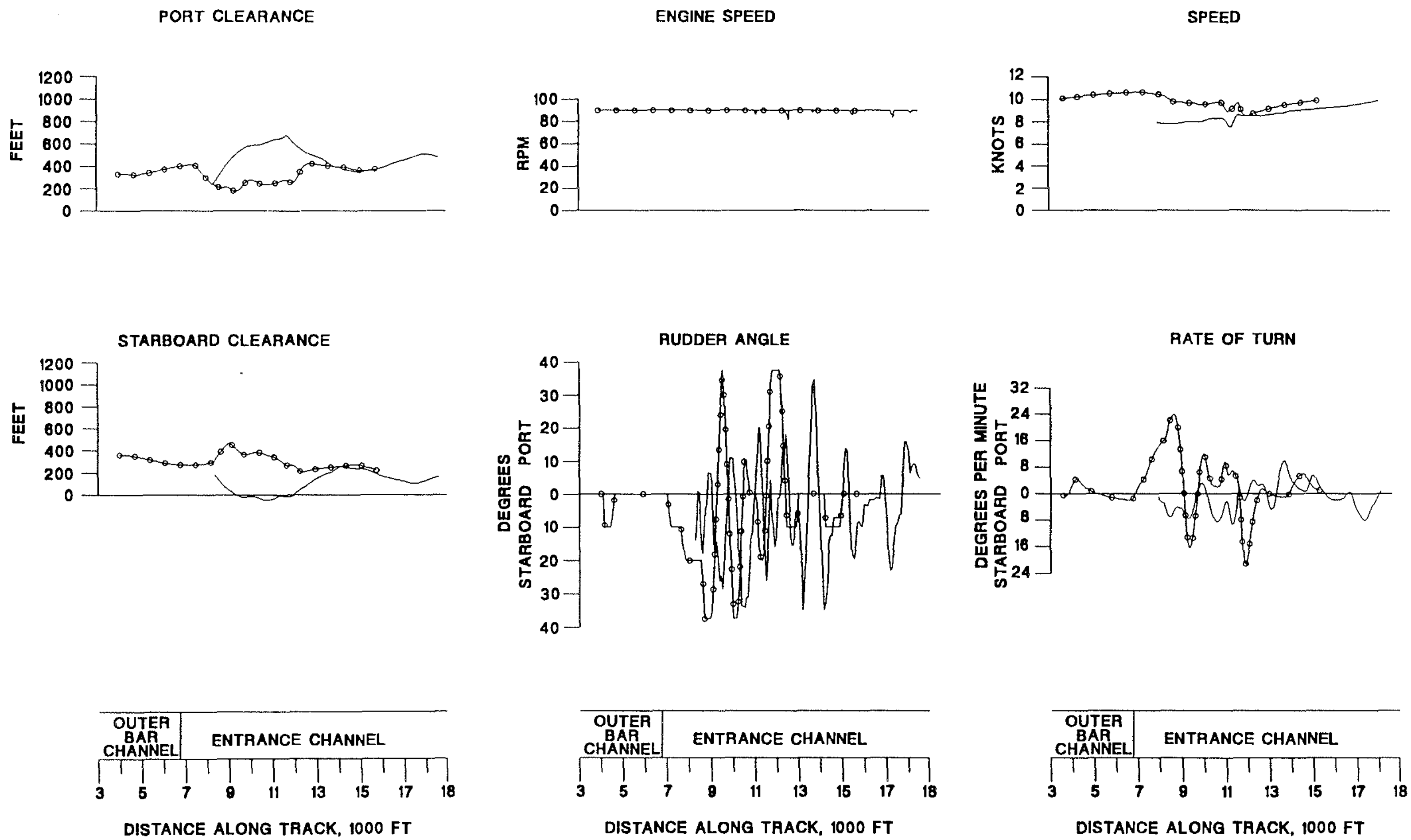


PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

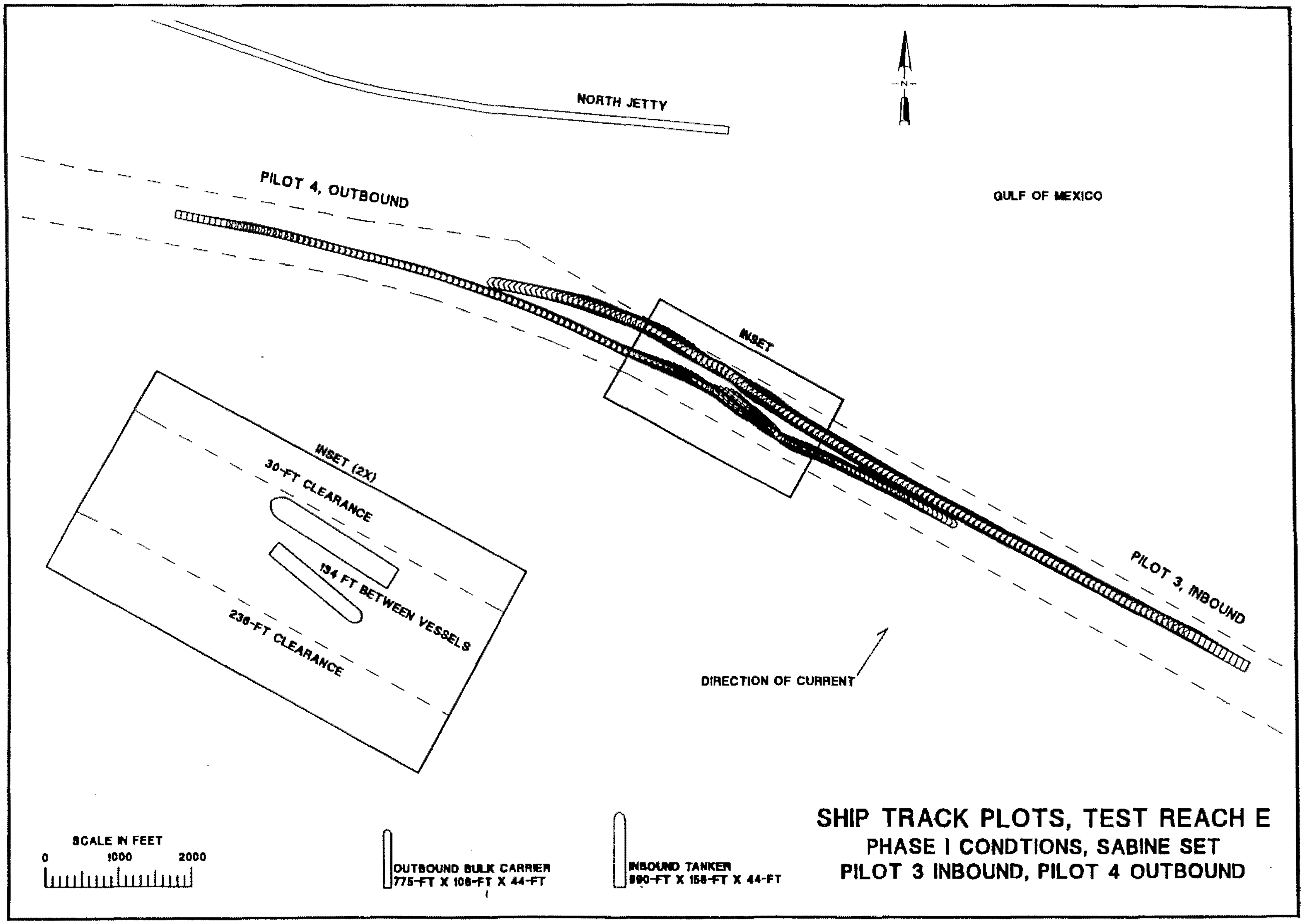


SHIP TRACK PLOTS, TEST REACH E
EXISTING CONDITIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



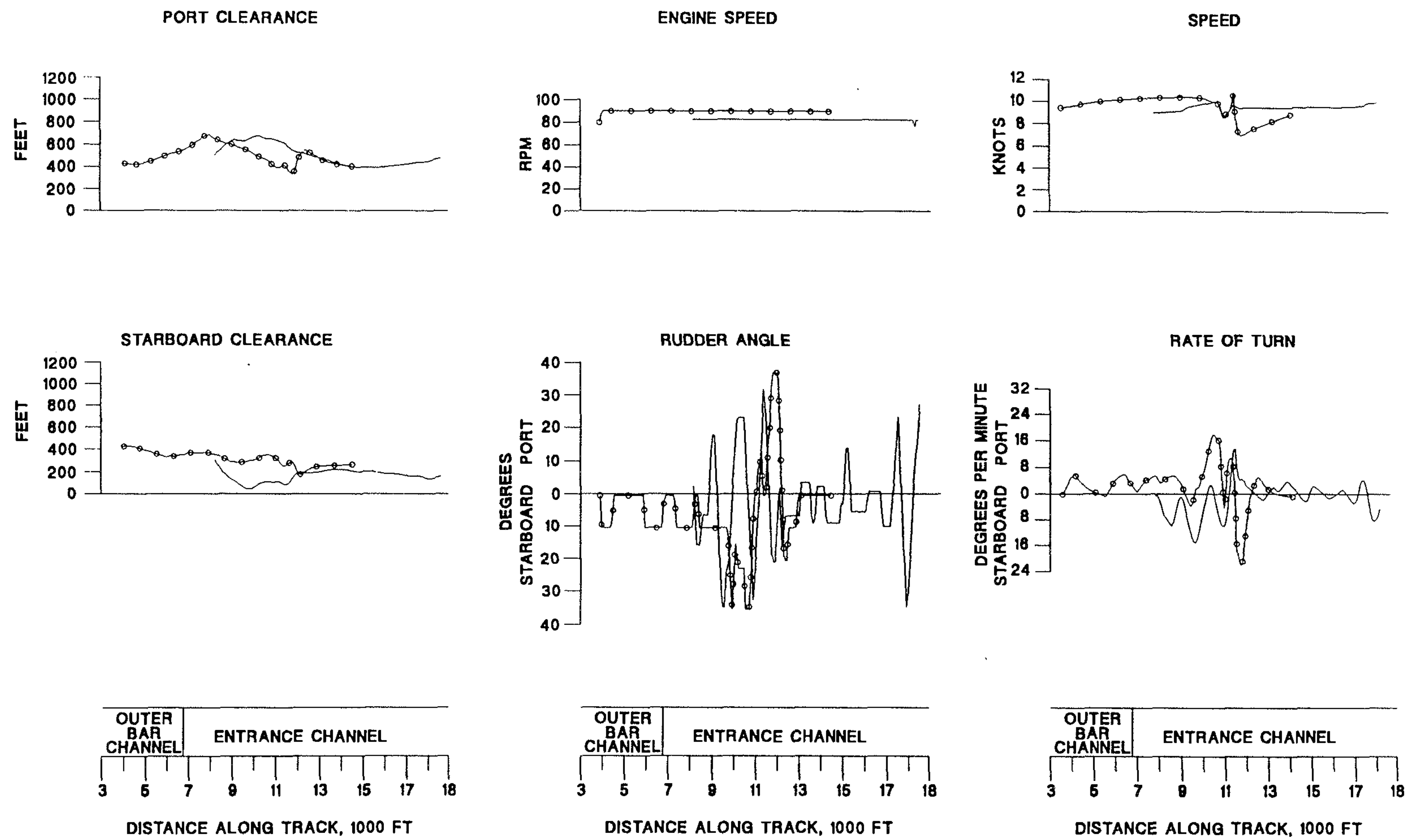
PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
EXISTING CONDITIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



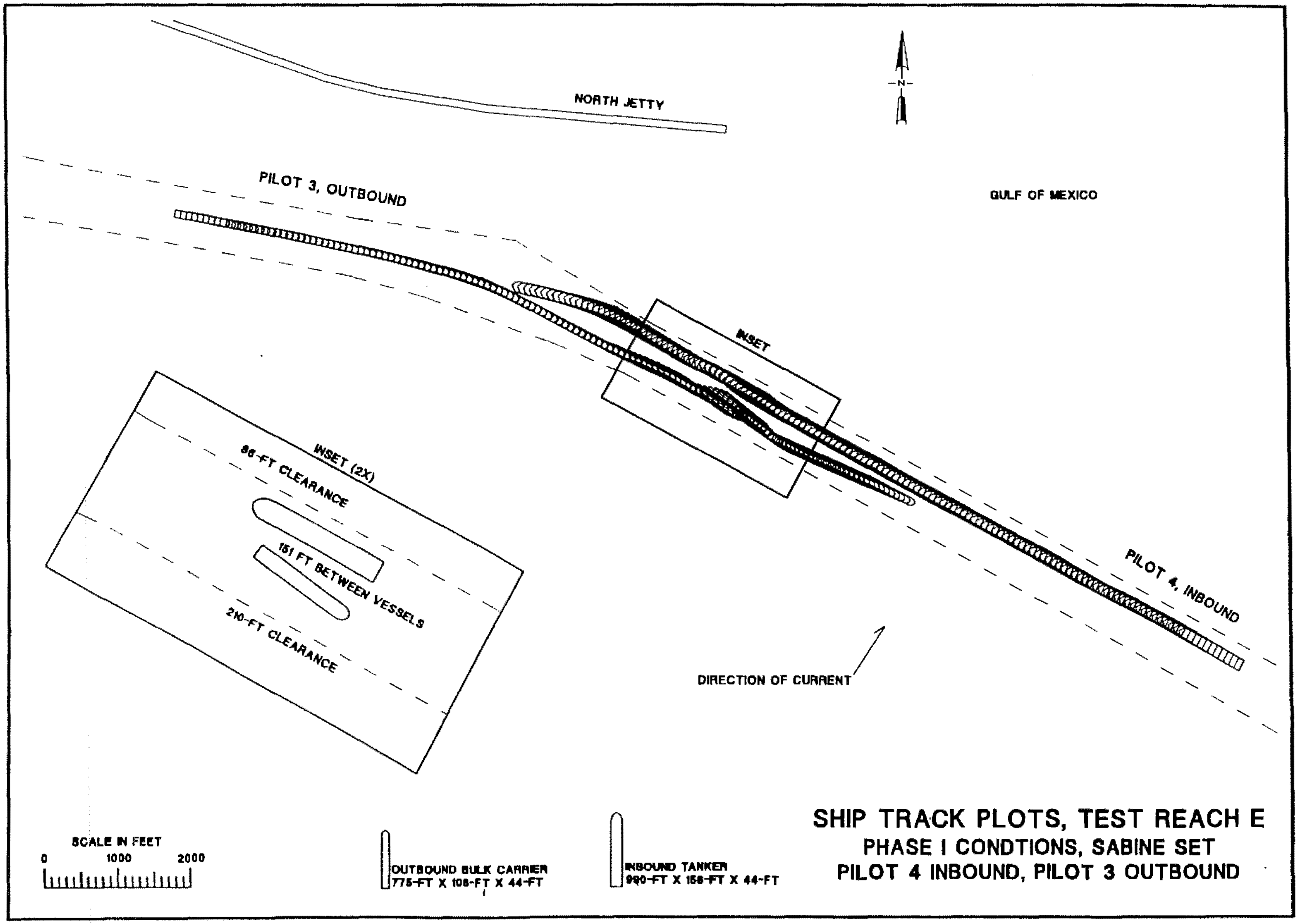
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 137

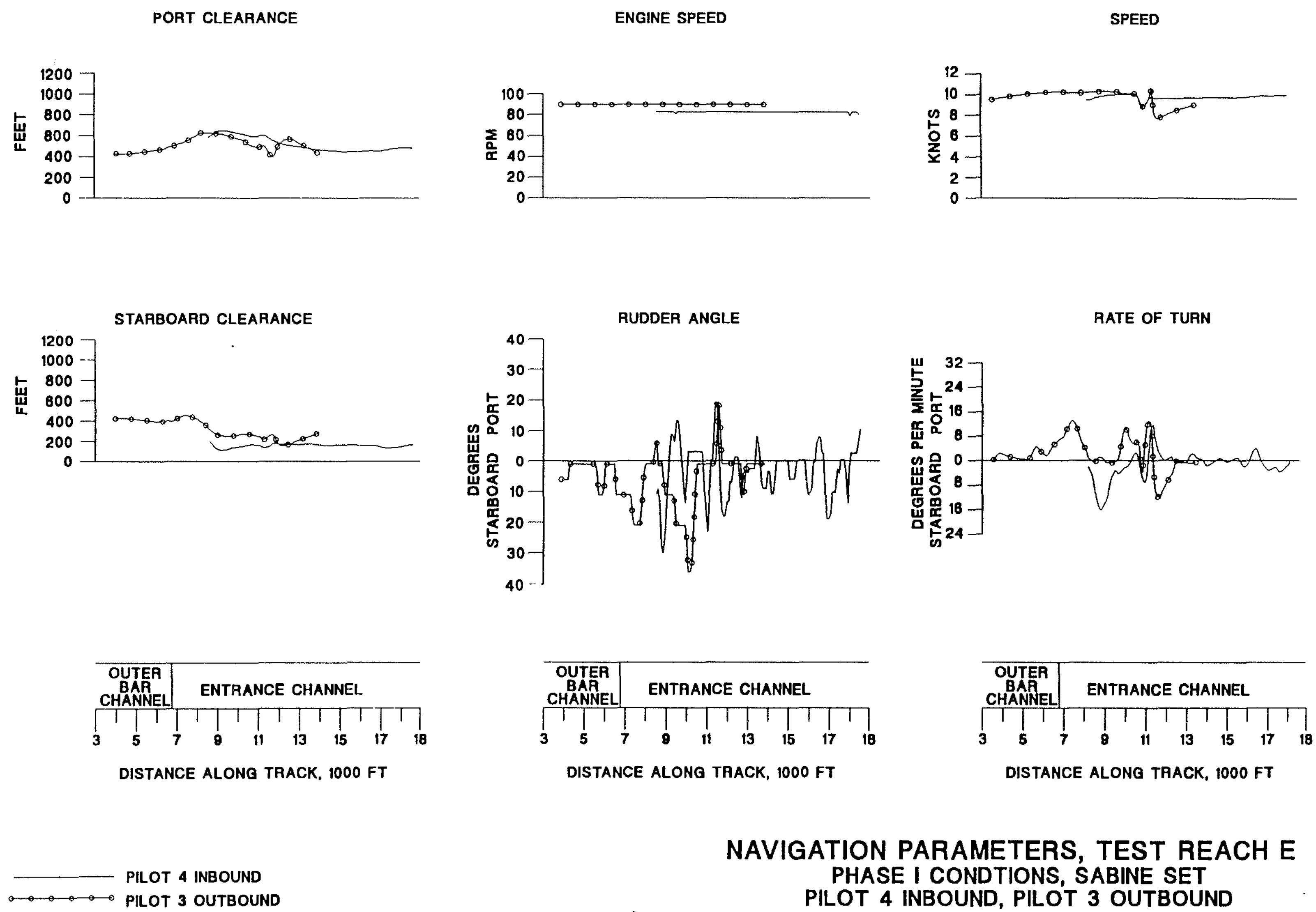


PILOT 3 INBOUND
PILOT 4 OUTBOUND

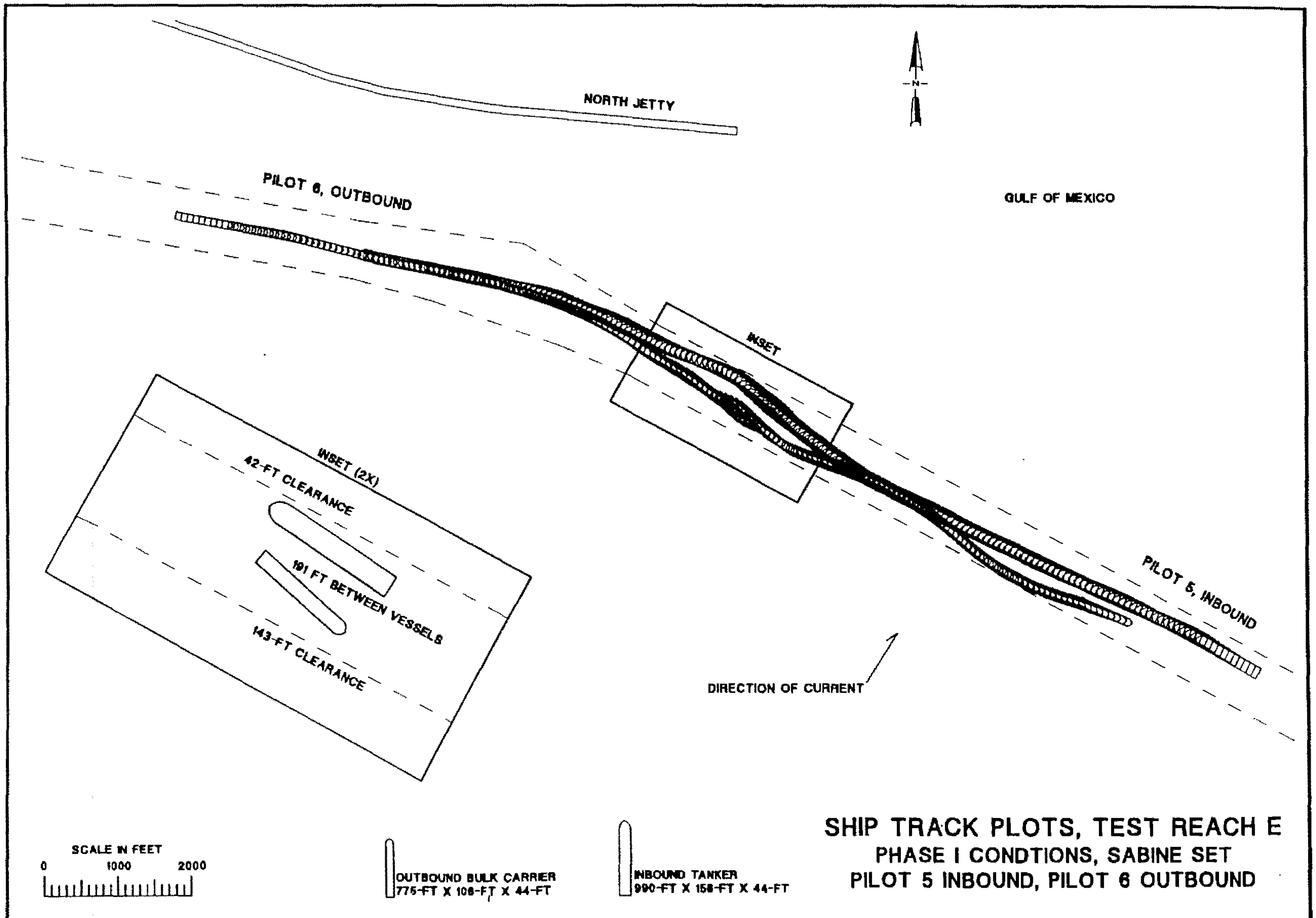
NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



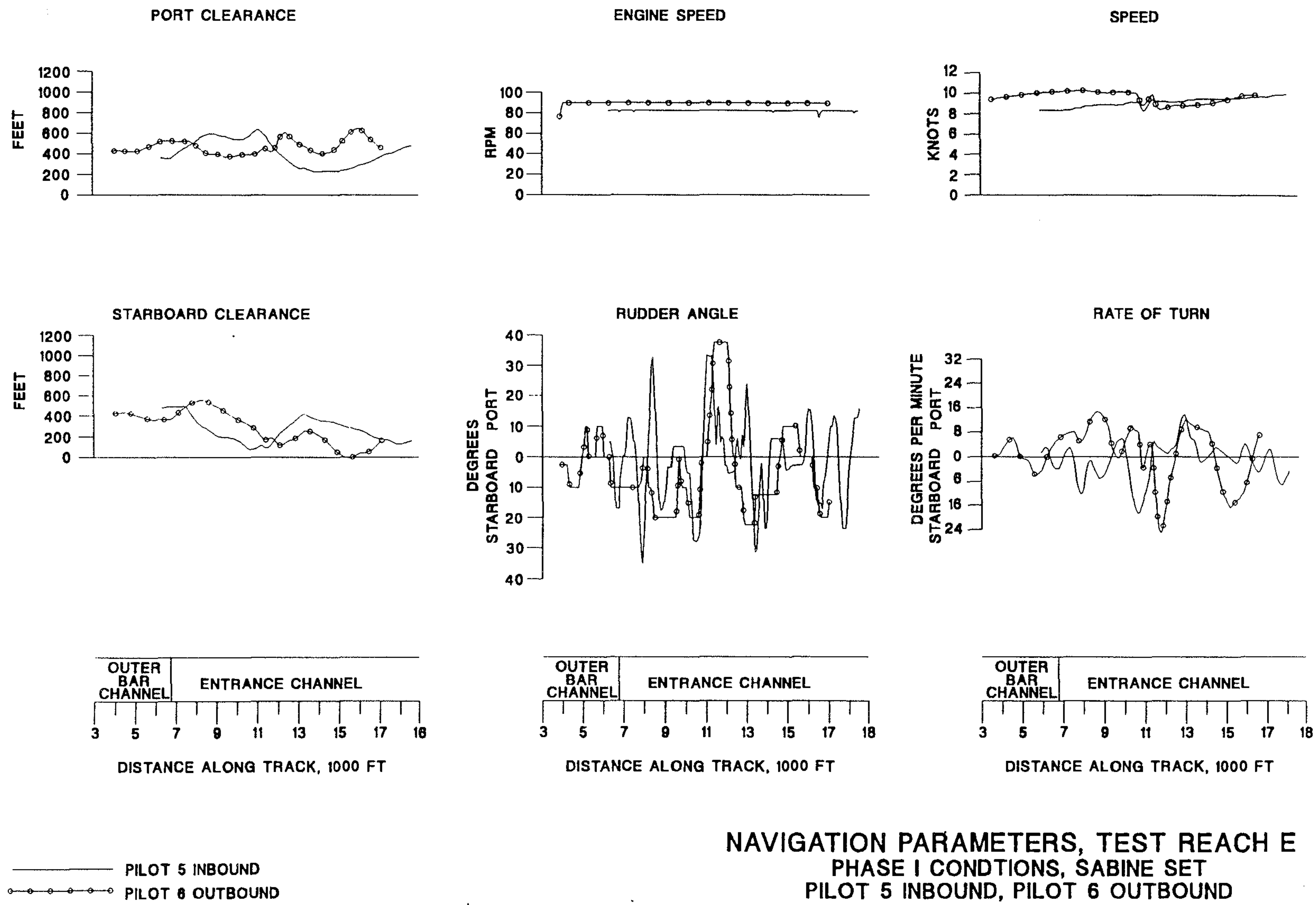
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



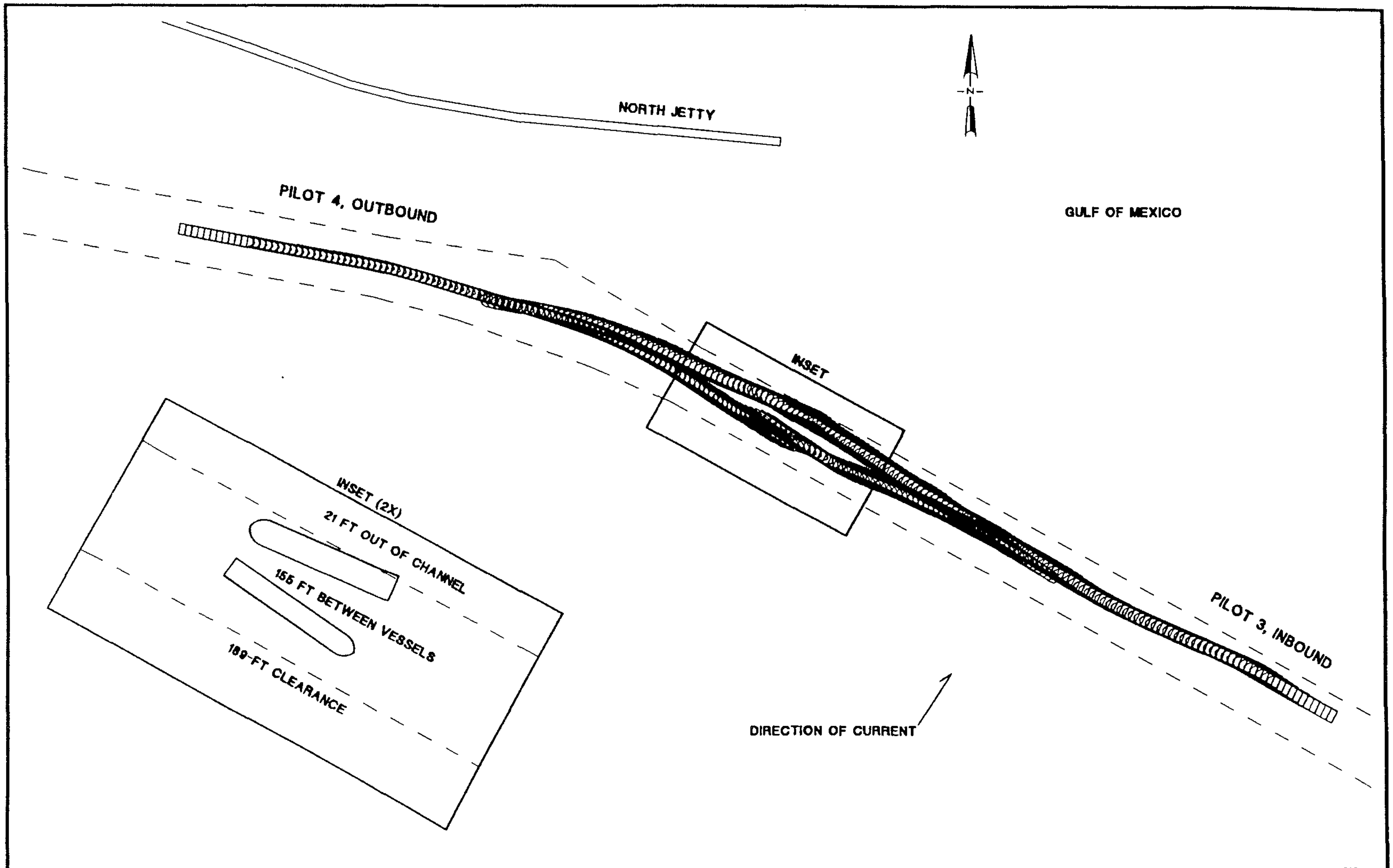
NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



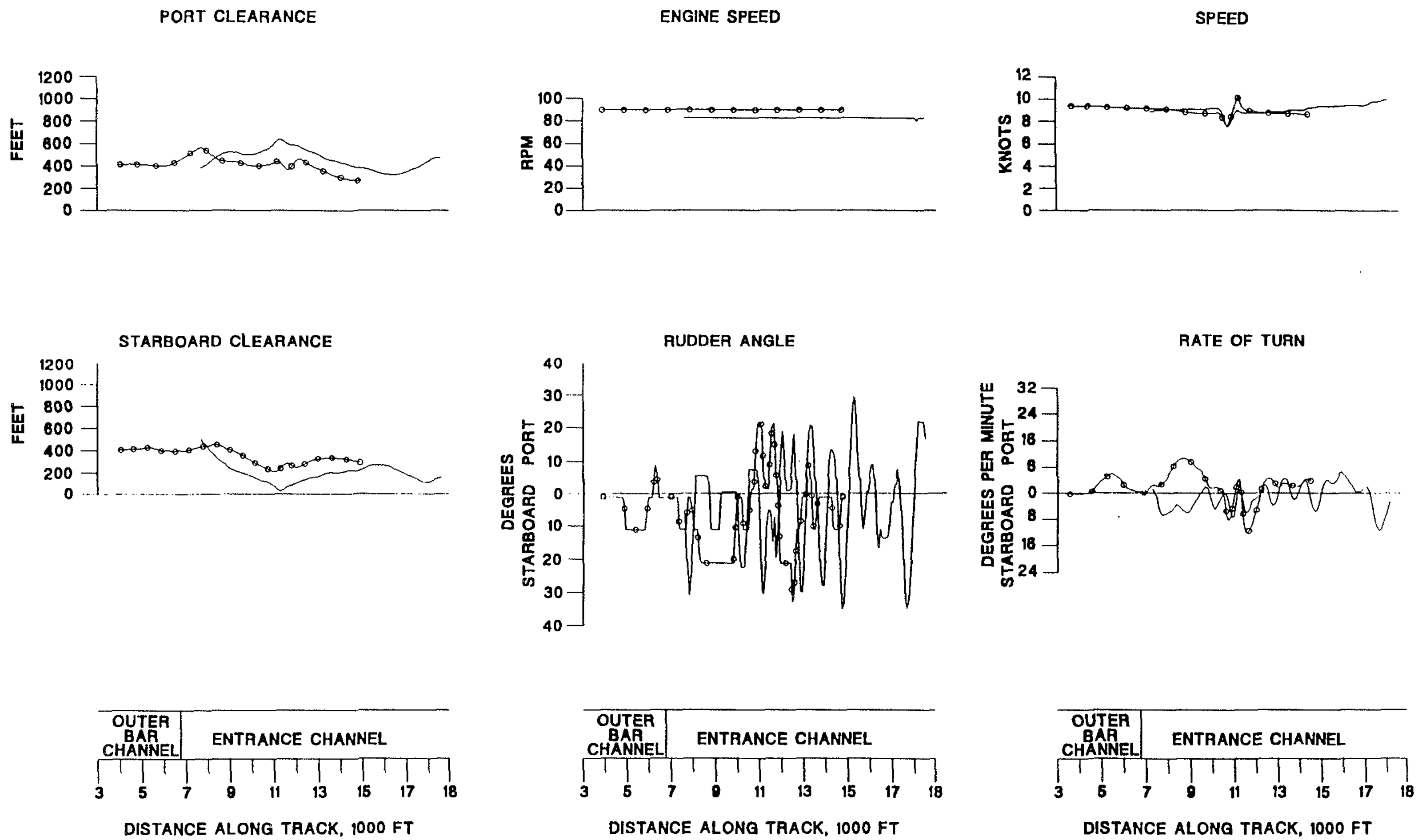
SHIP TRACK PLOTS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH E
PHASE I CONDTIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

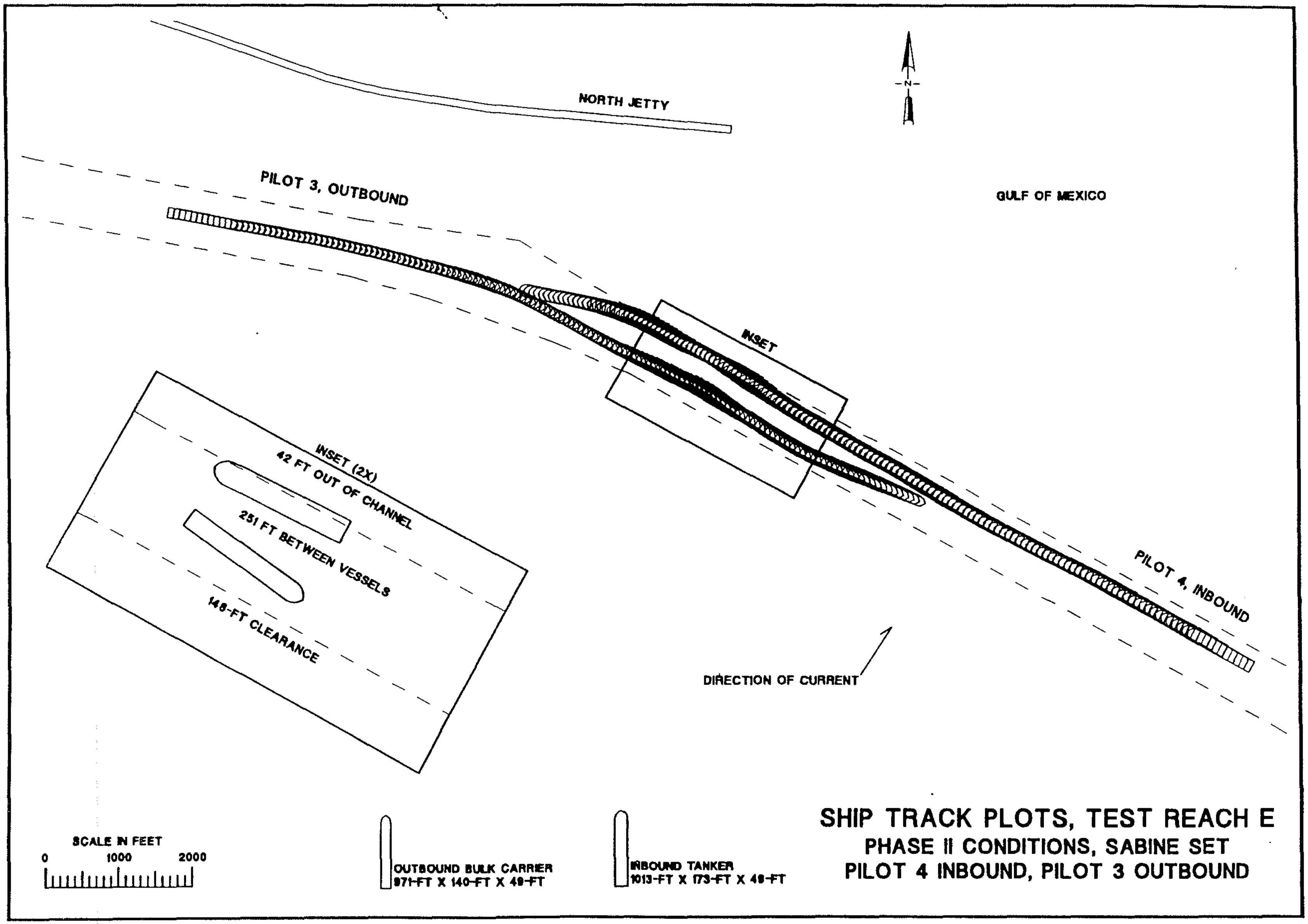


SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

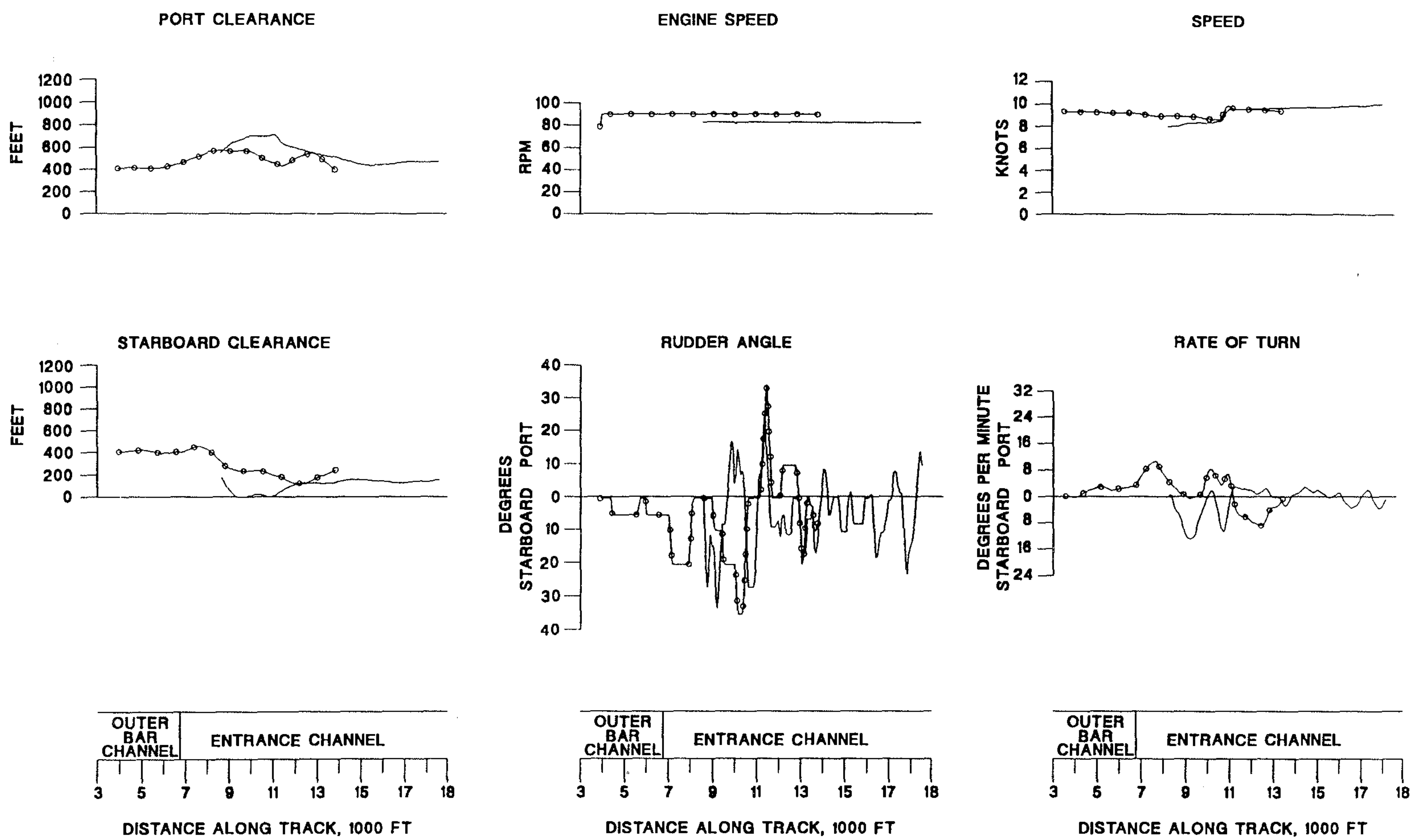


PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

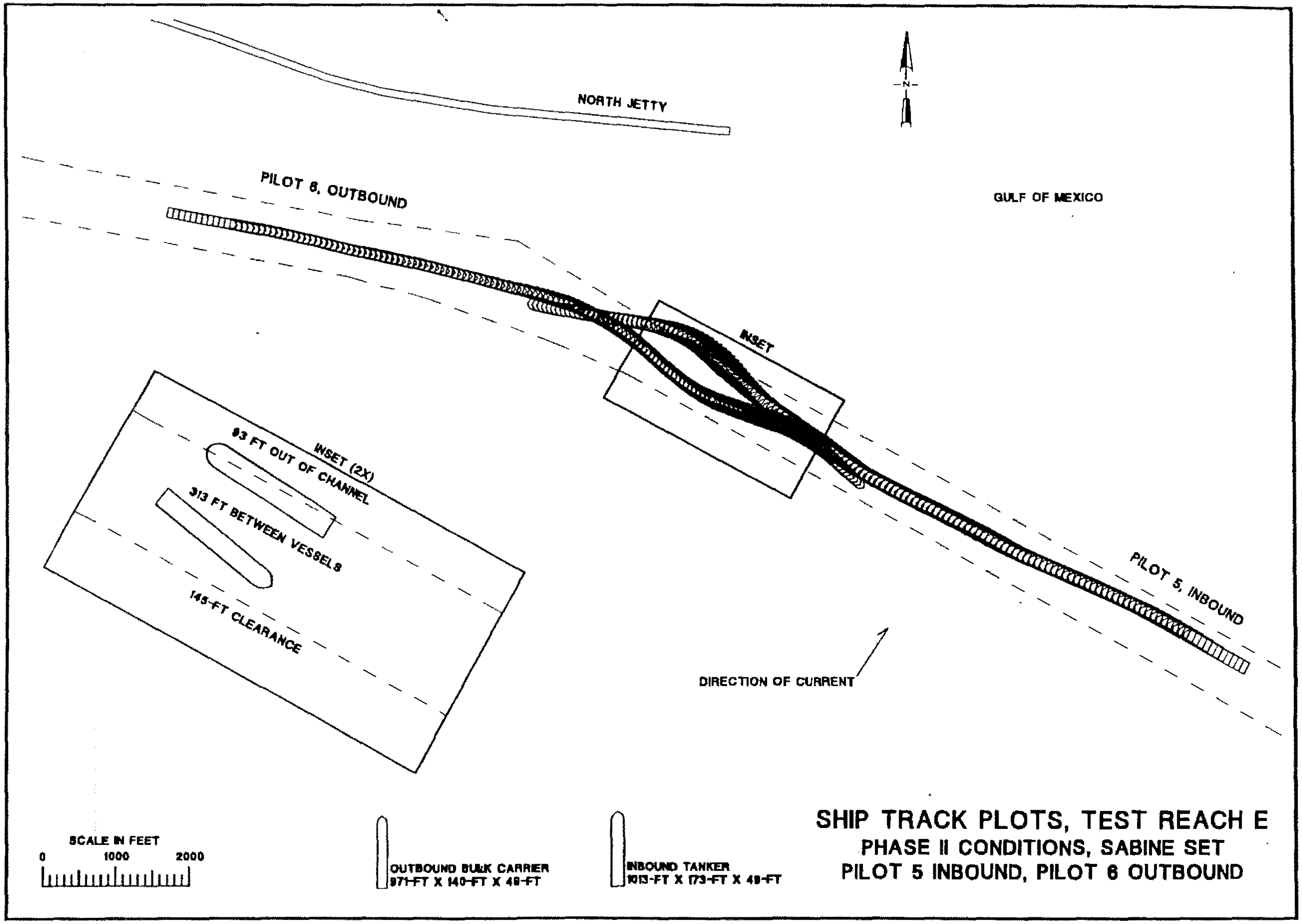


SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

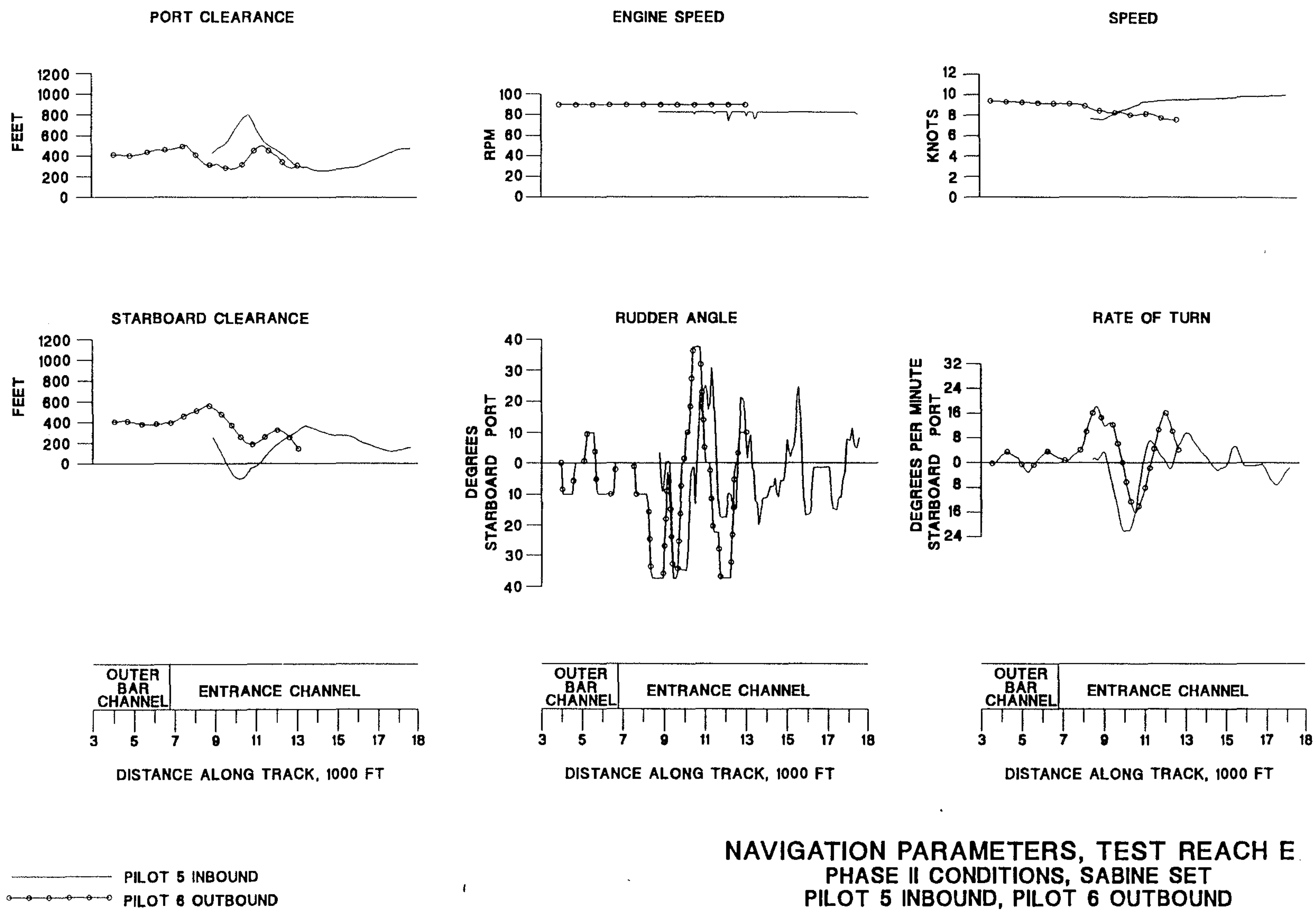


PILOT 4 INBOUND
PILOT 3 OUTBOUND

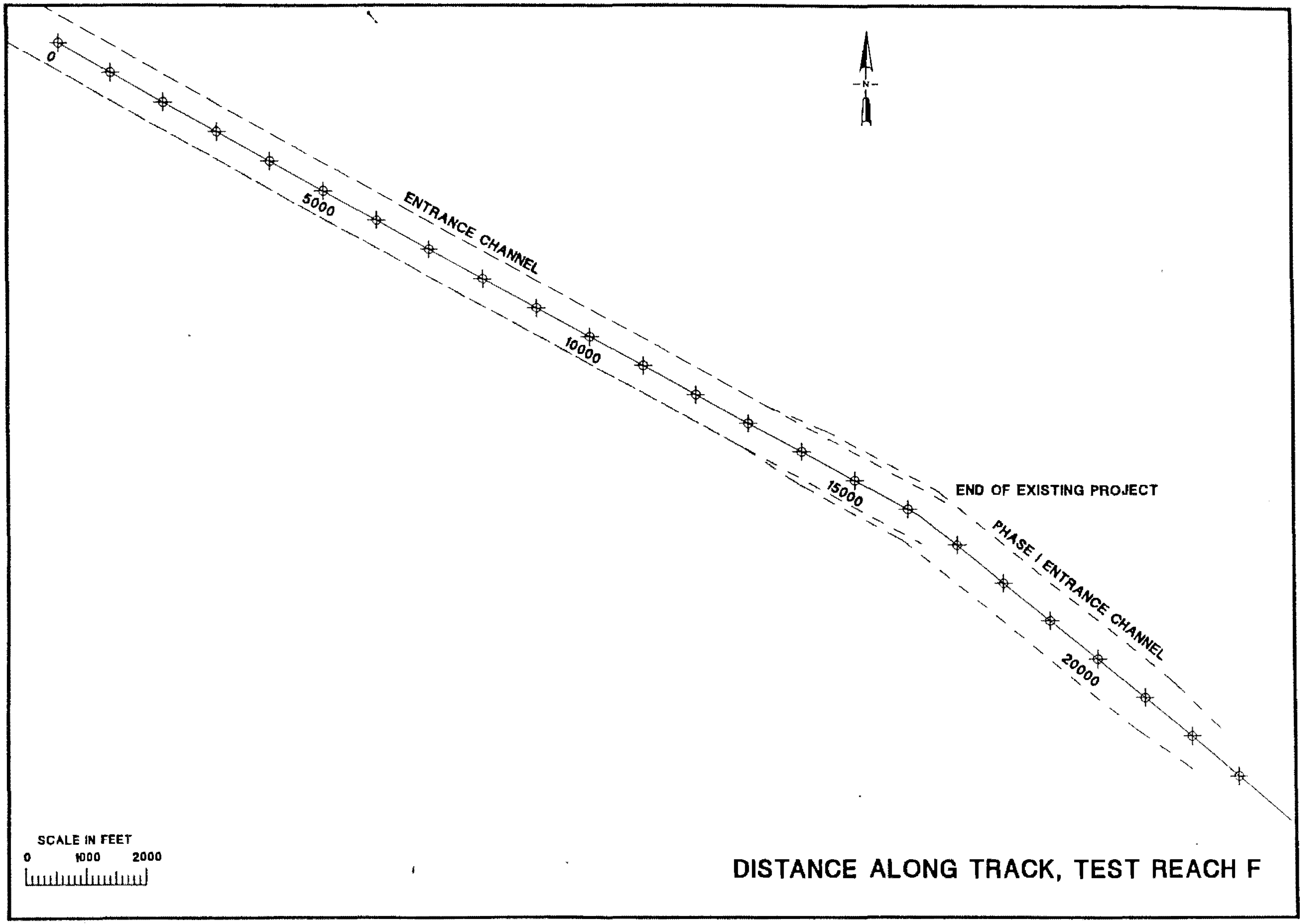
NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



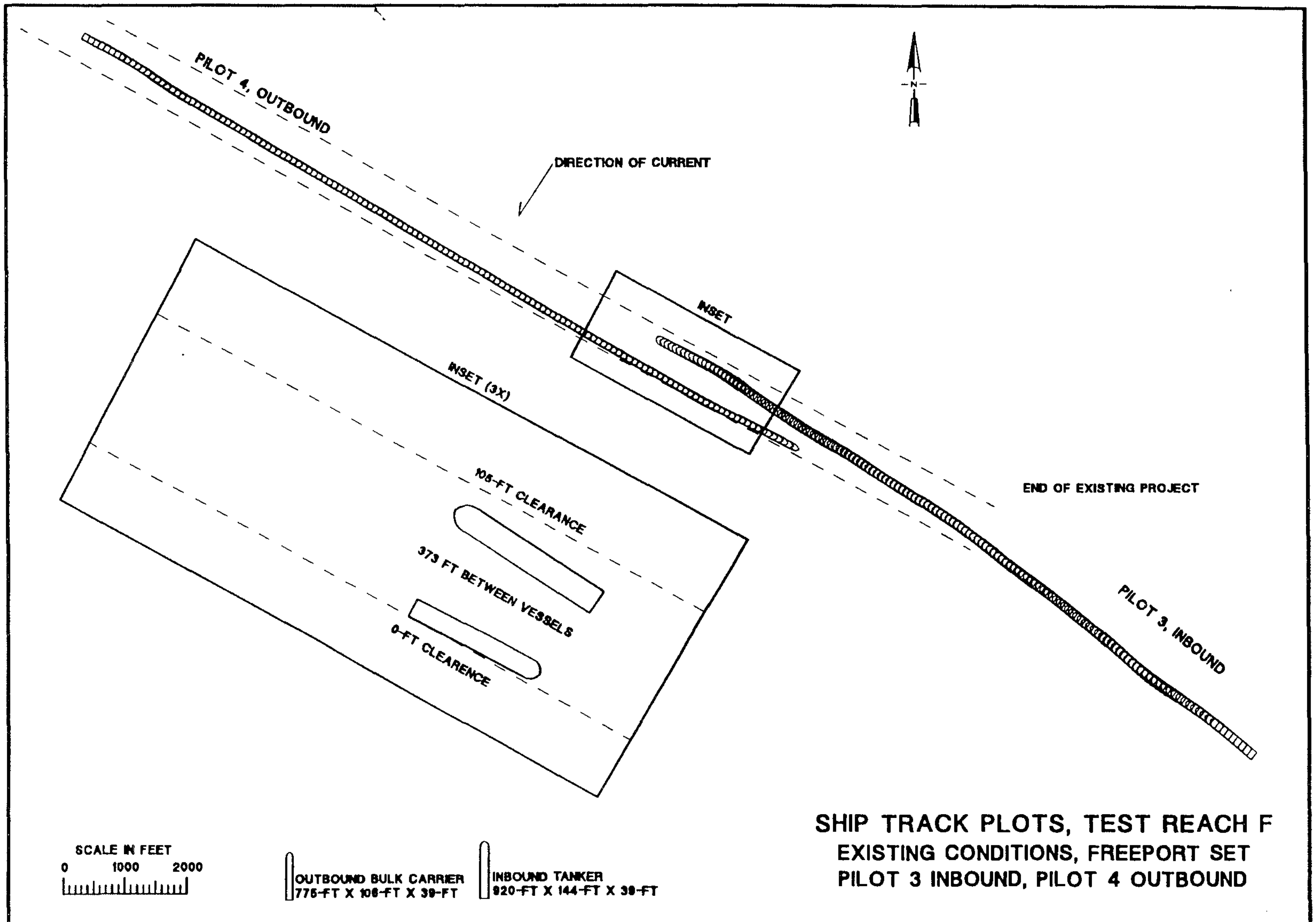
SHIP TRACK PLOTS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



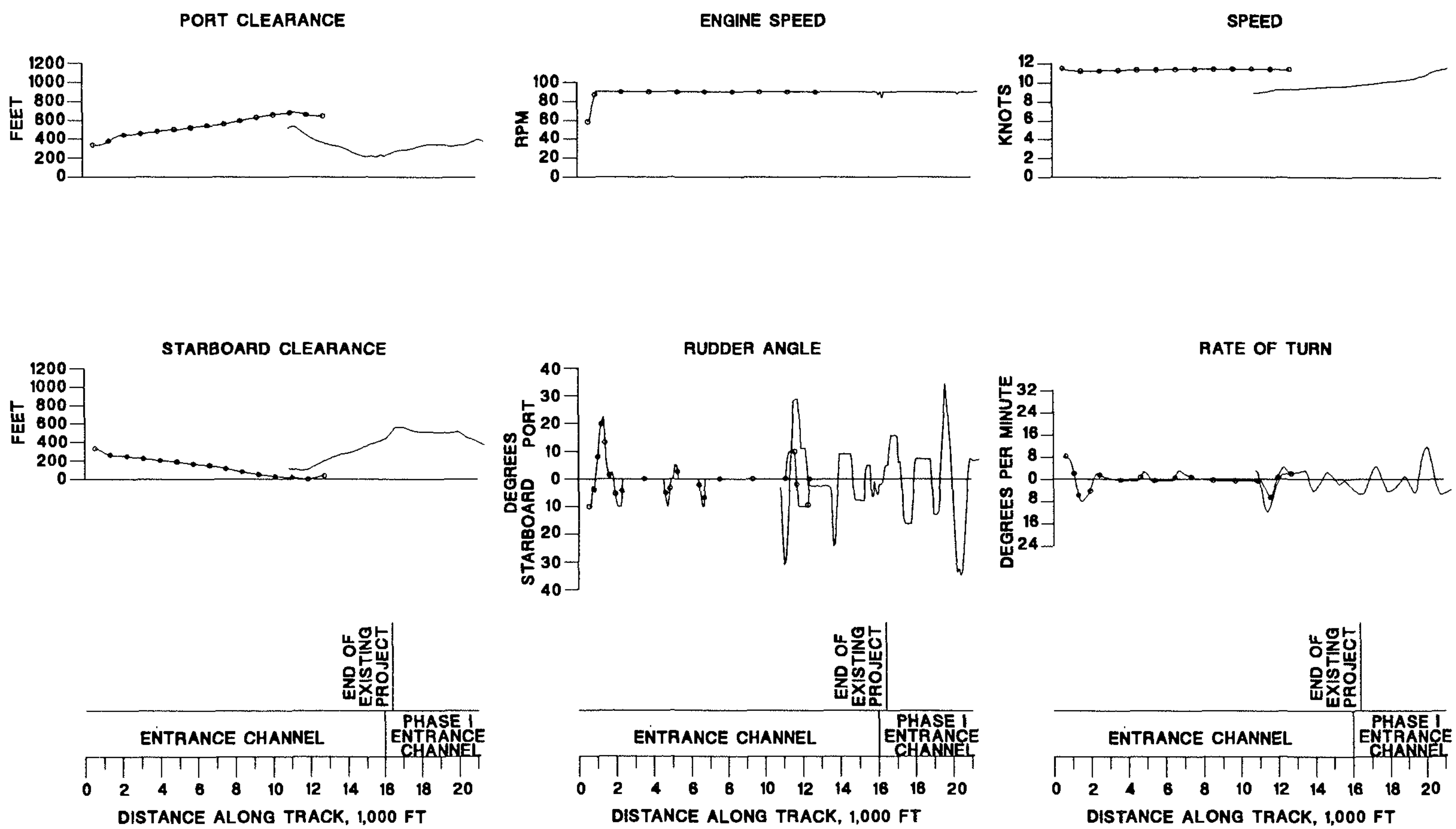
NAVIGATION PARAMETERS, TEST REACH E
PHASE II CONDITIONS, SABINE SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



DISTANCE ALONG TRACK, TEST REACH F



SHIP TRACK PLOTS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

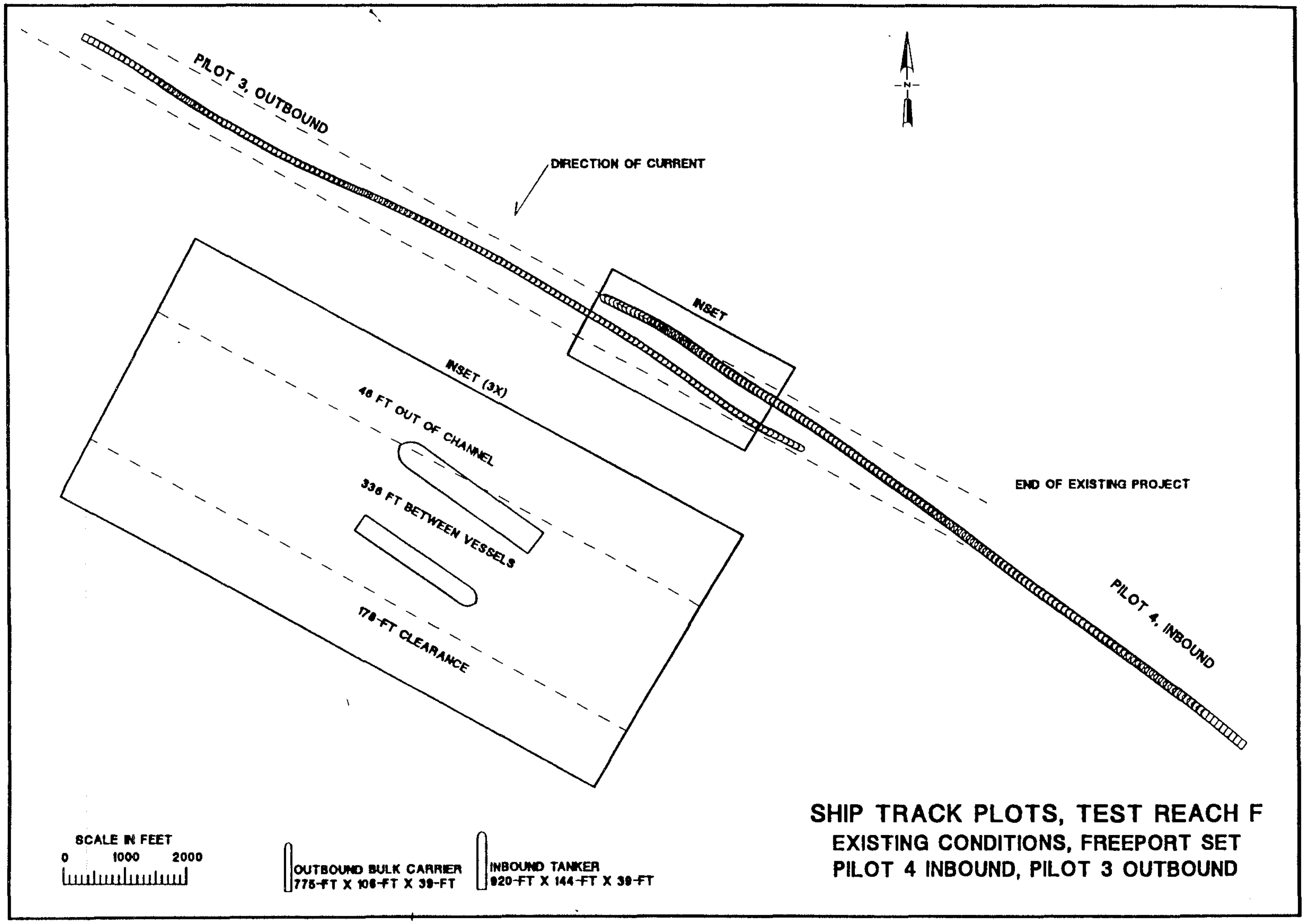


PILOT 3 INBOUND

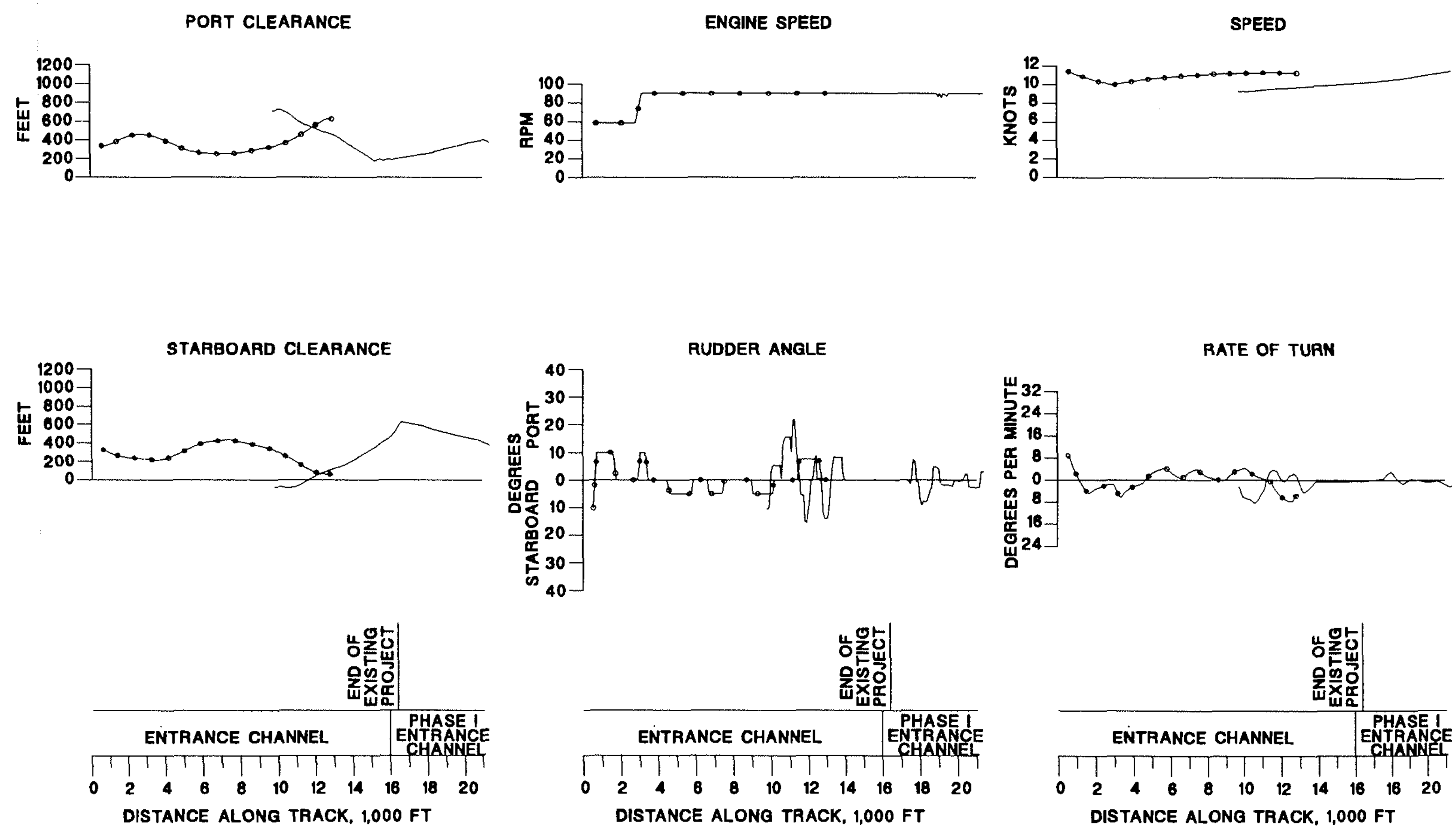
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

Plate 152



SHIP TRACK PLOTS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

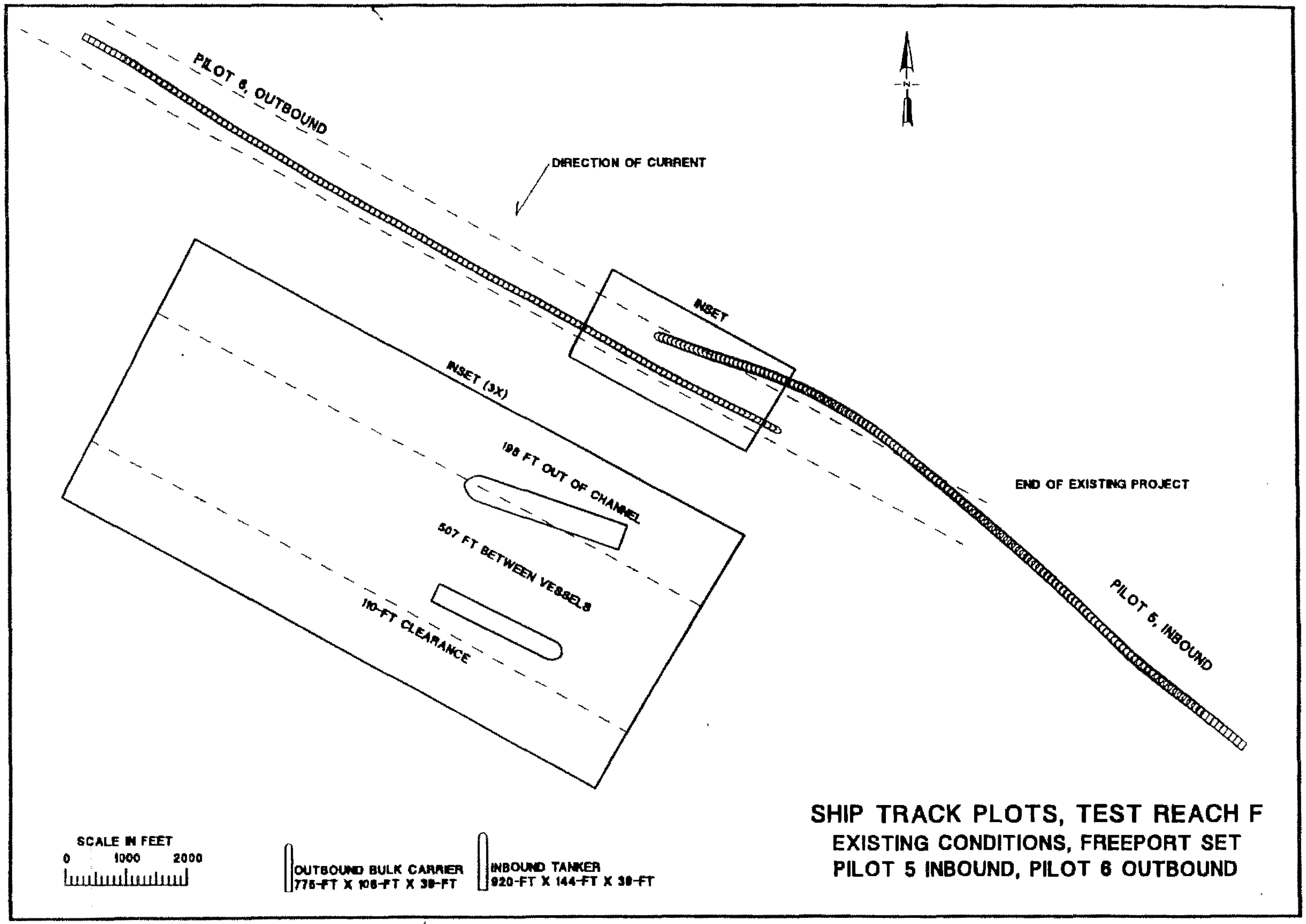


PILOT 4 INBOUND

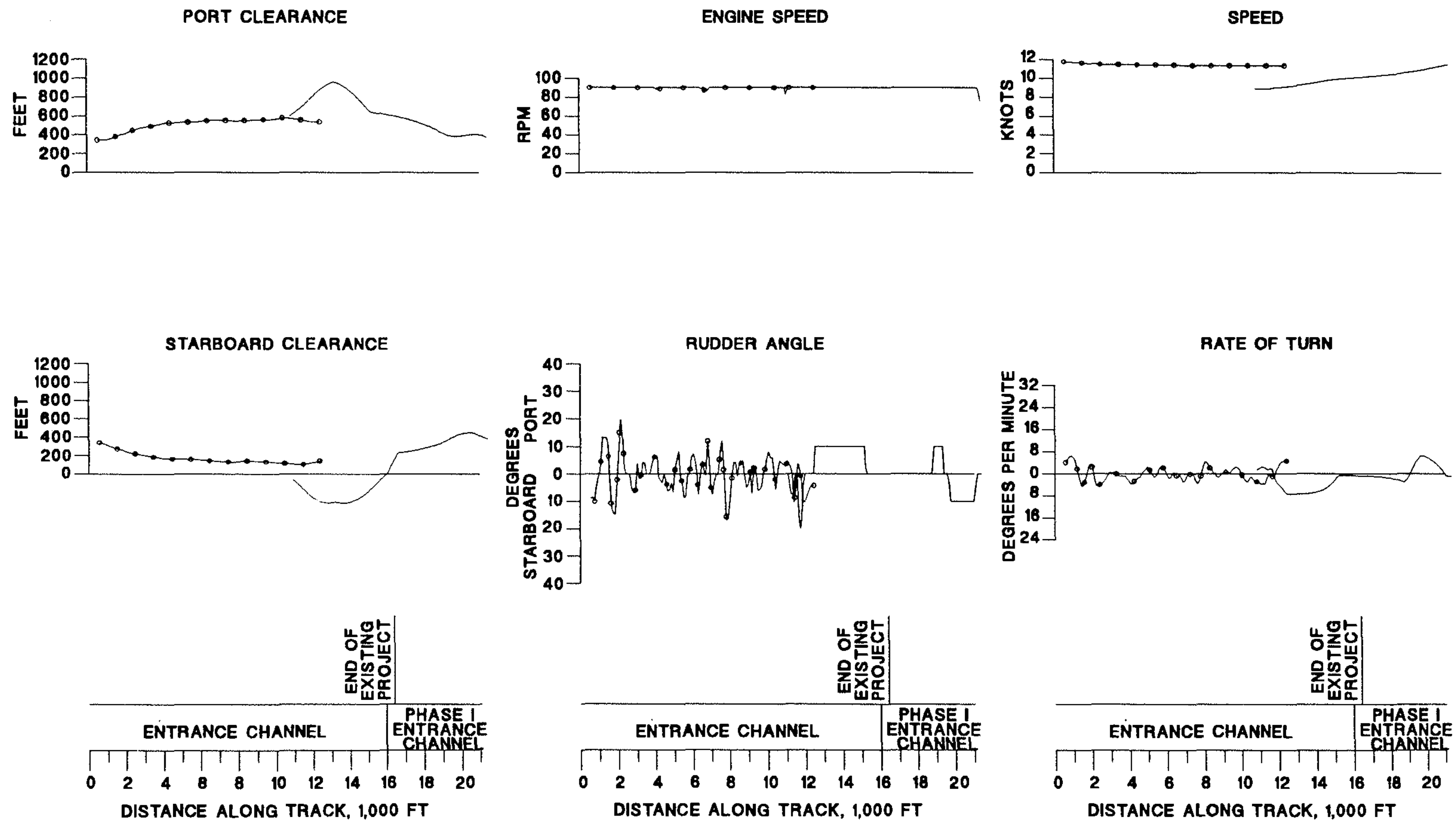
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH F

EXISTING CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

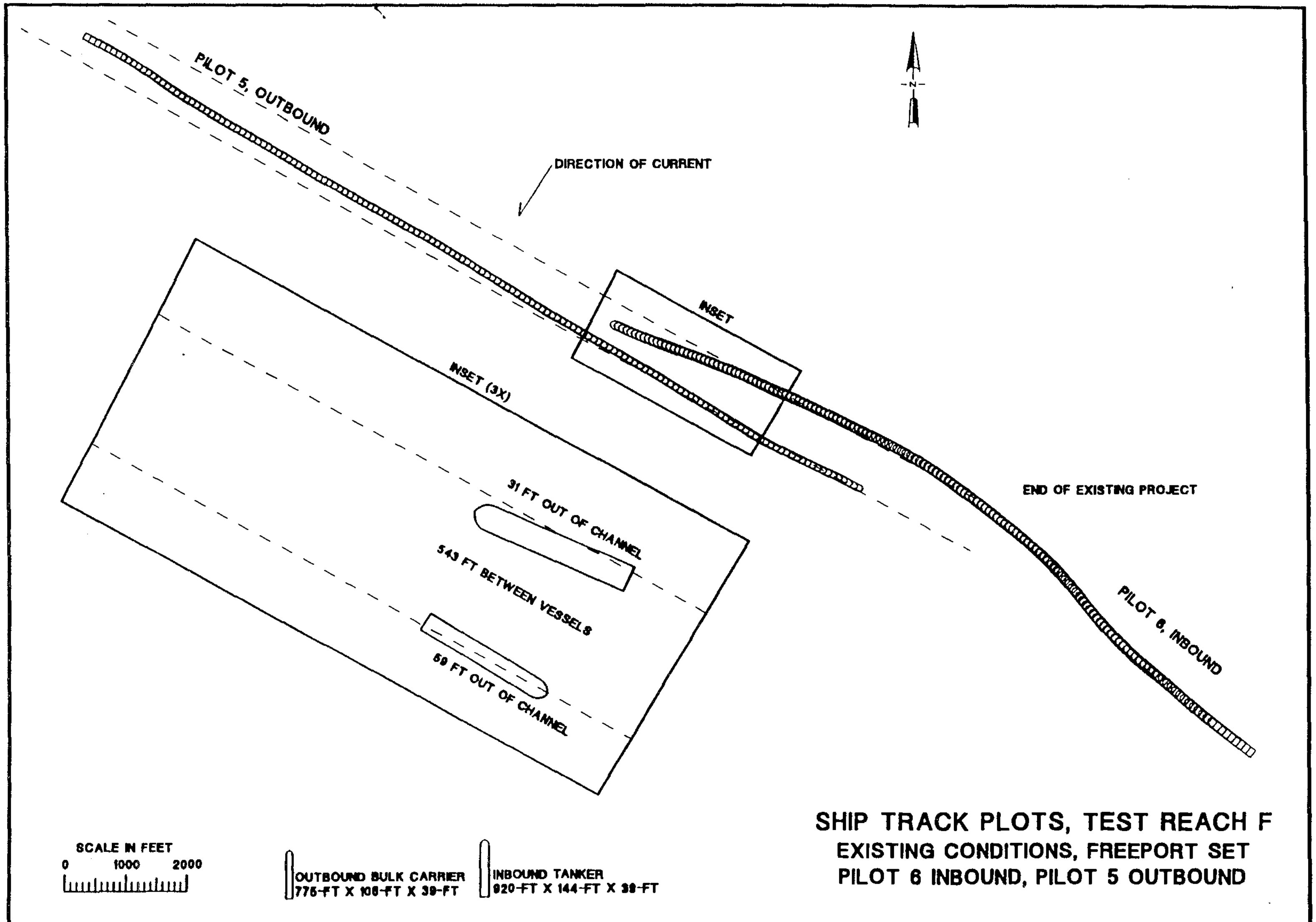


SHIP TRACK PLOTS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

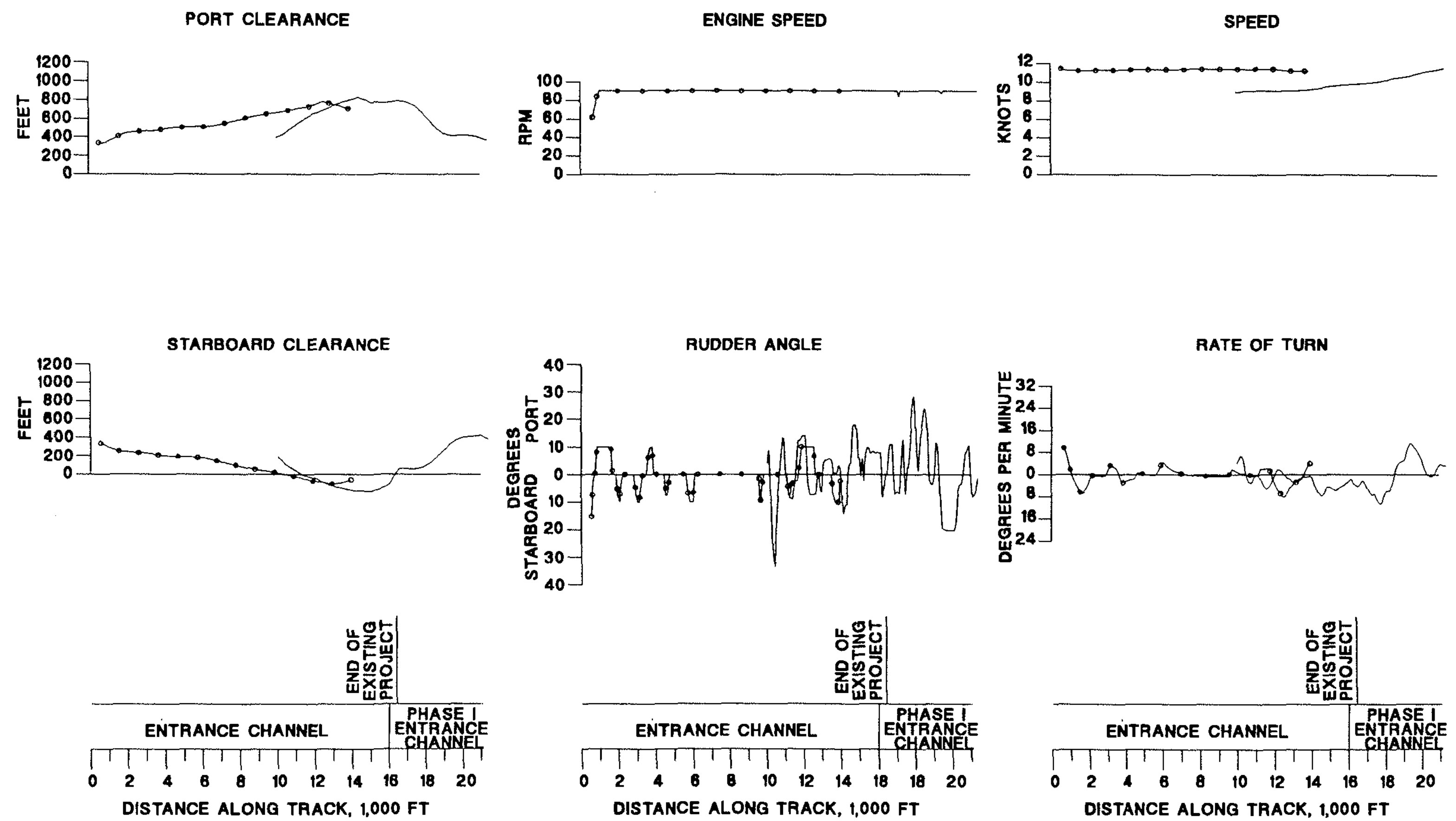


PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

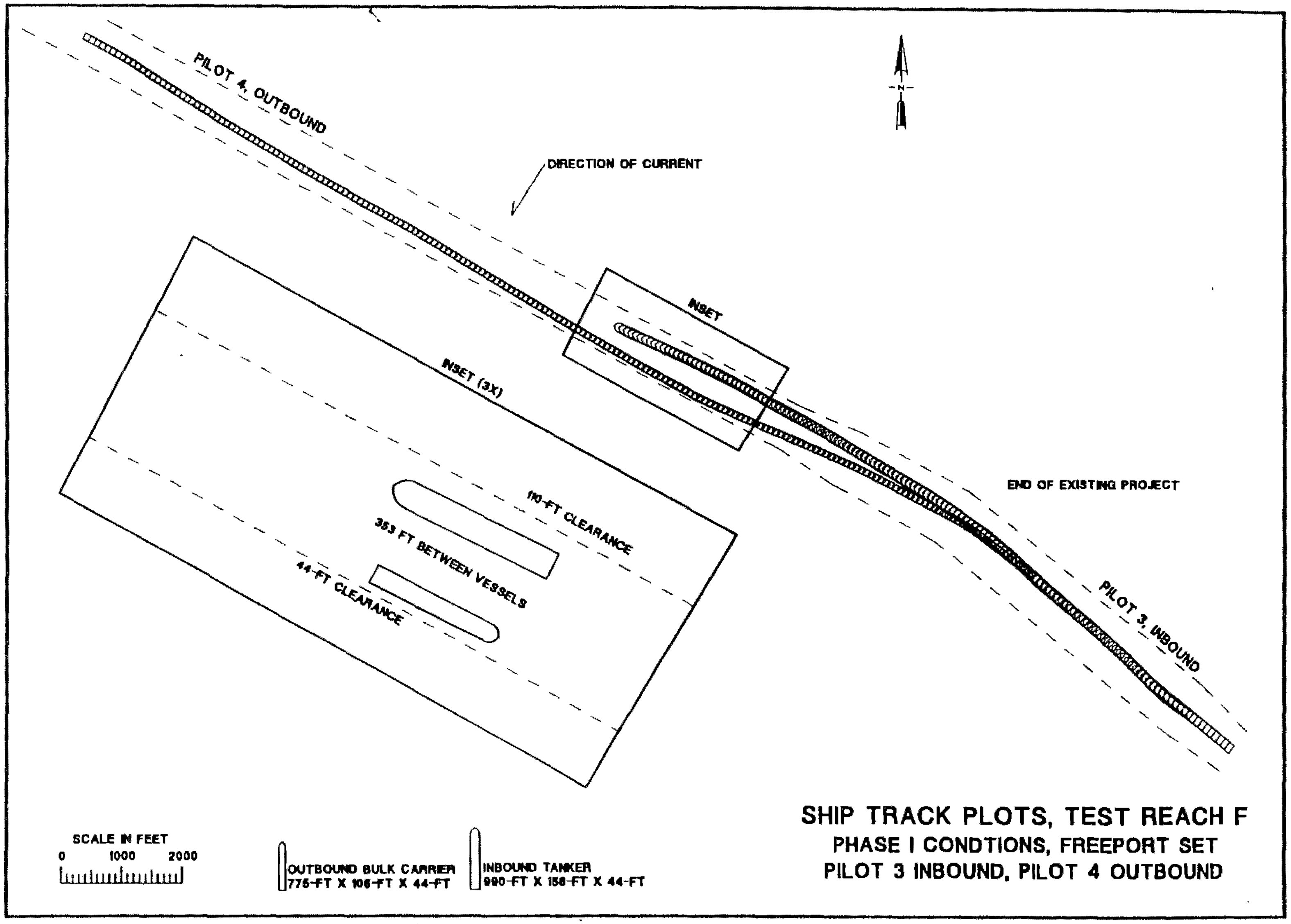


SHIP TRACK PLOTS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

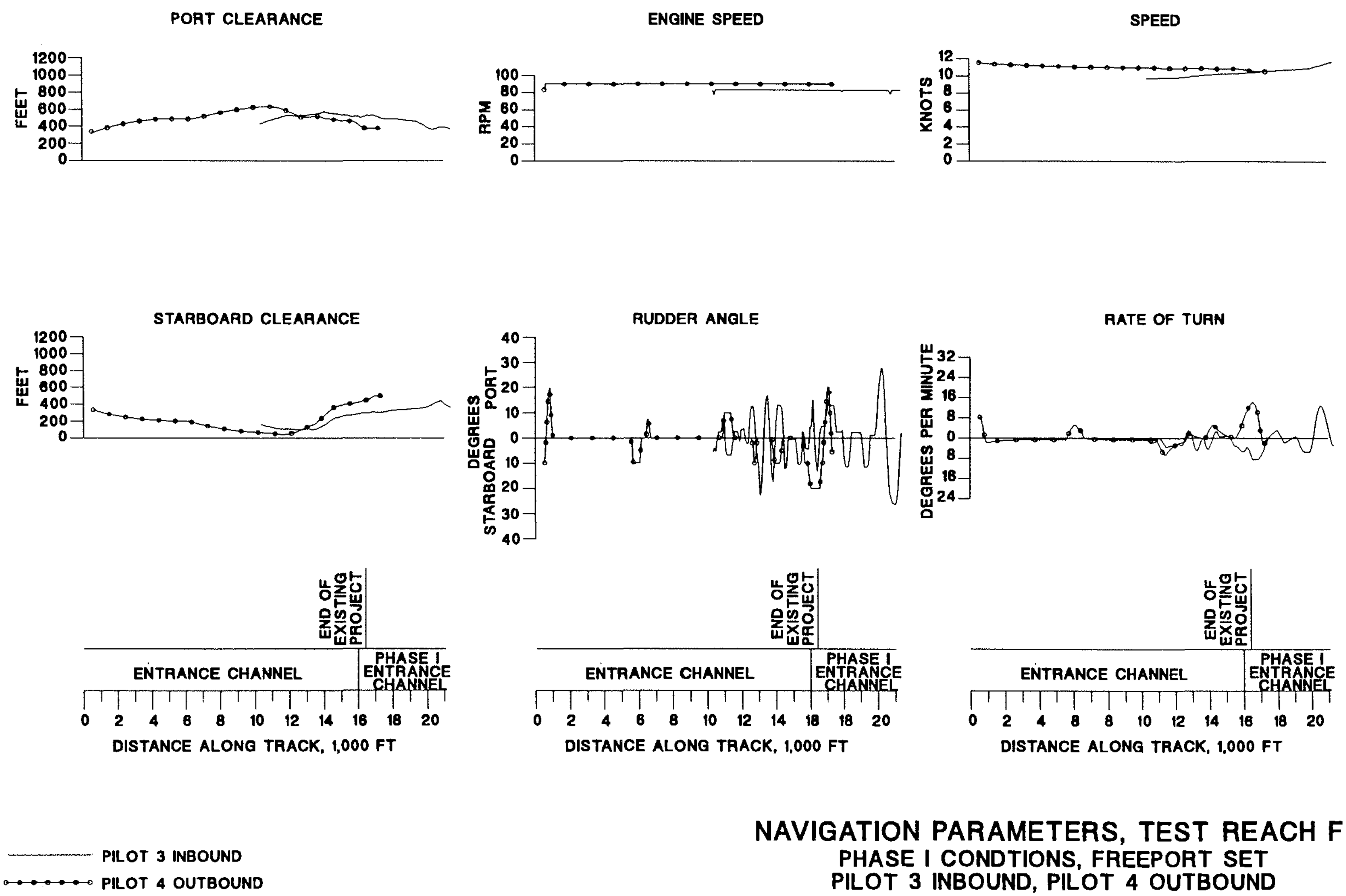


PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH F
EXISTING CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

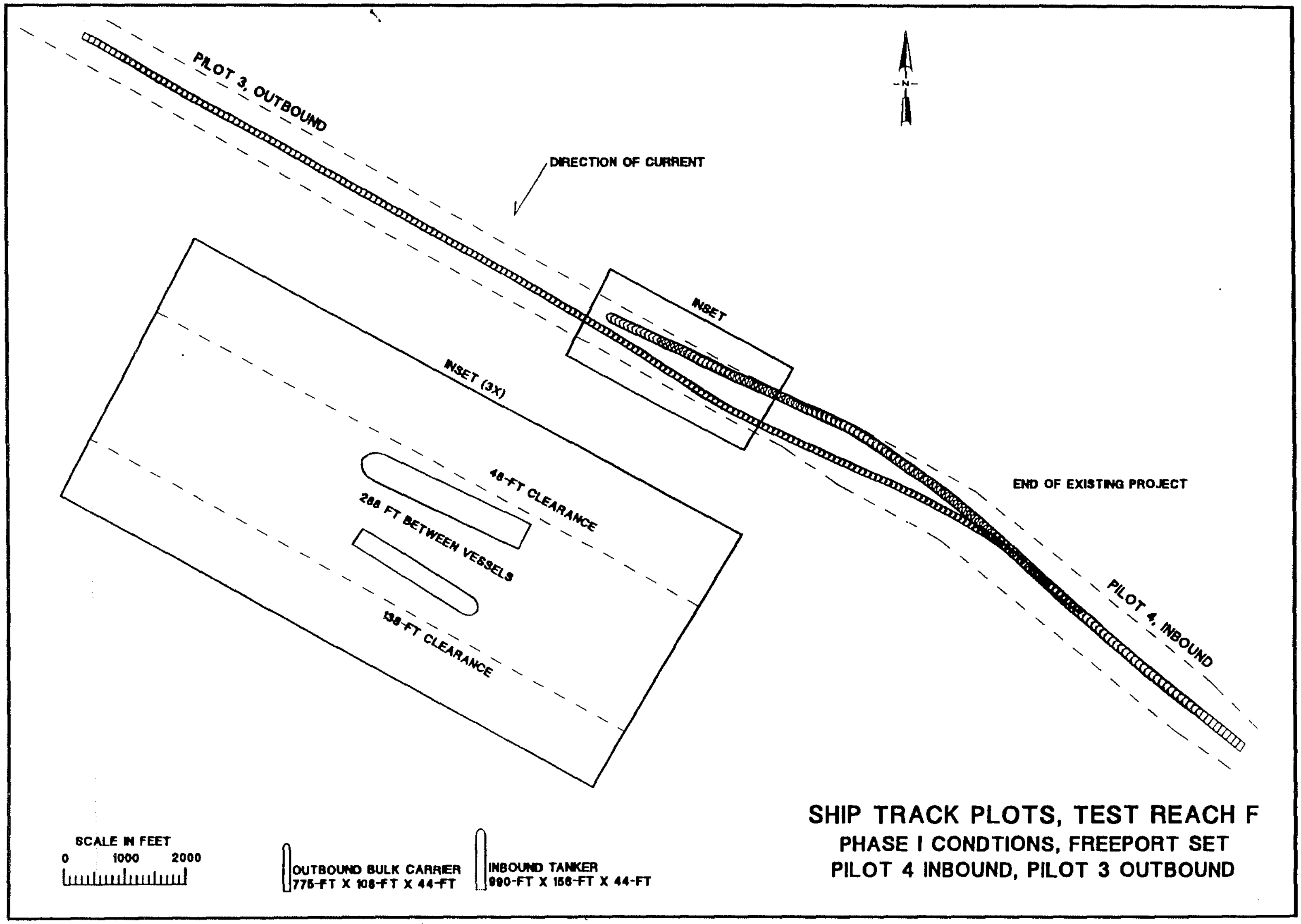


SHIP TRACK PLOTS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

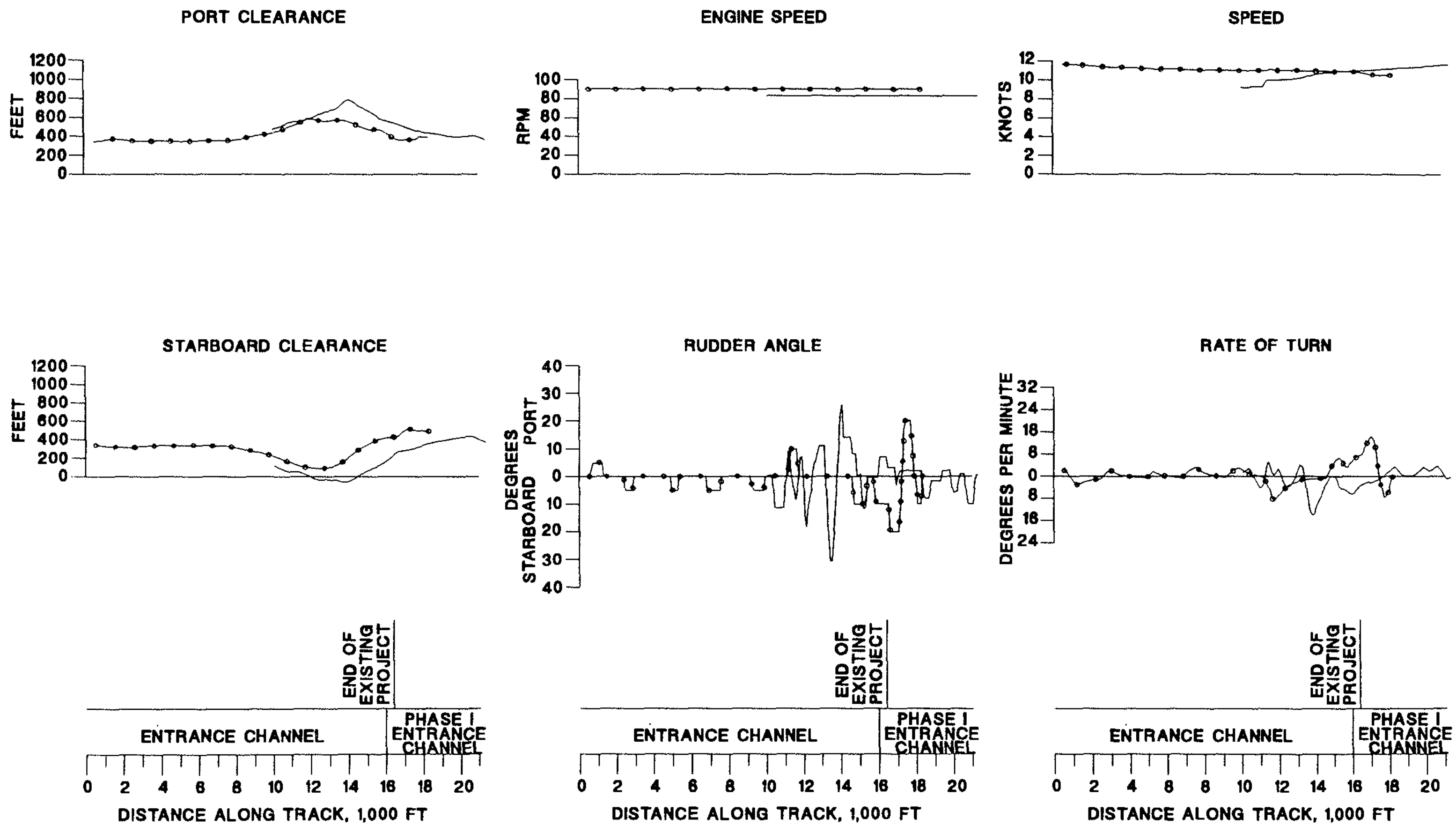


NAVIGATION PARAMETERS, TEST REACH F

PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



SHIP TRACK PLOTS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



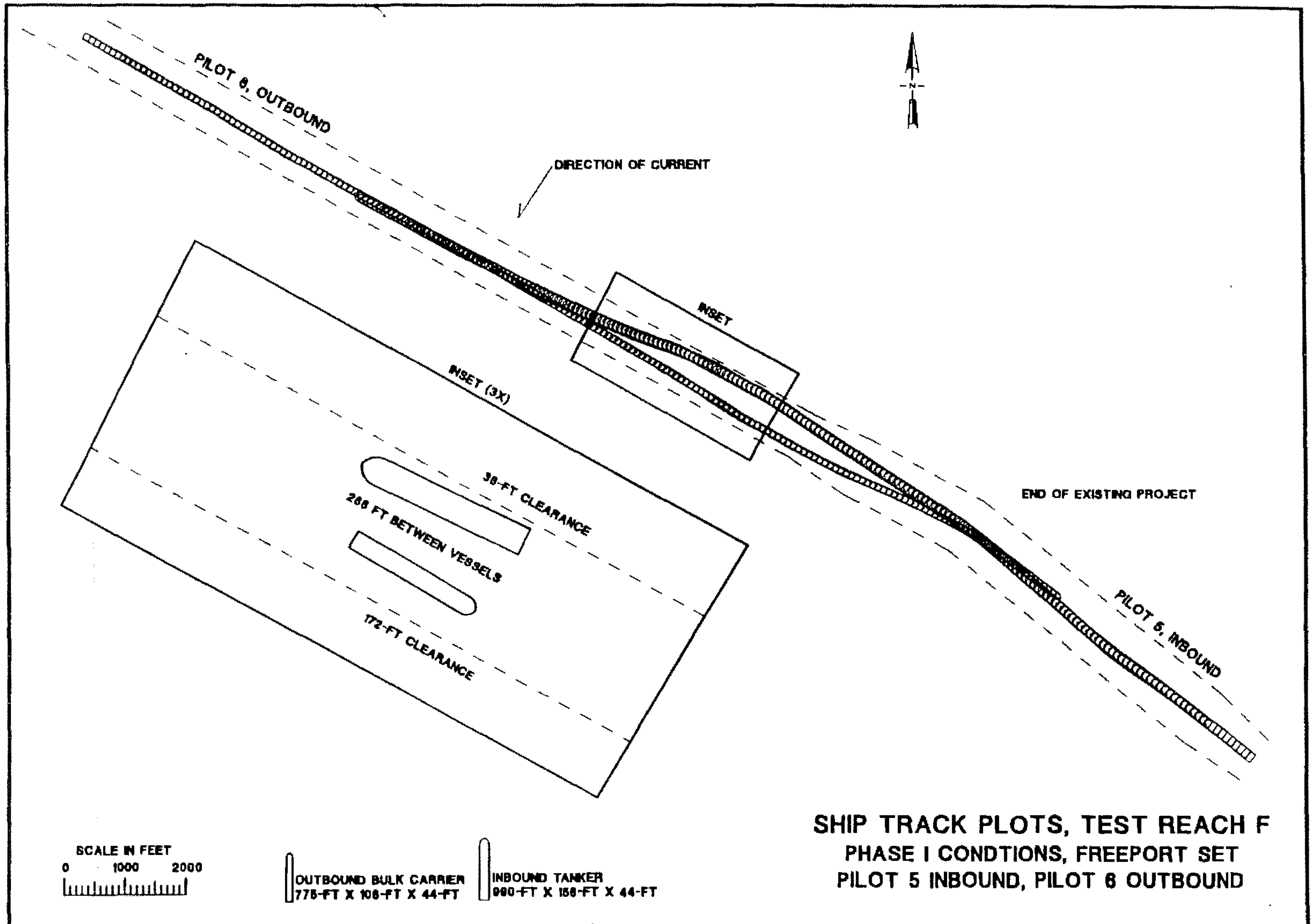
PILOT 4 INBOUND

PILOT 3 OUTBOUND

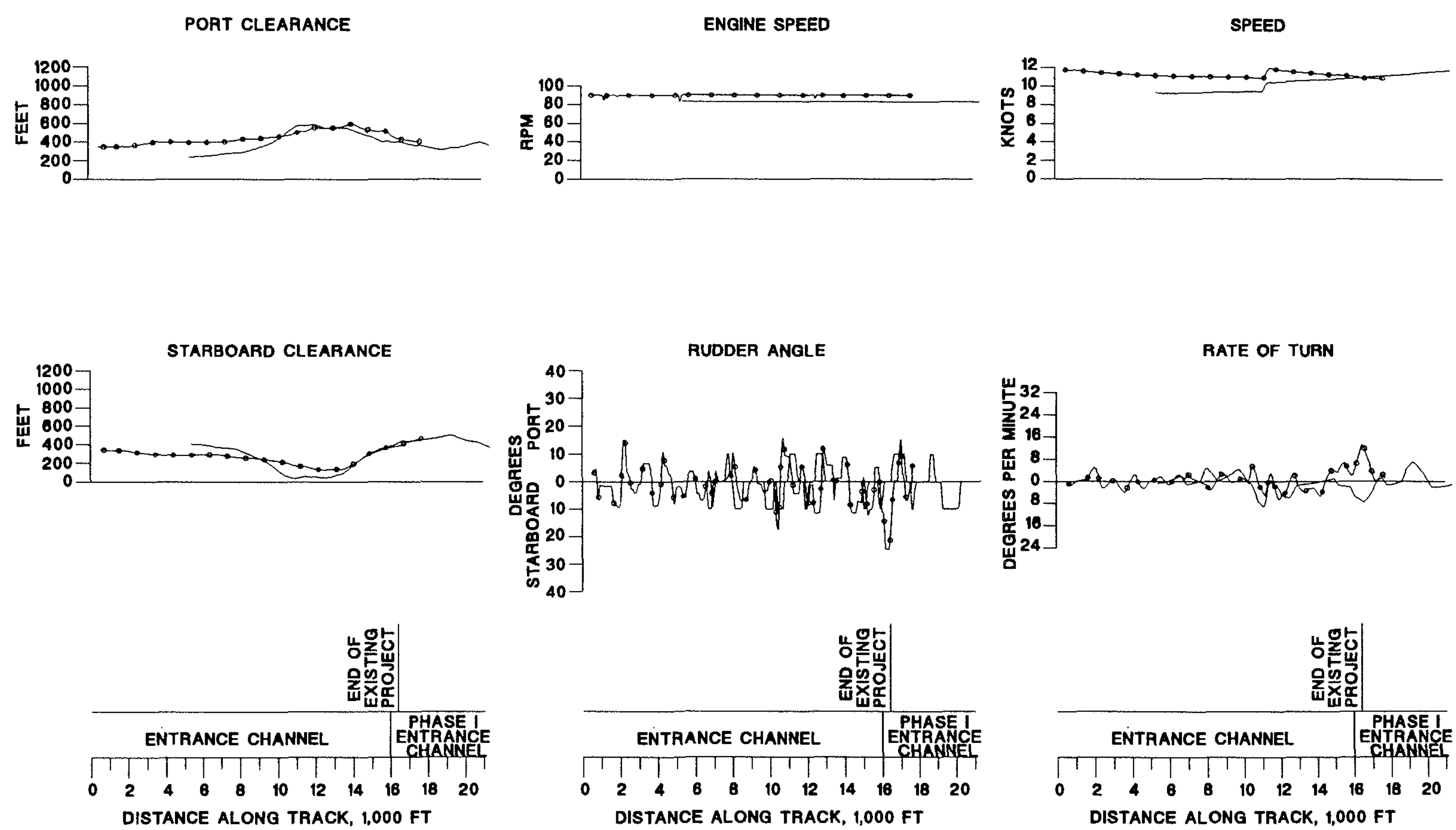
NAVIGATION PARAMETERS, TEST REACH F

PHASE I CONDTIONS, FREEPORT SET

PILOT 4 INBOUND, PILOT 3 OUTBOUND

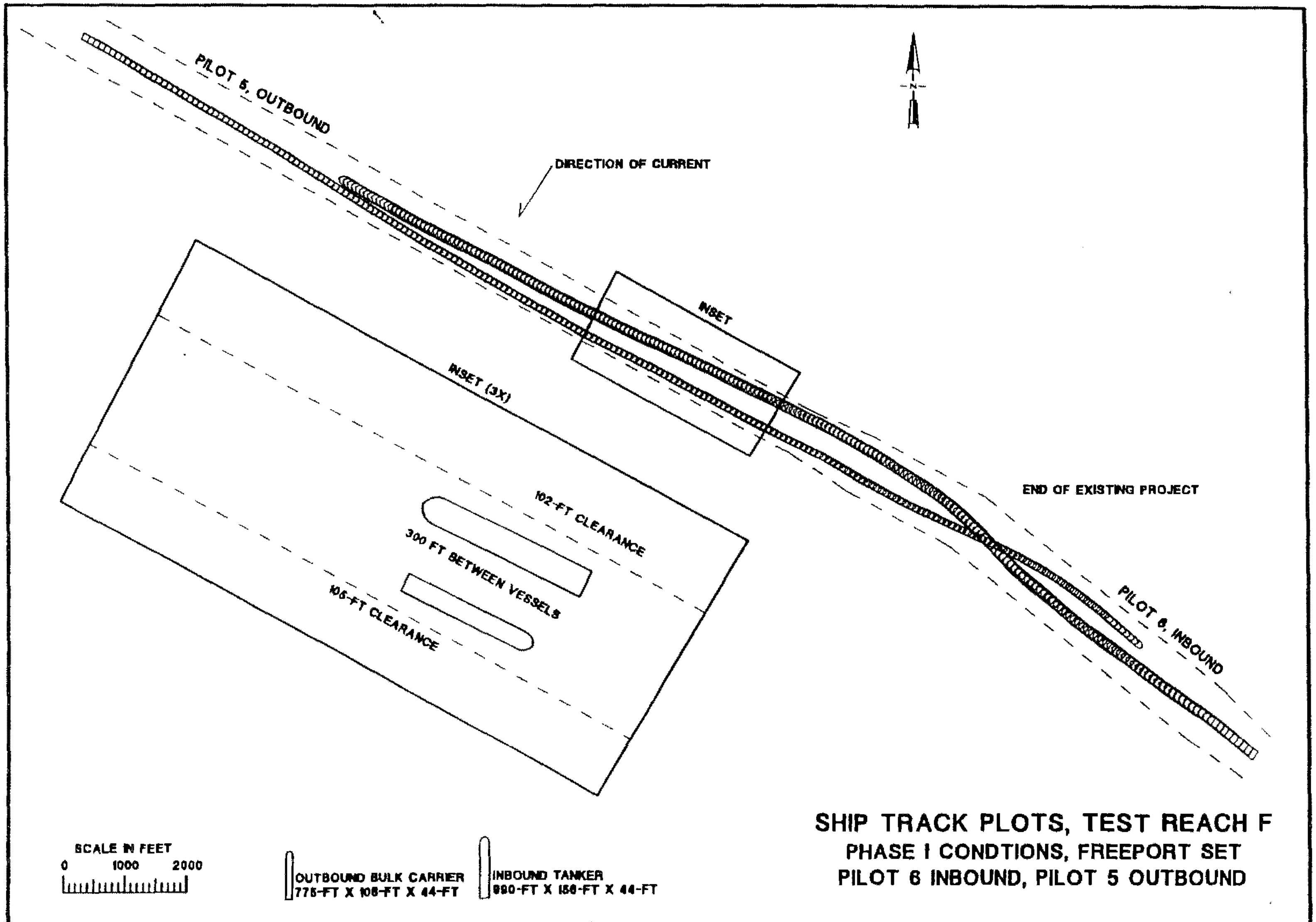


SHIP TRACK PLOTS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

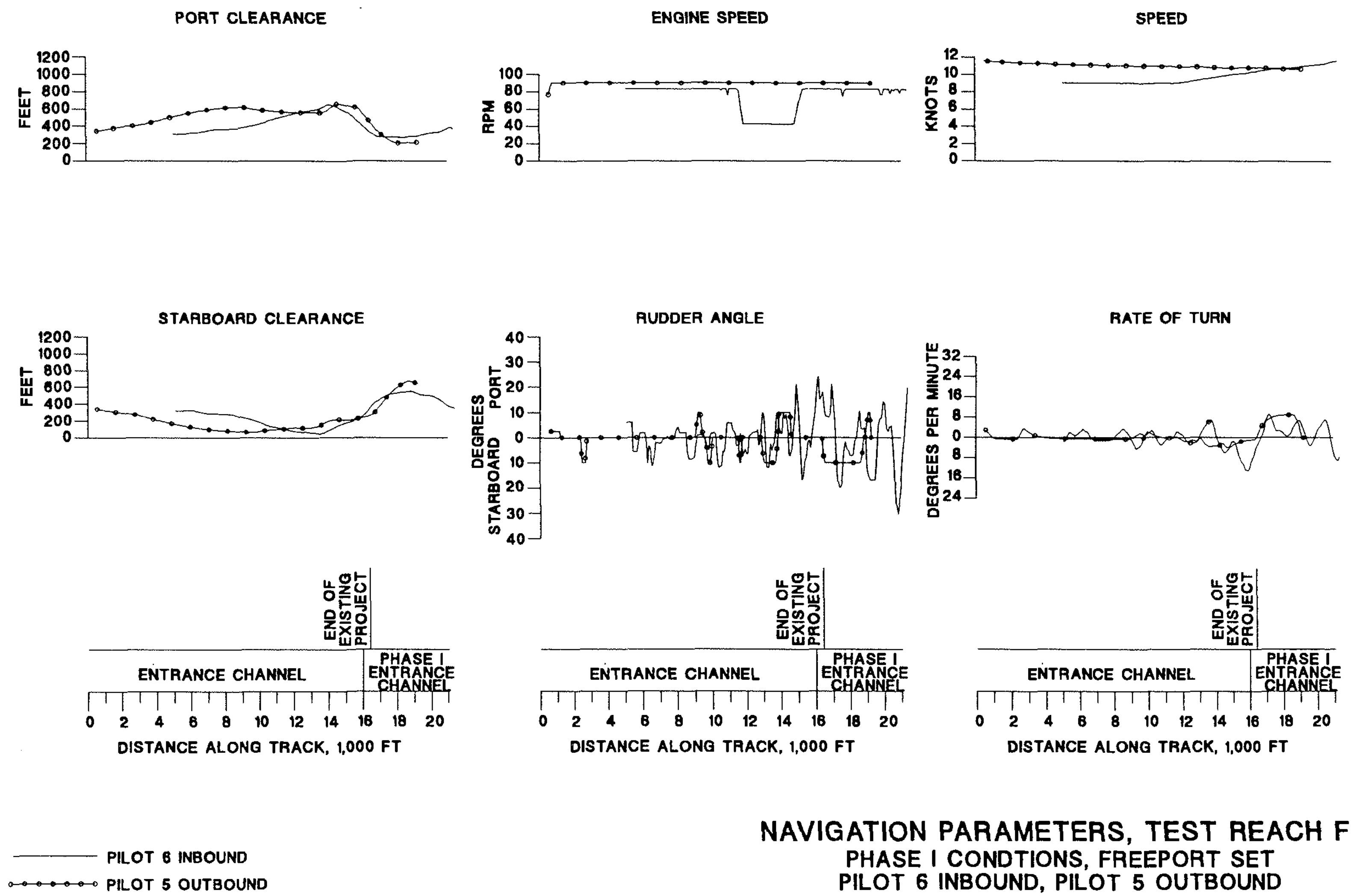


PILOT 5 INBOUND
PILOT 6 OUTBOUND

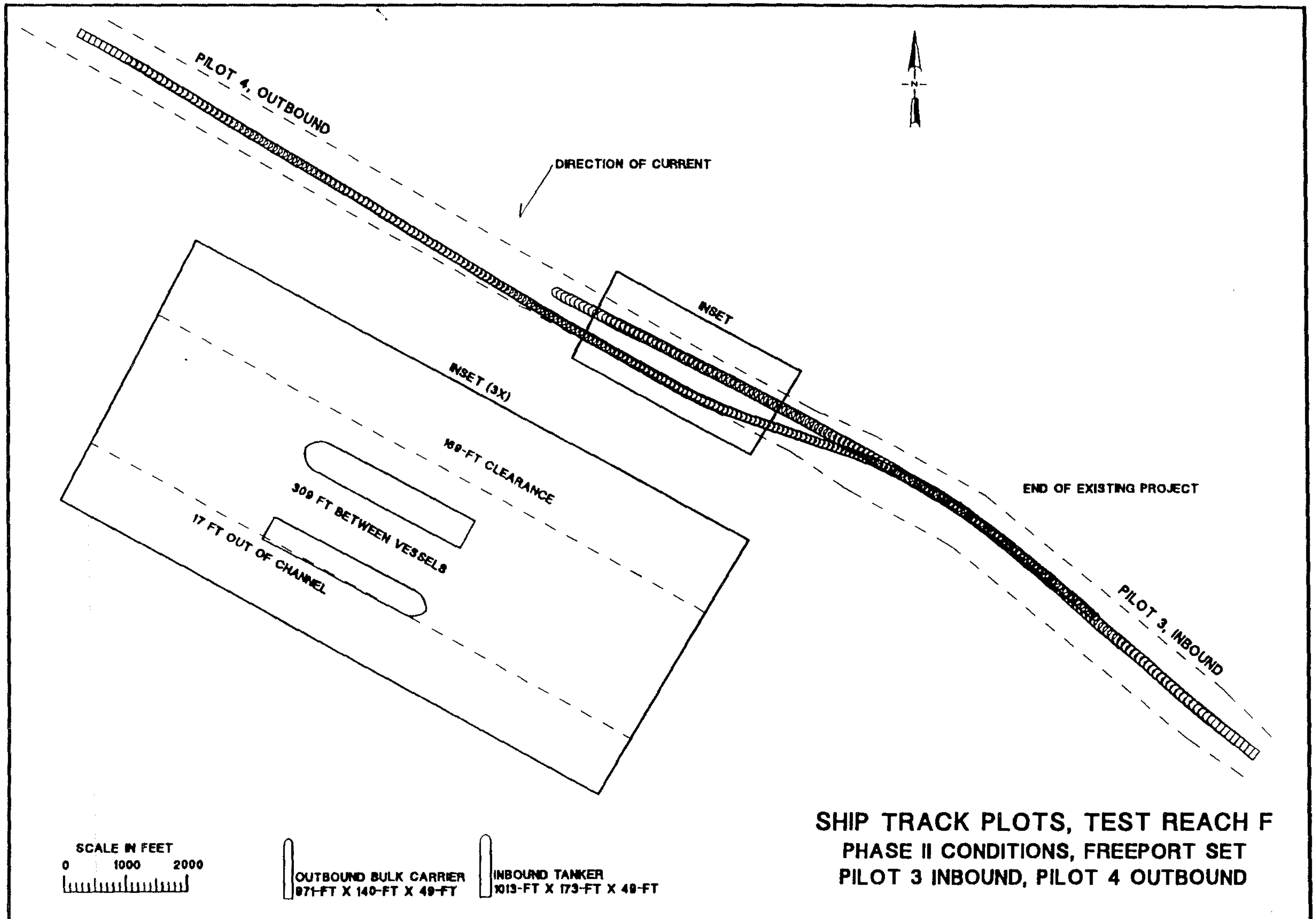
NAVIGATION PARAMETERS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



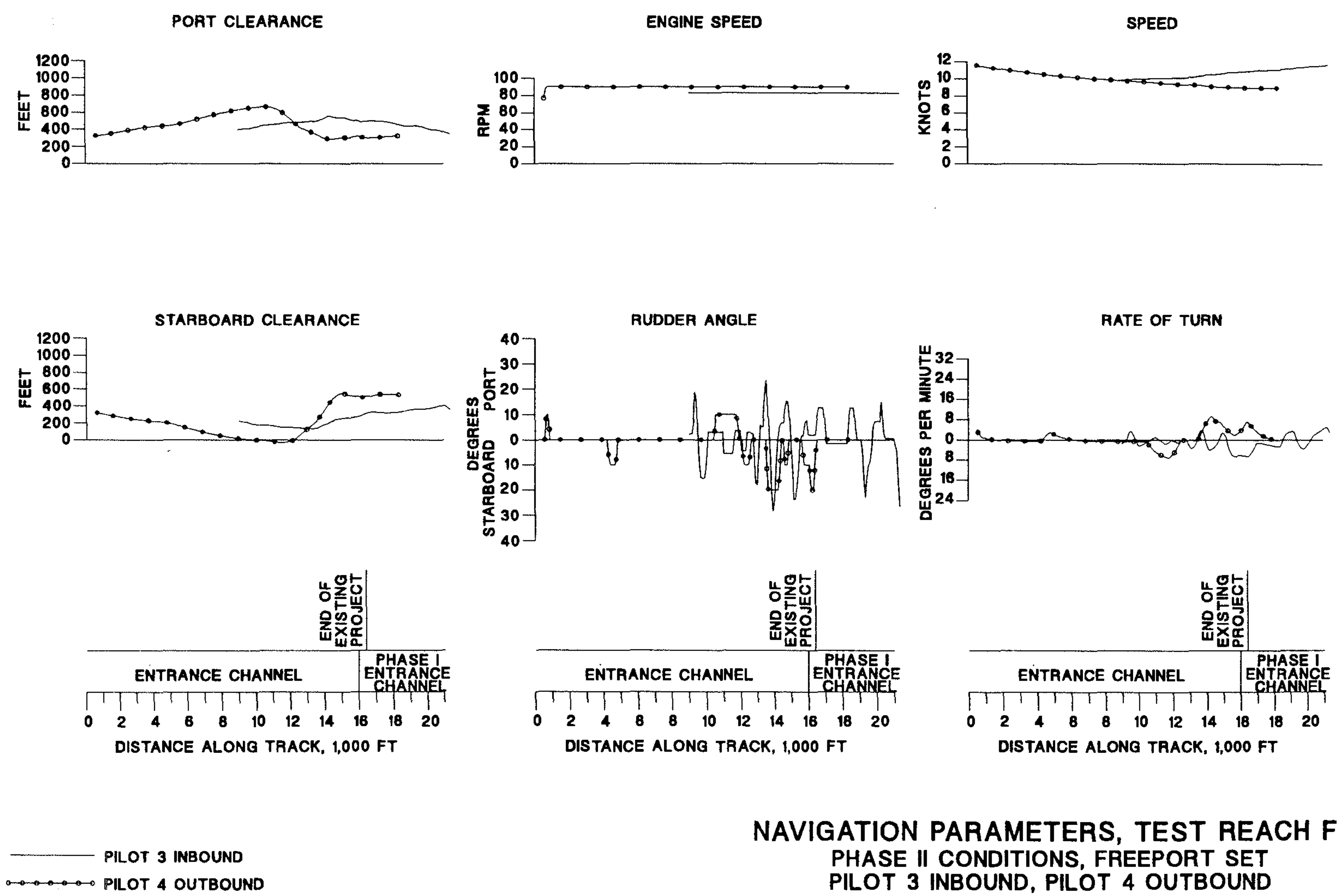
SHIP TRACK PLOTS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



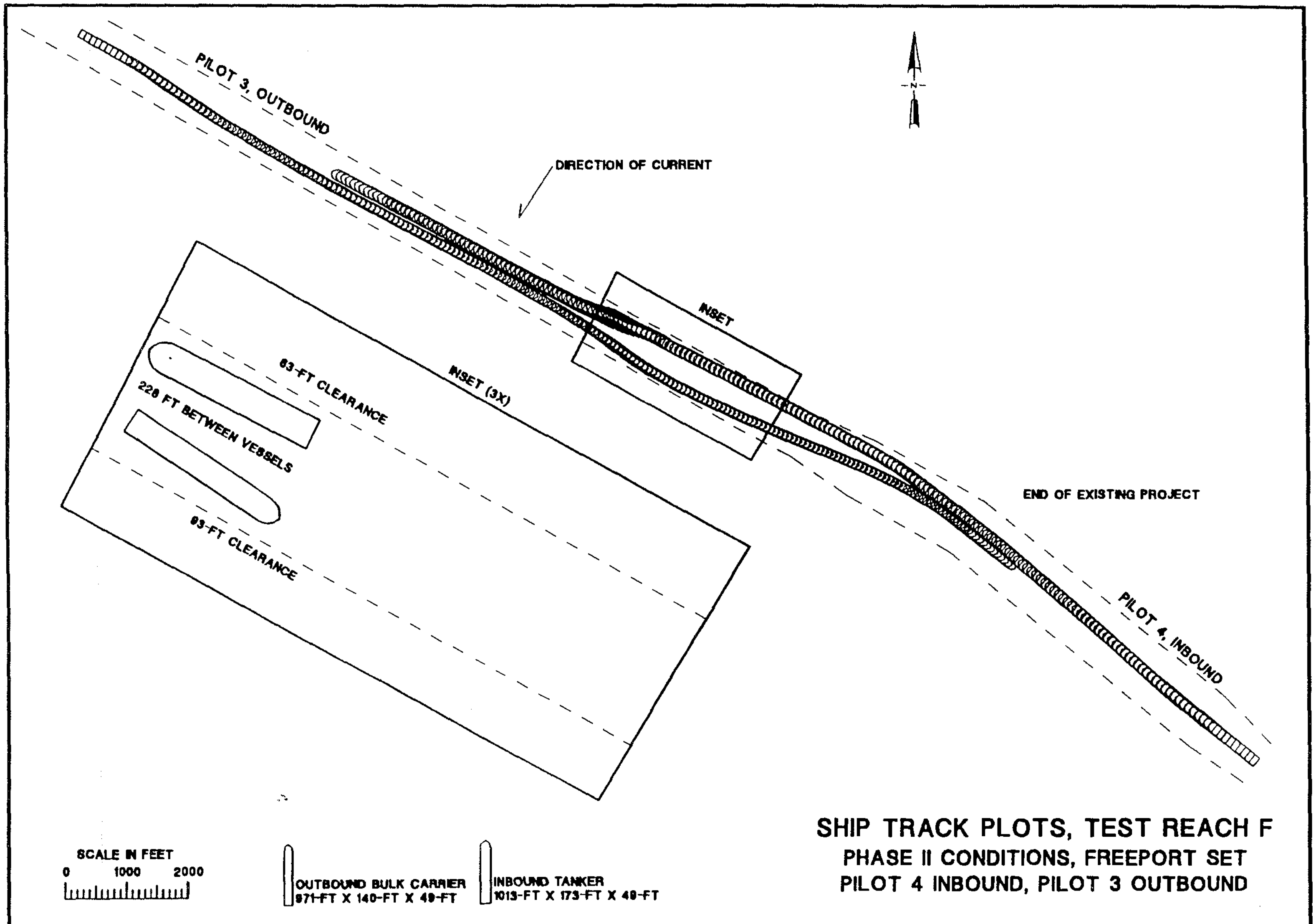
NAVIGATION PARAMETERS, TEST REACH F
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



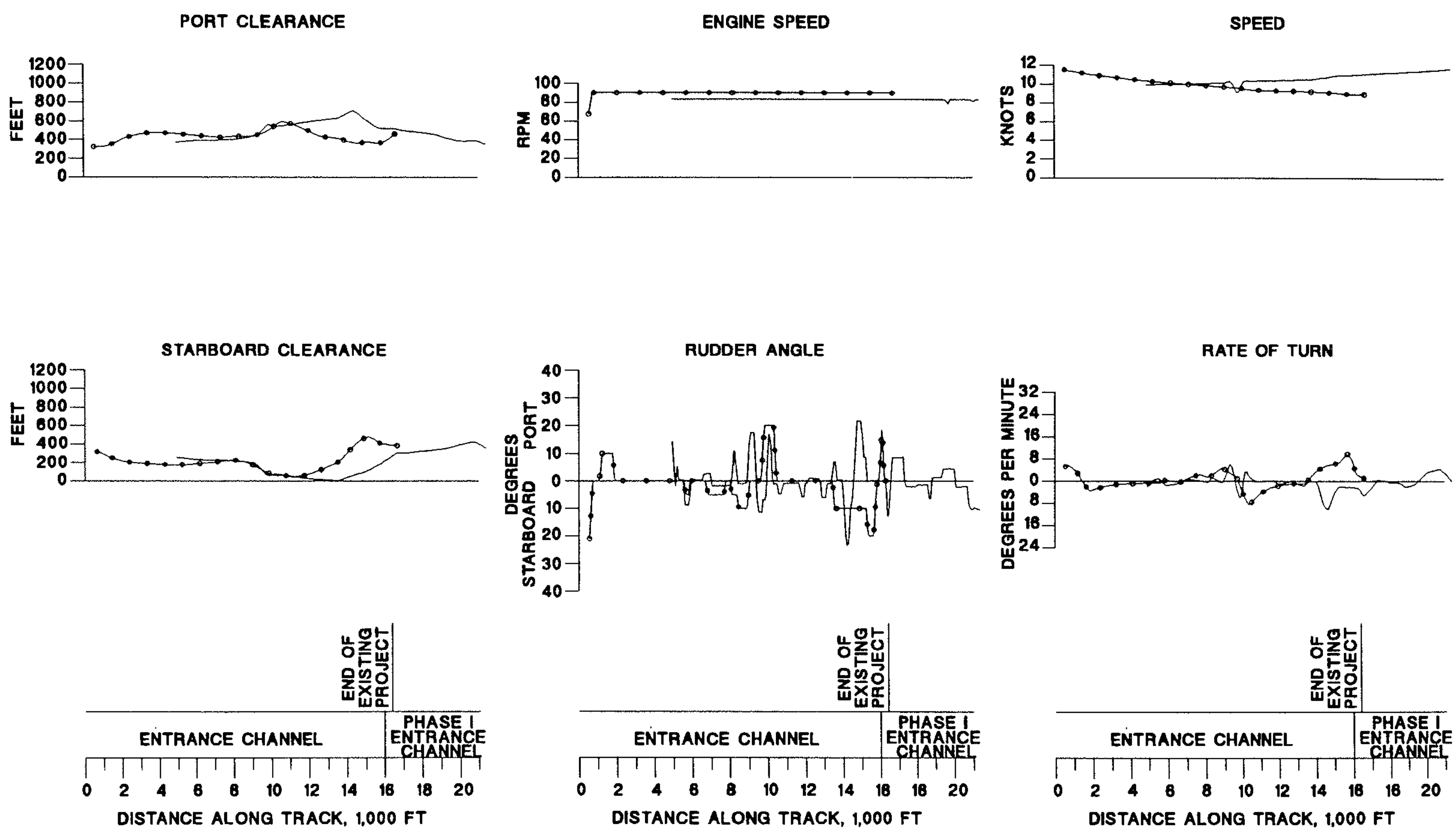
SHIP TRACK PLOTS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



SHIP TRACK PLOTS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

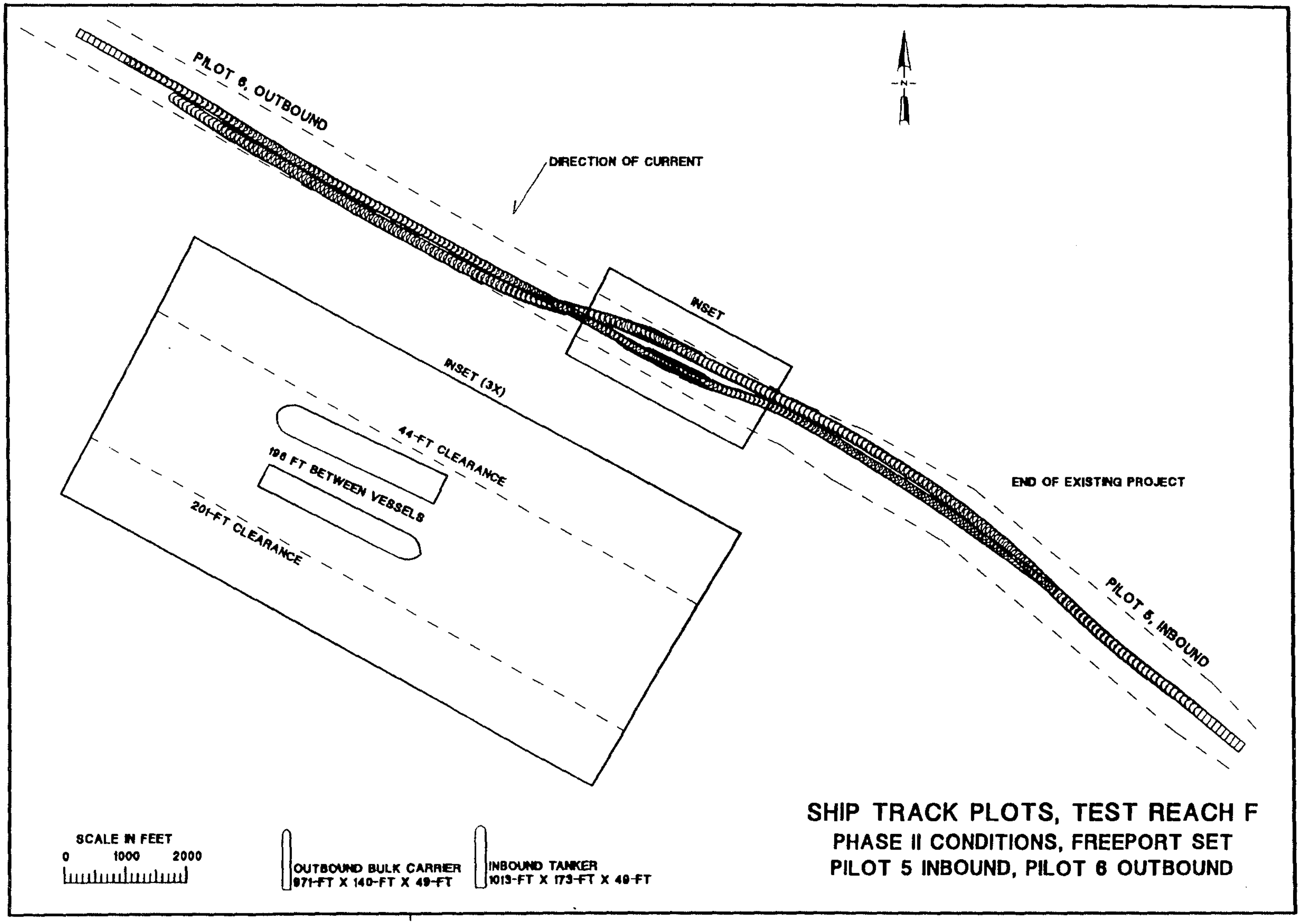


PILOT 4 INBOUND
PILOT 3 OUTBOUND

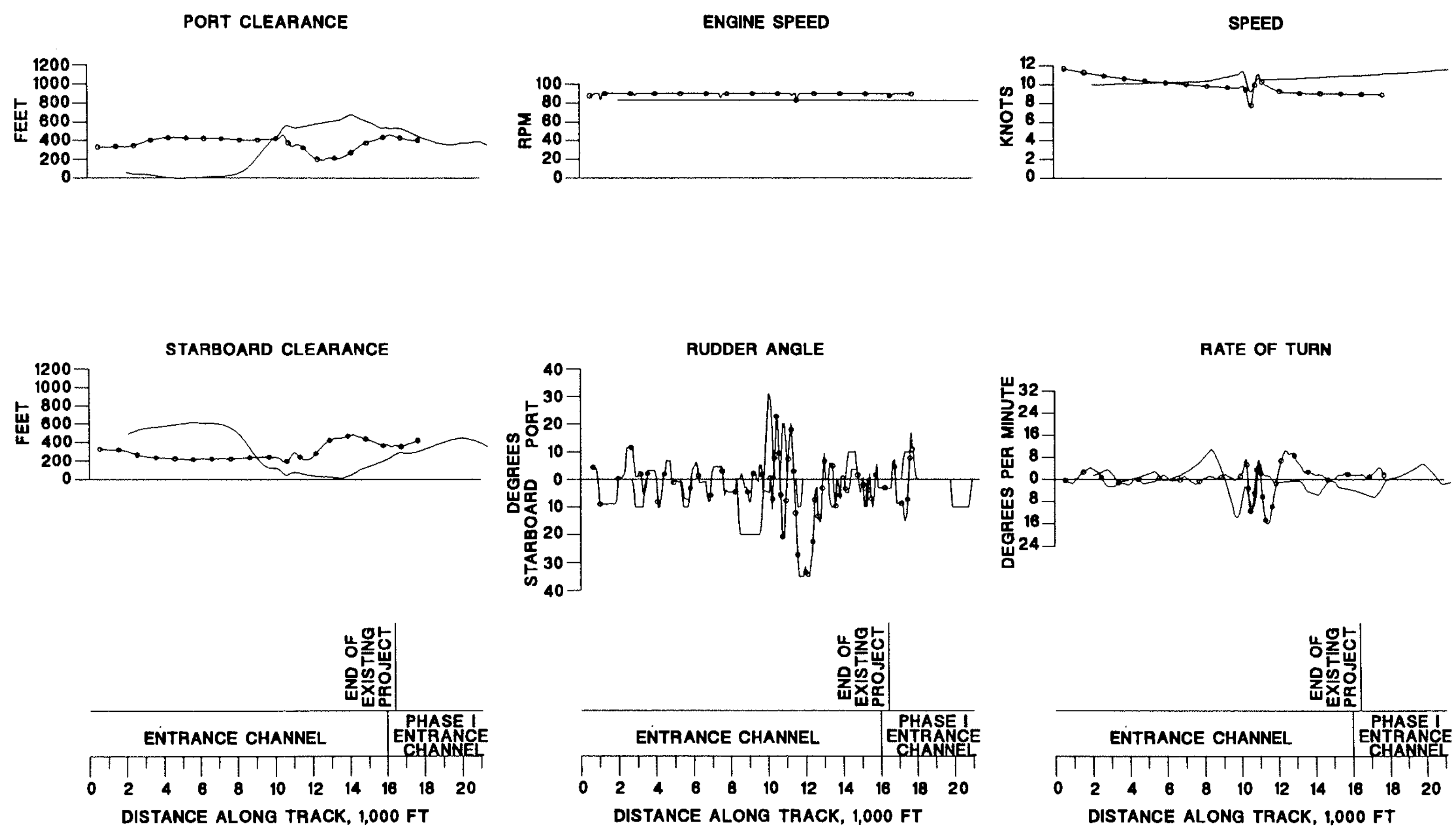
NAVIGATION PARAMETERS, TEST REACH F

PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 170



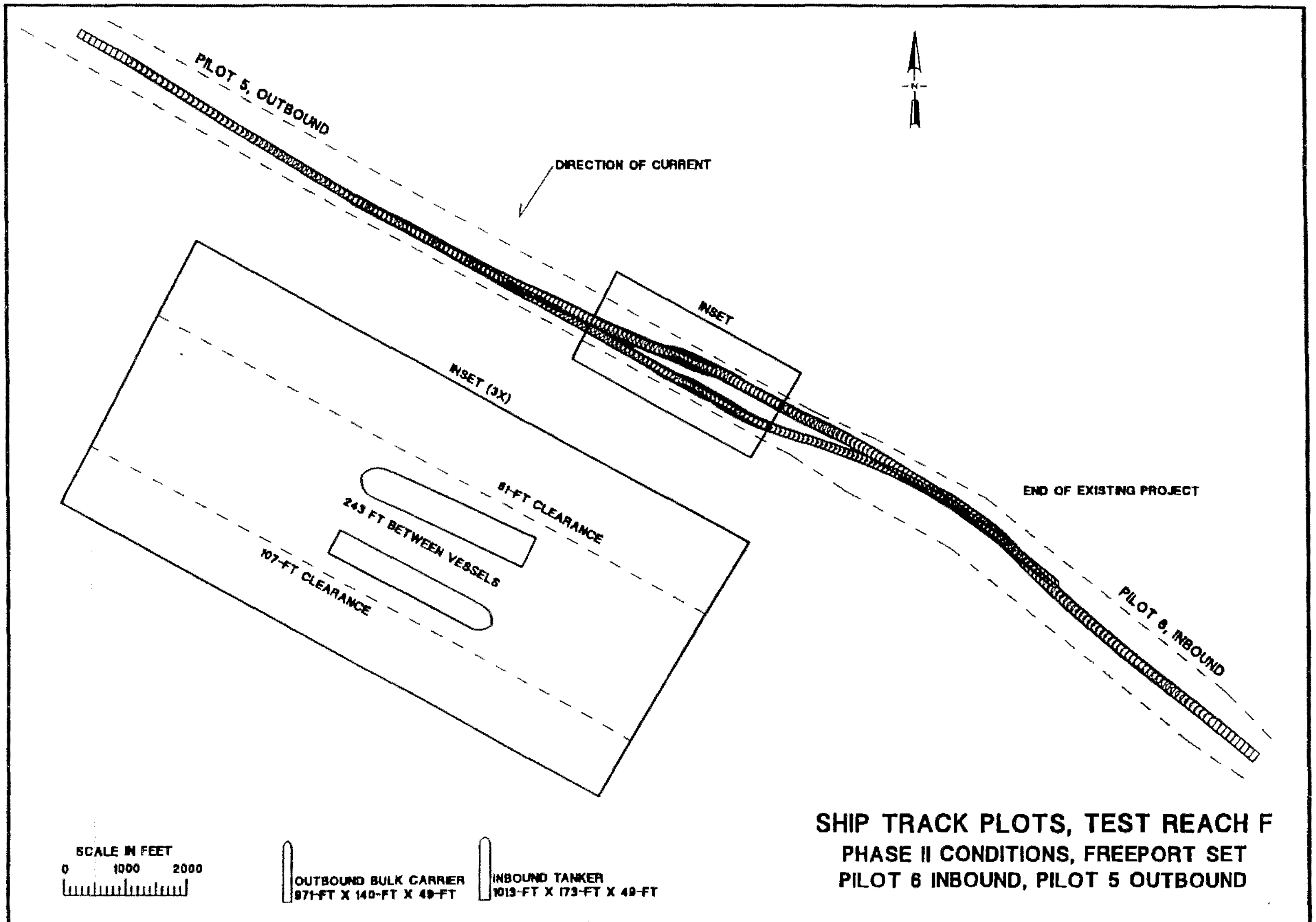
SHIP TRACK PLOTS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



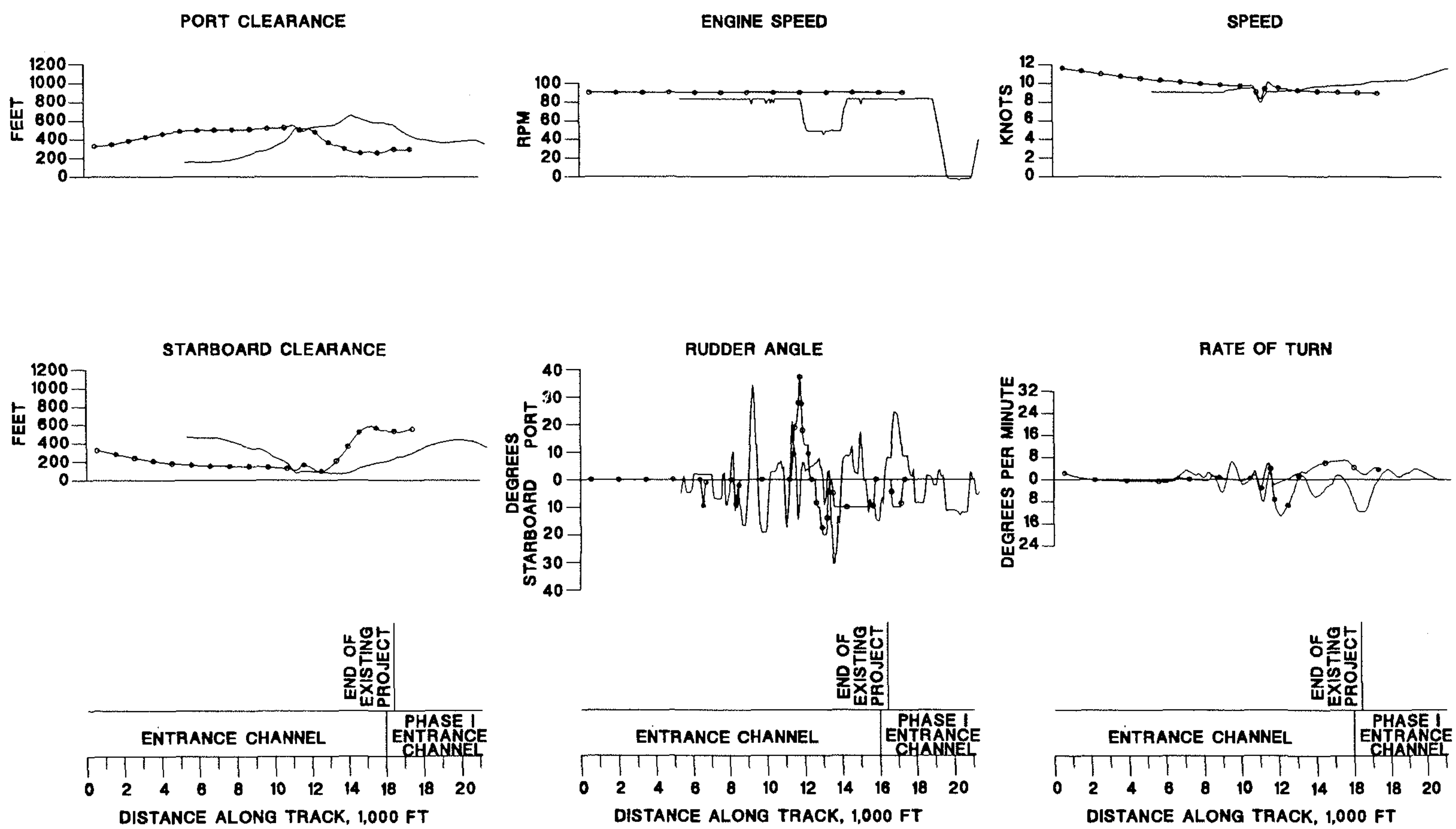
PILOT 5 INBOUND

PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



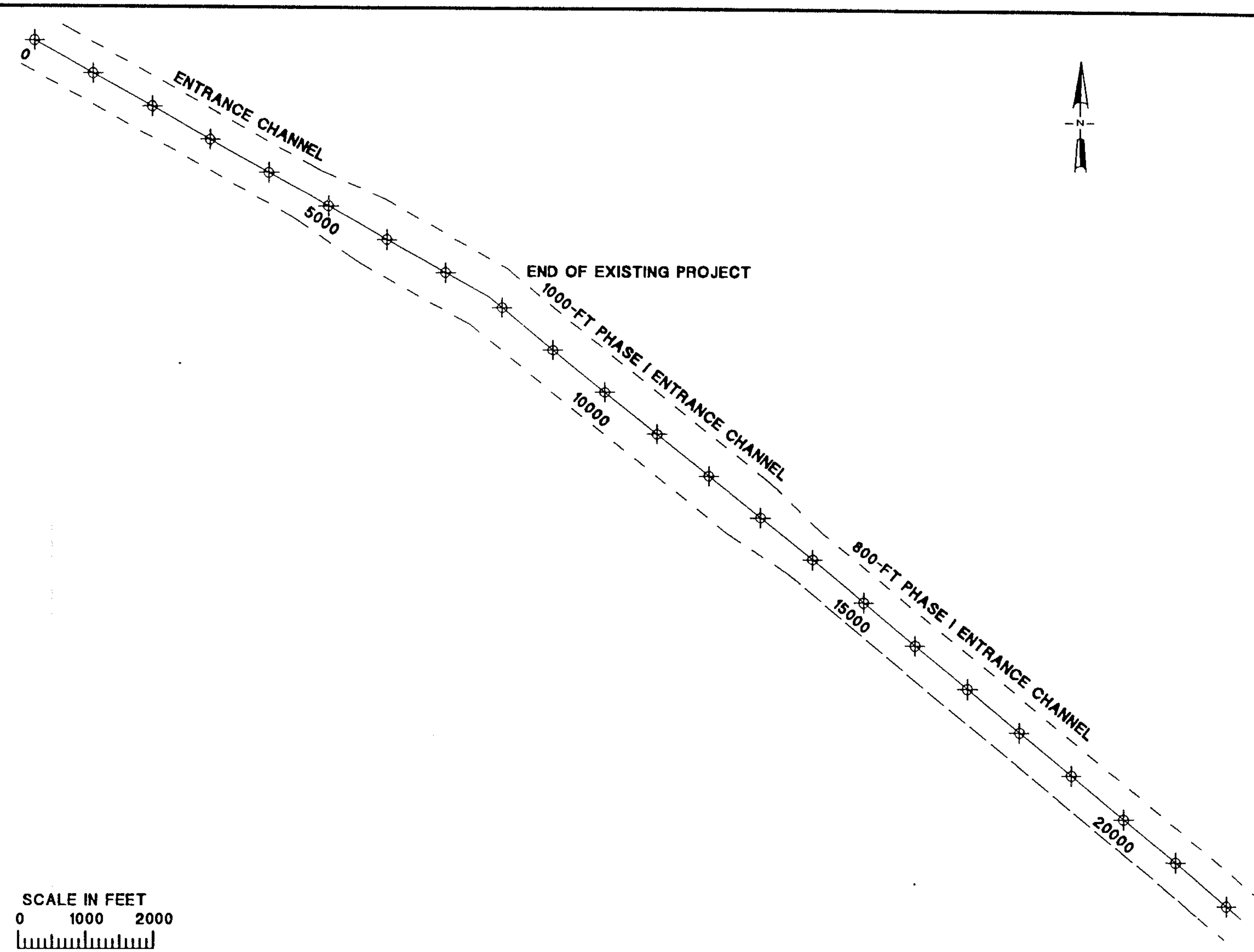
SHIP TRACK PLOTS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



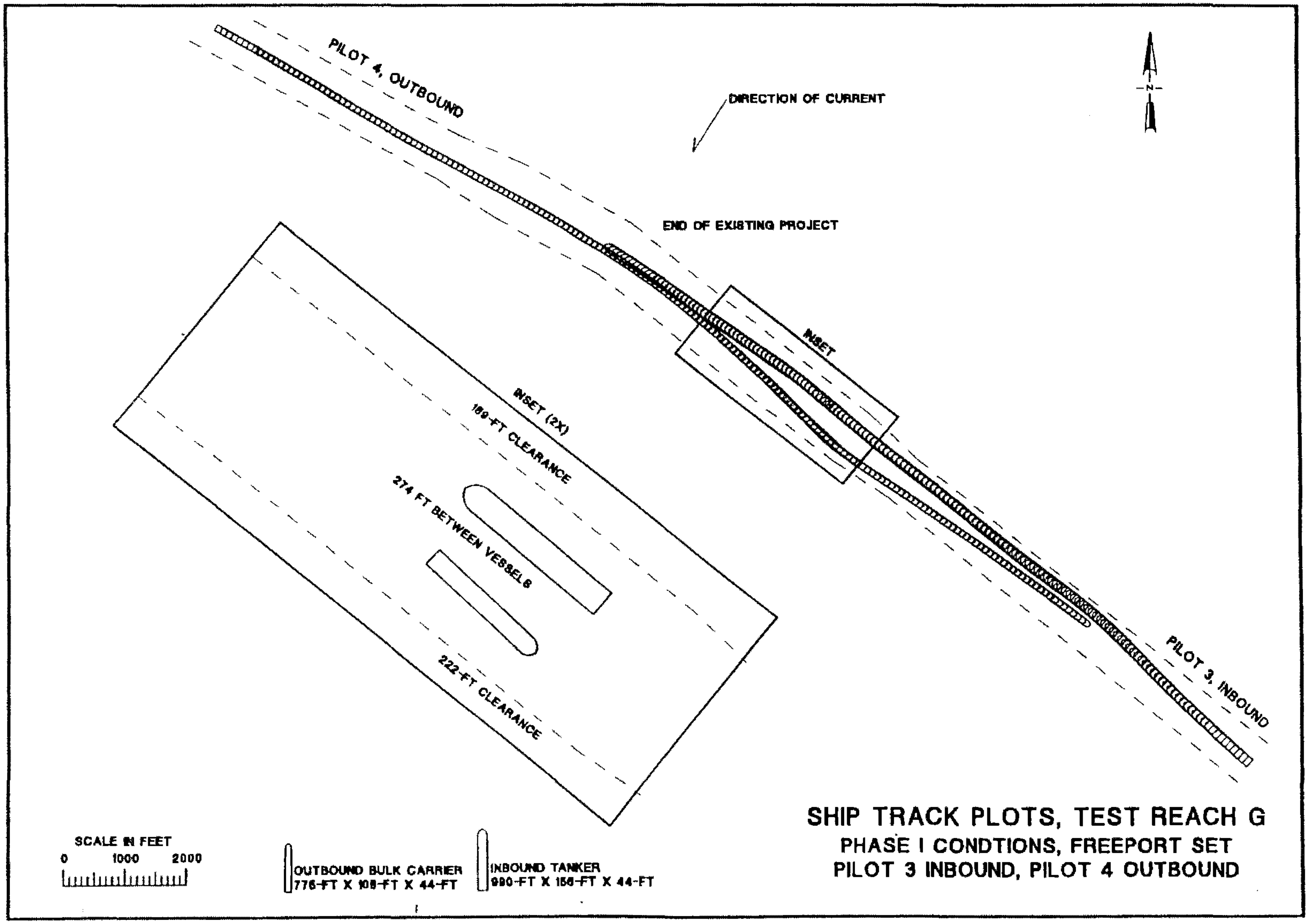
PILOT 8 INBOUND

PILOT 5 OUTBOUND

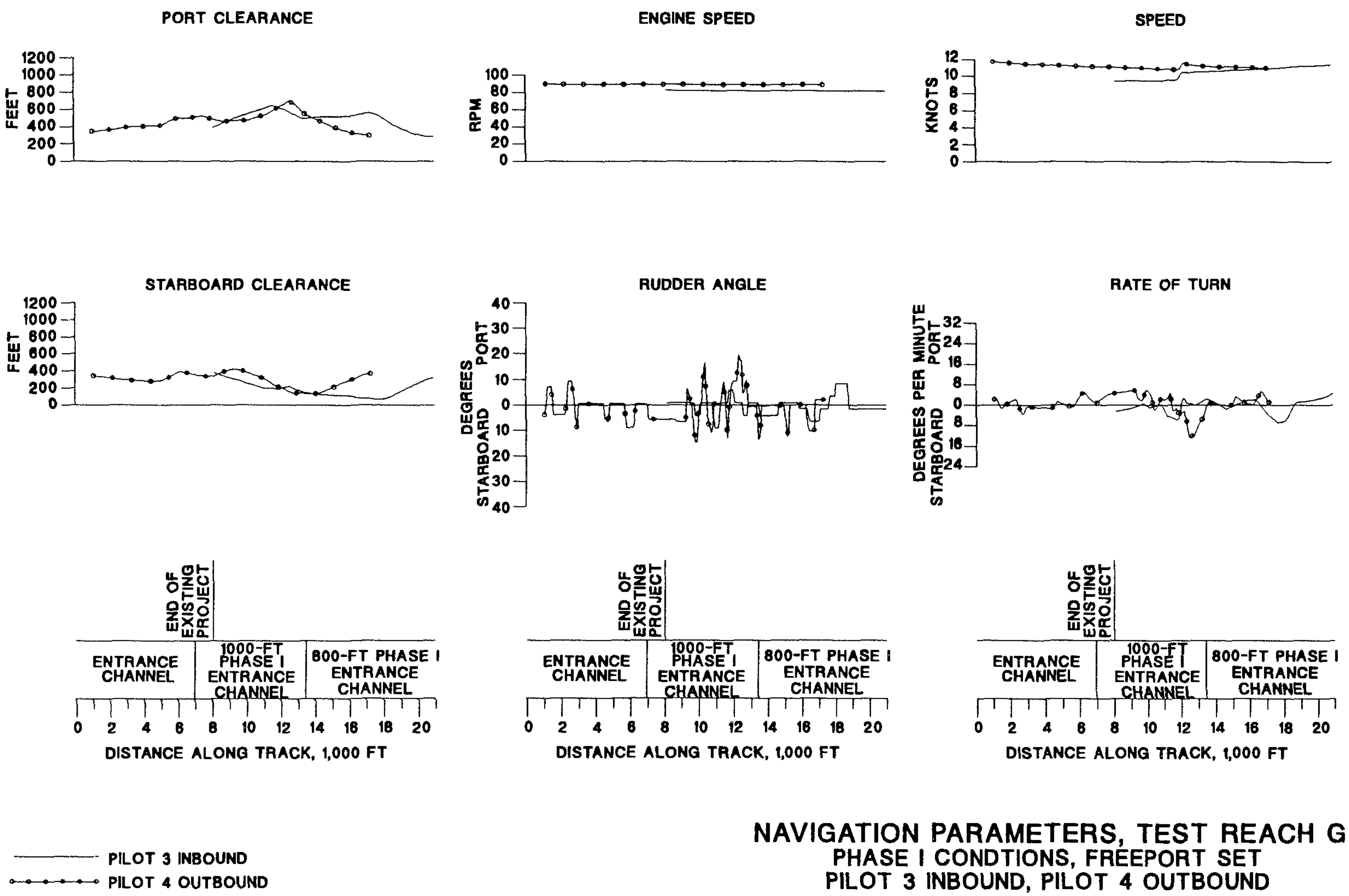
NAVIGATION PARAMETERS, TEST REACH F
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



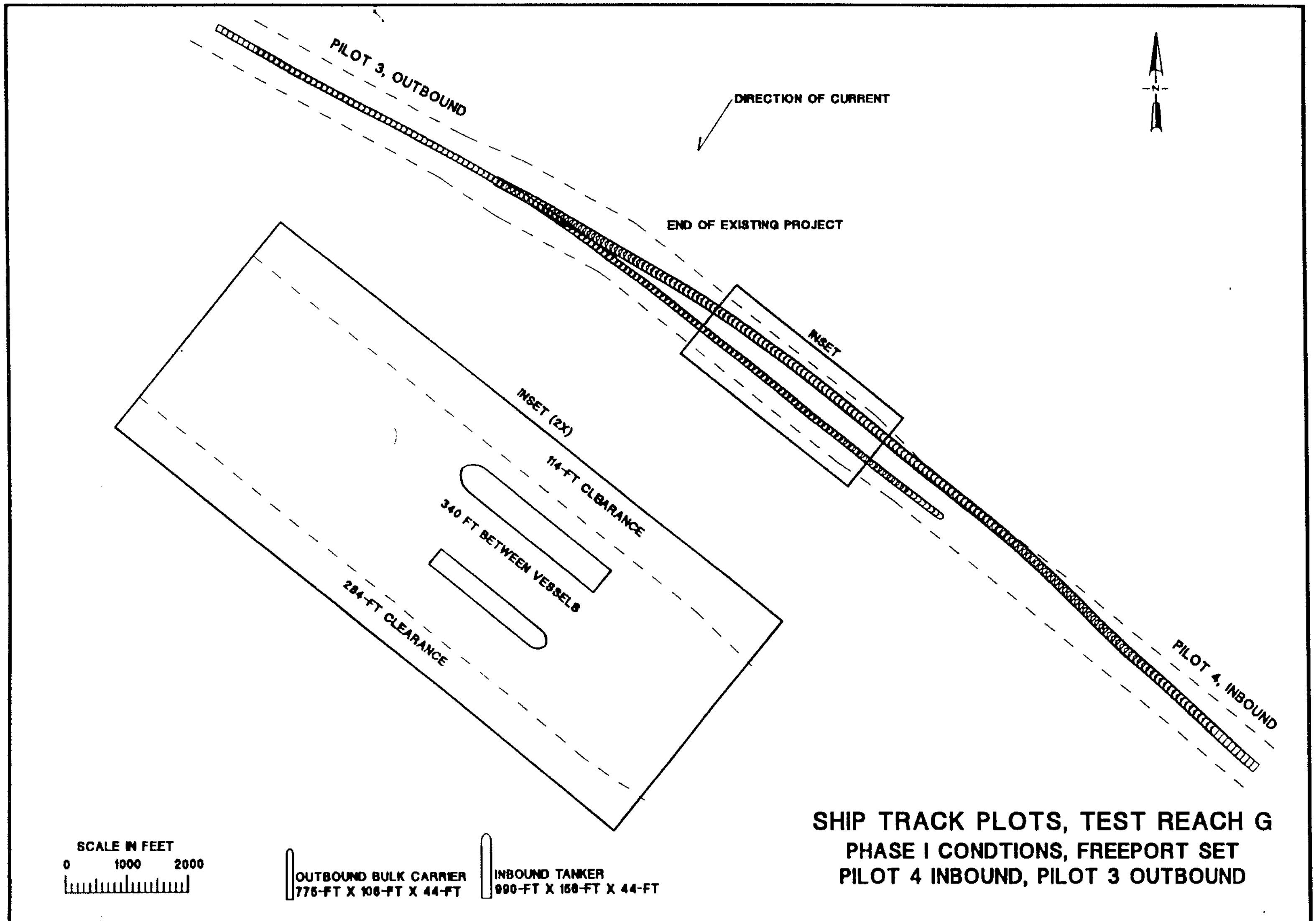
DISTANCE ALONG TRACK, TEST REACH G



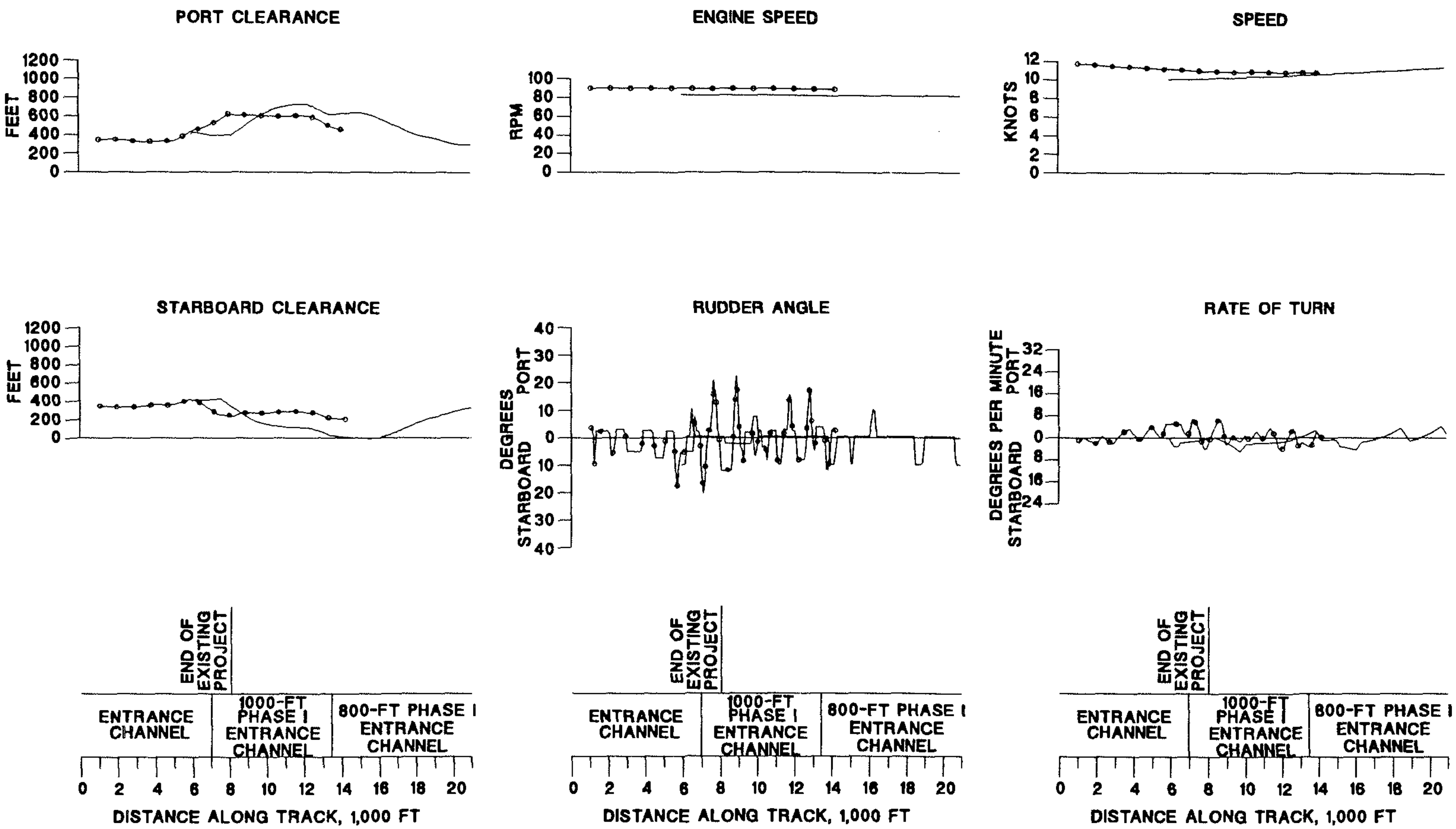
SHIP TRACK PLOTS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

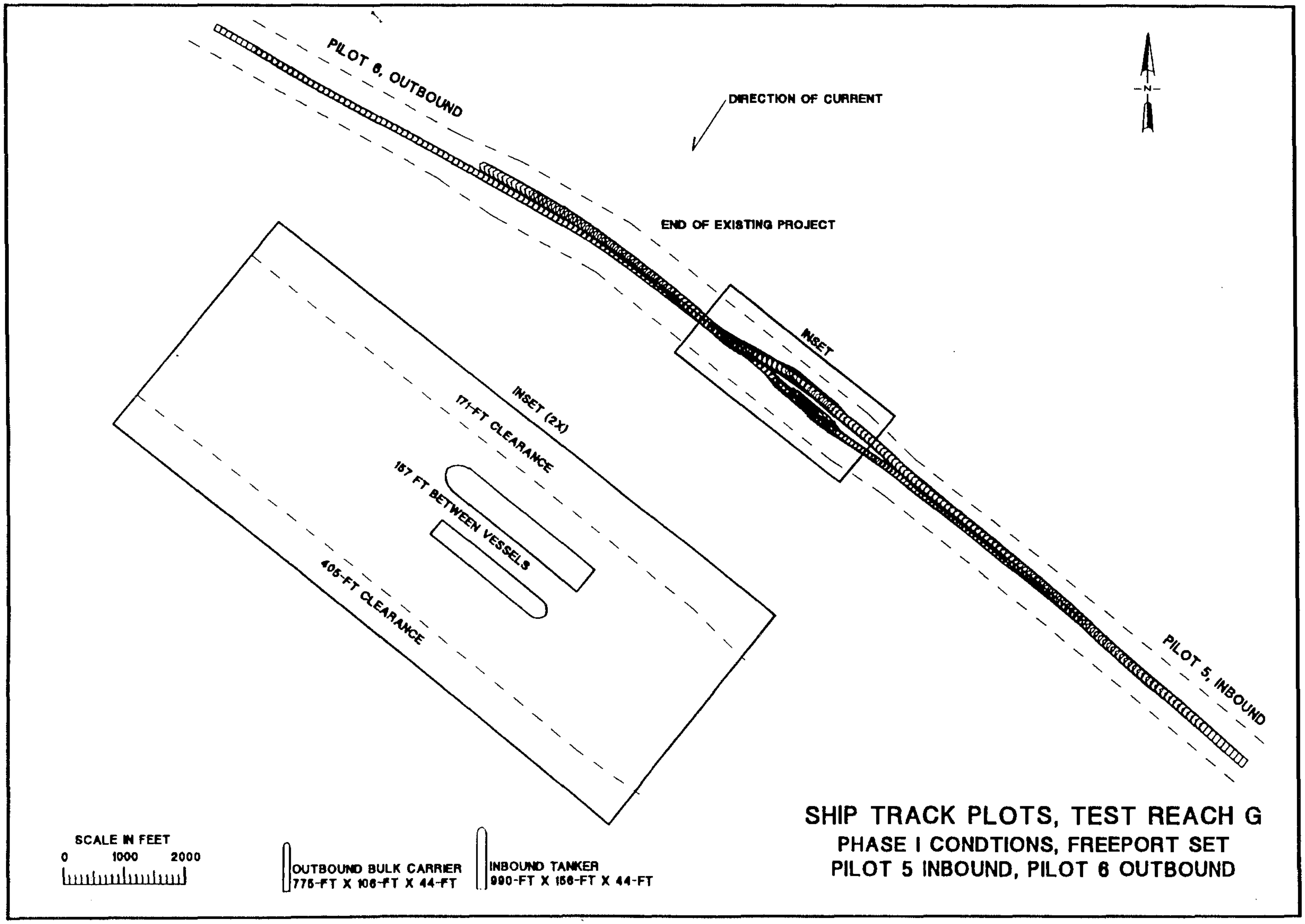


SHIP TRACK PLOTS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

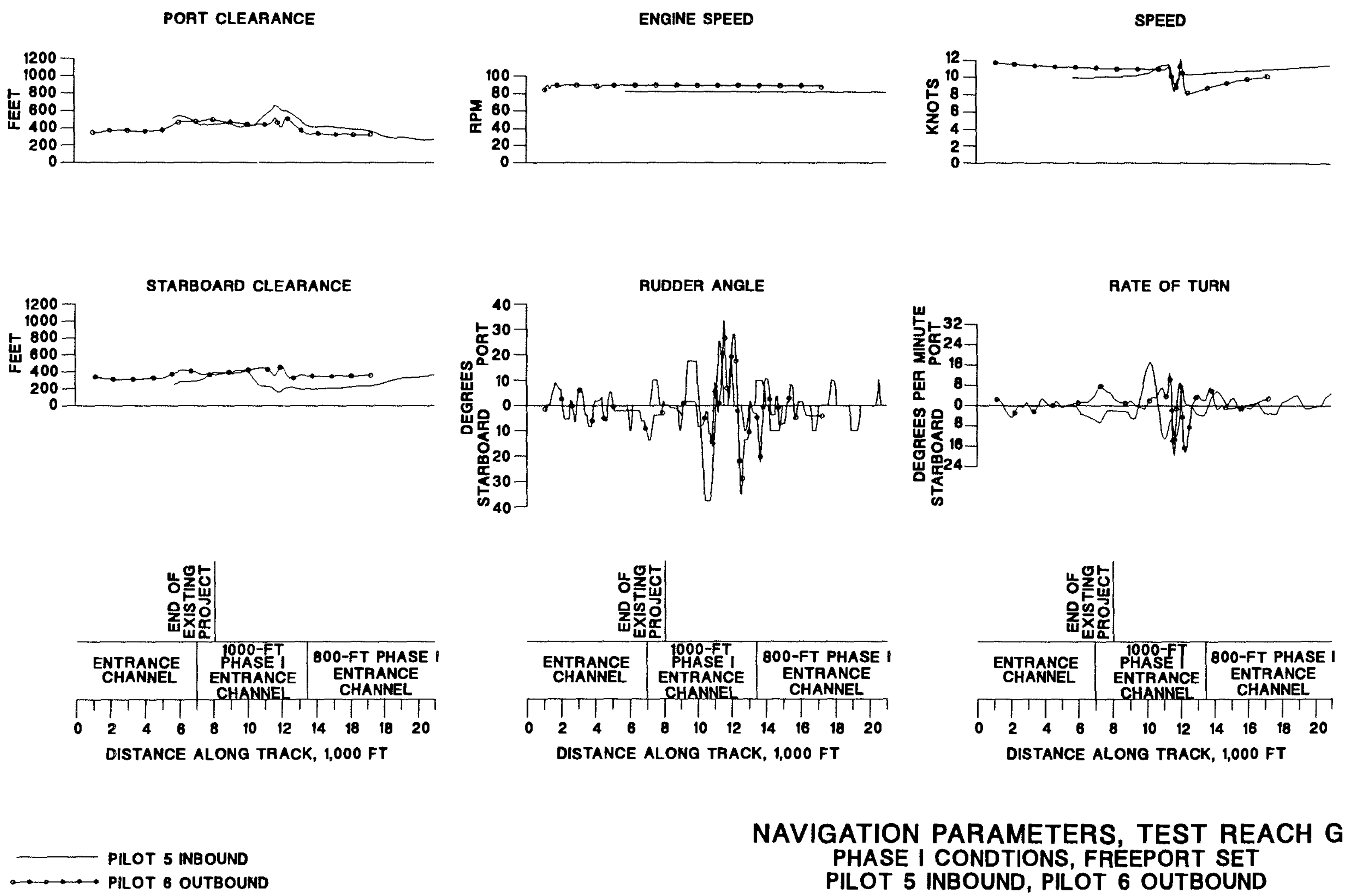


PILOT 4 INBOUND
PILOT 3 OUTBOUND

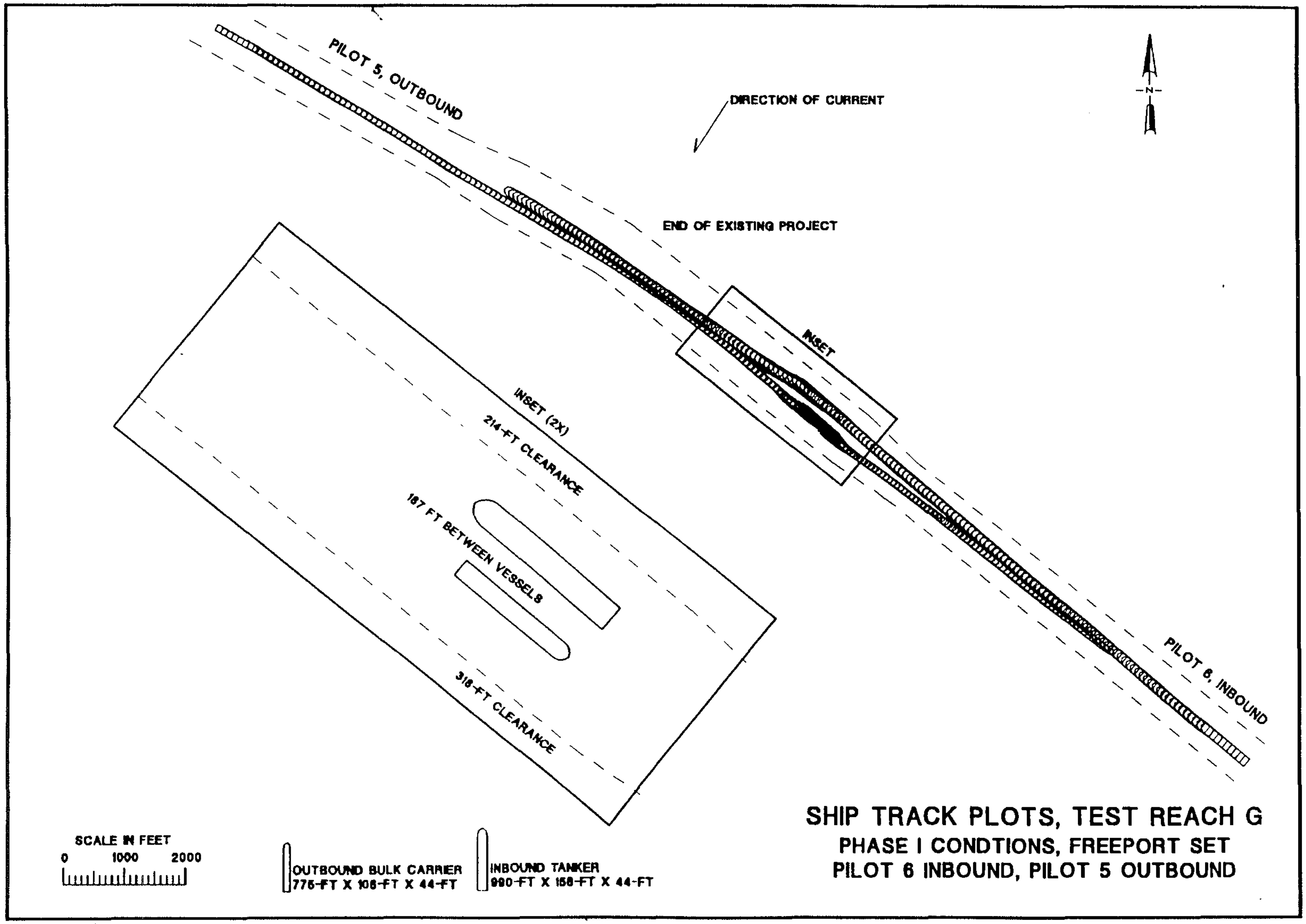
NAVIGATION PARAMETERS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



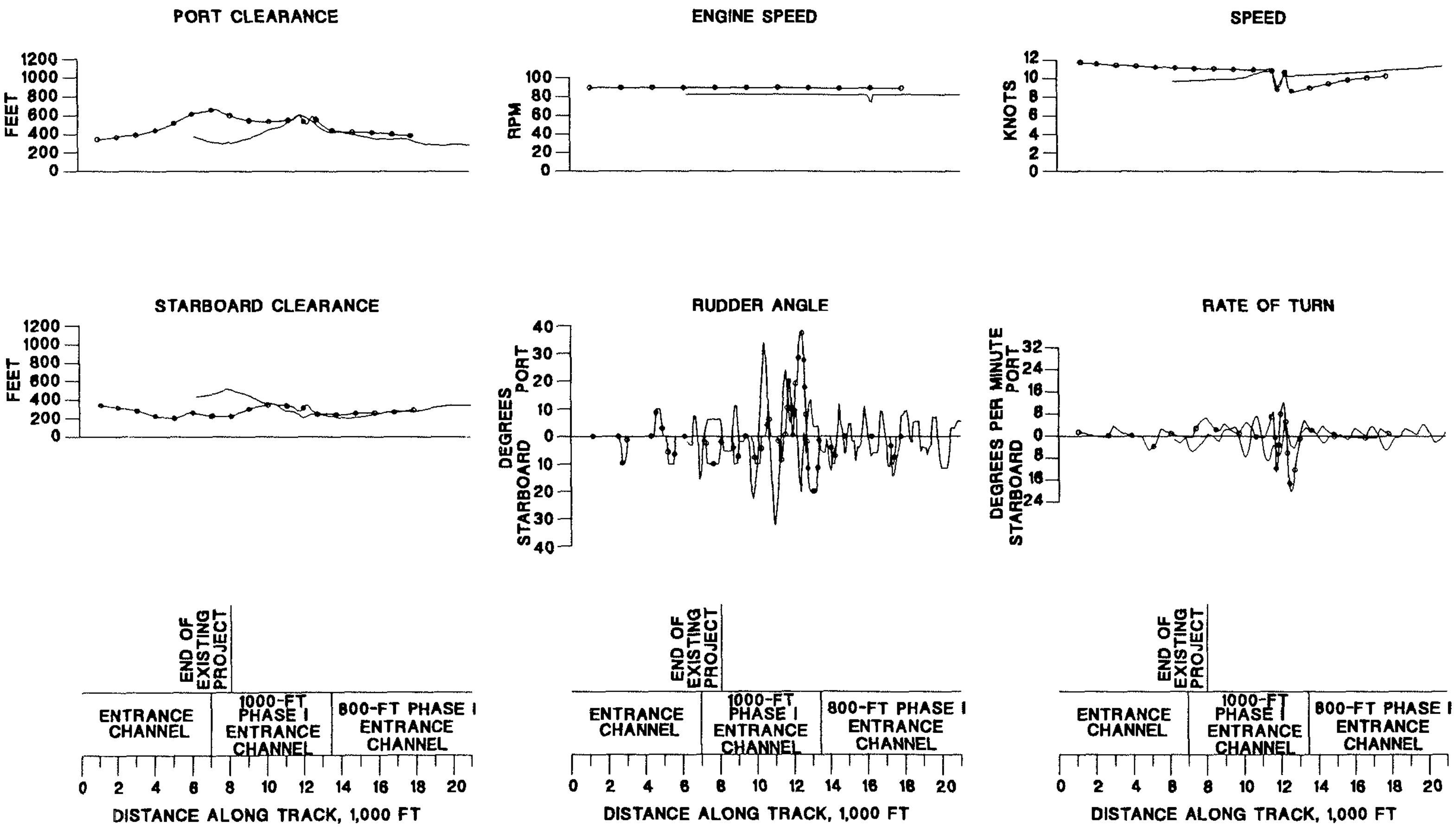
SHIP TRACK PLOTS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

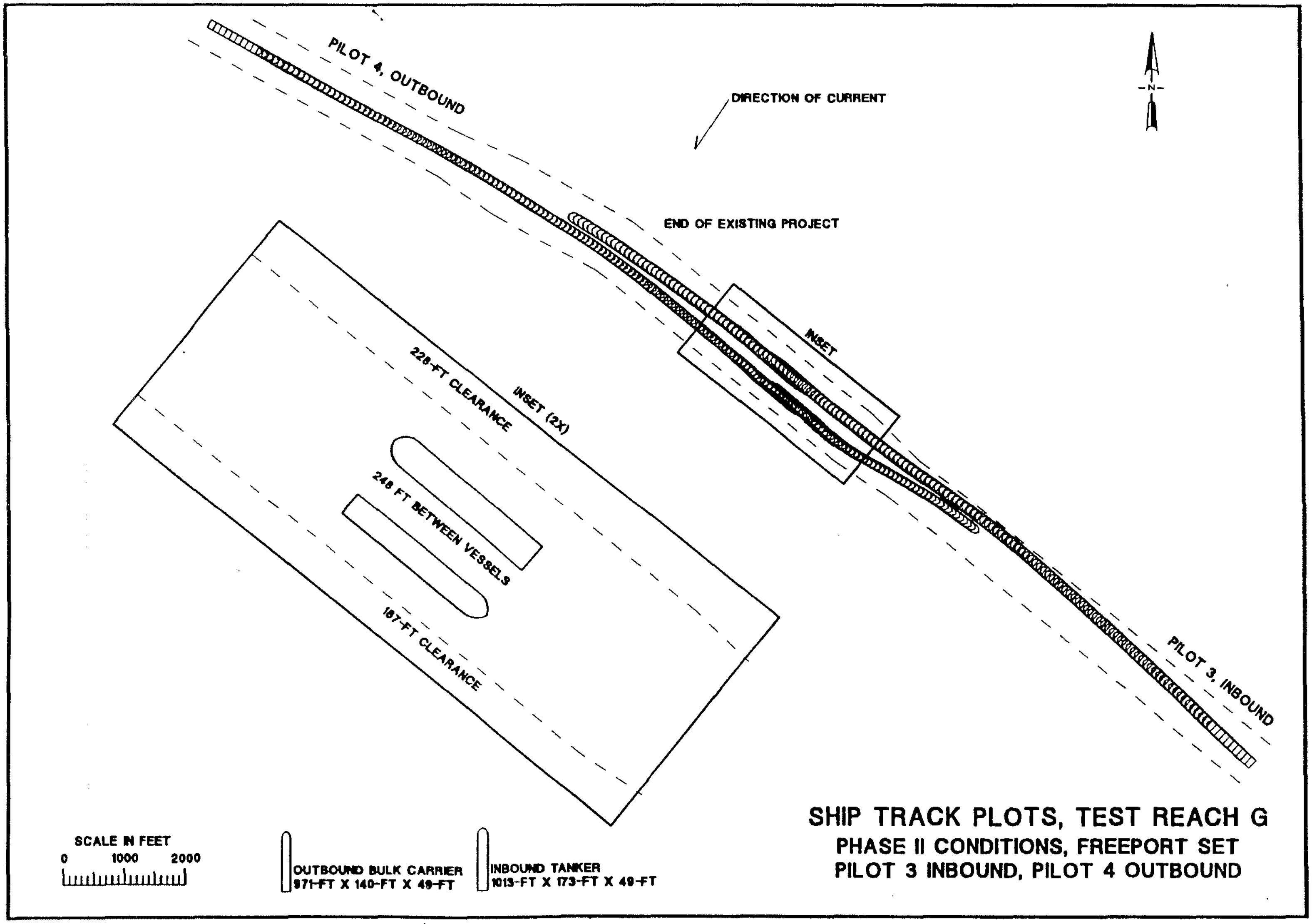


SHIP TRACK PLOTS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

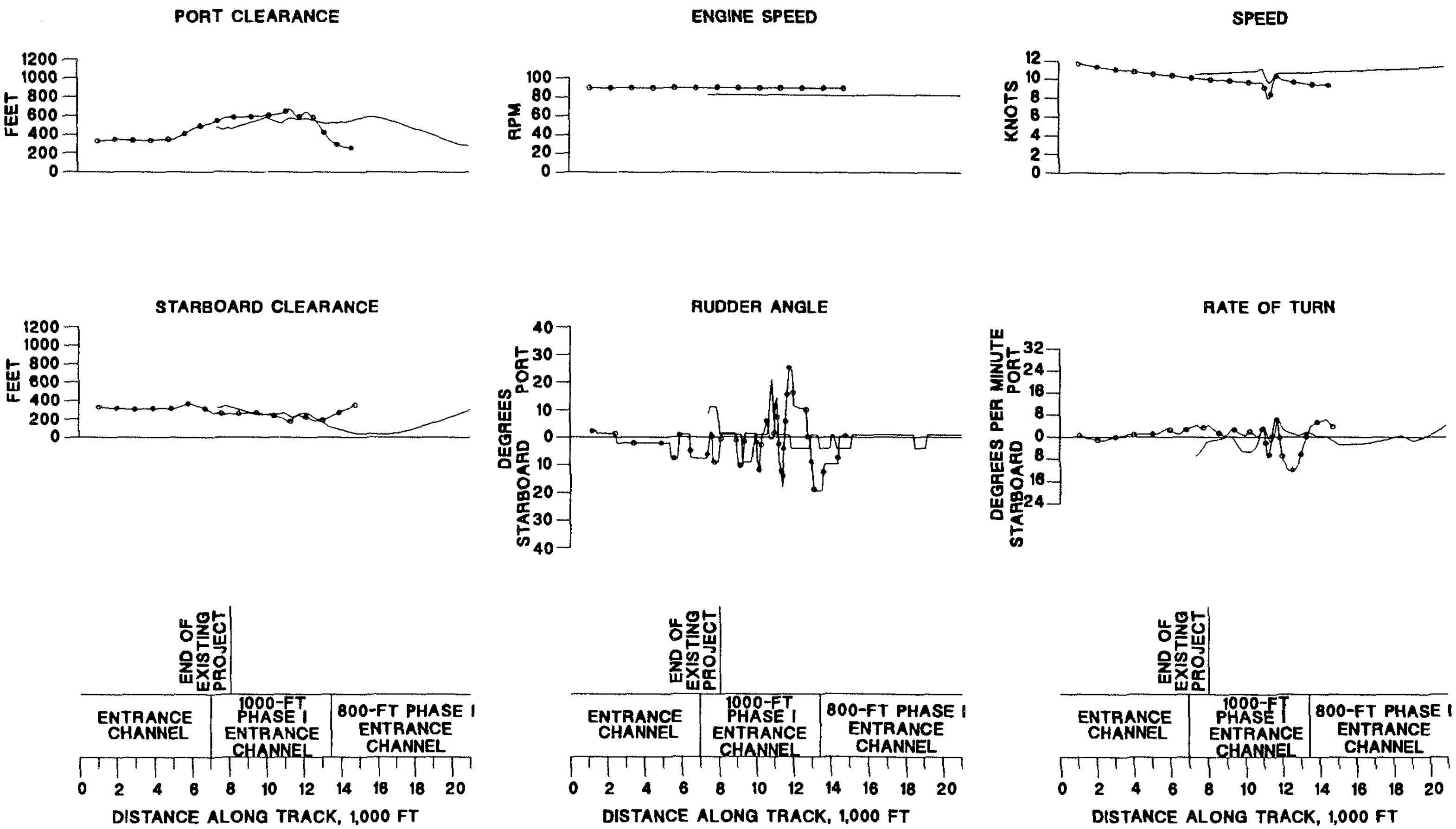


PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH G
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

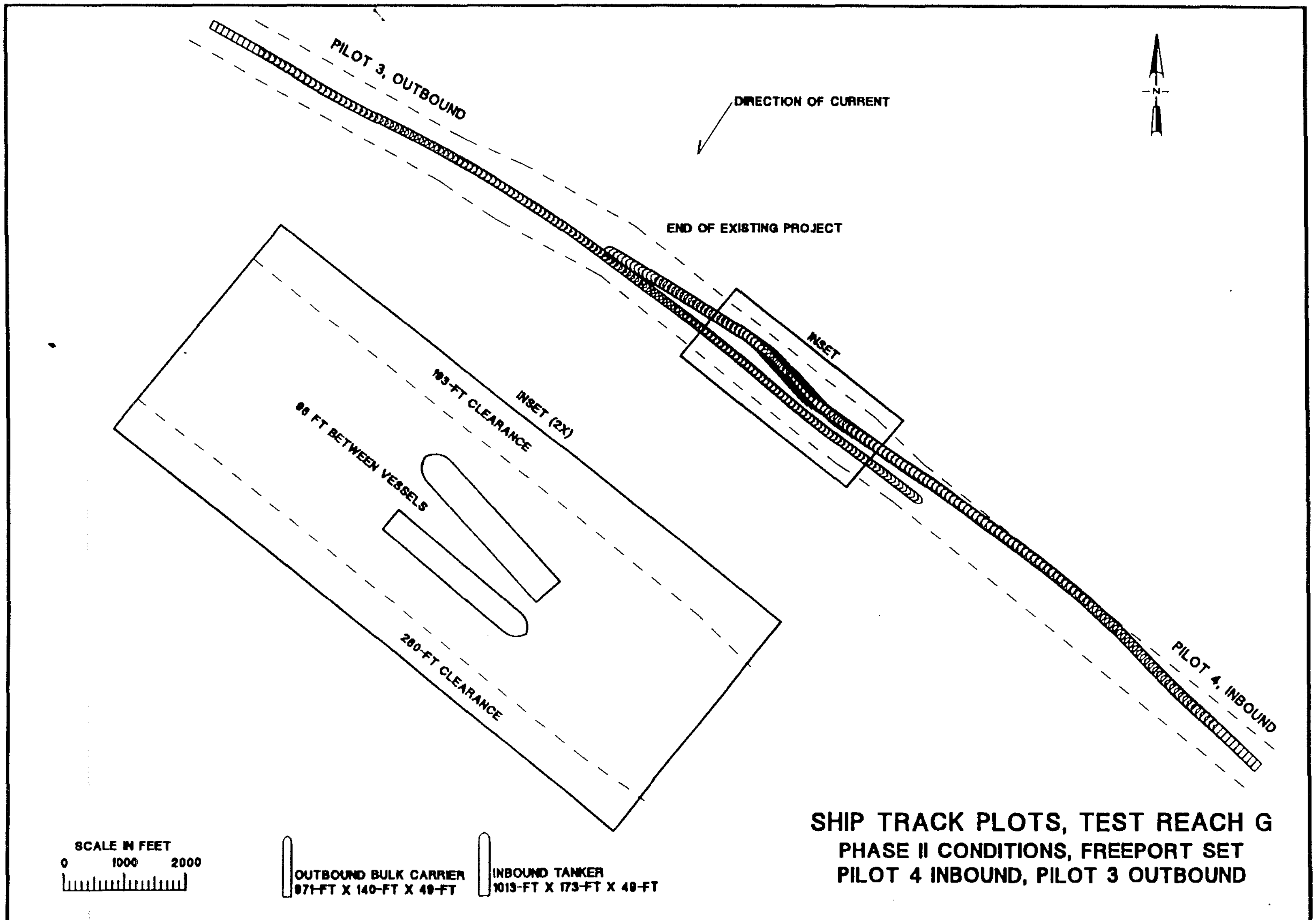


SHIP TRACK PLOTS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

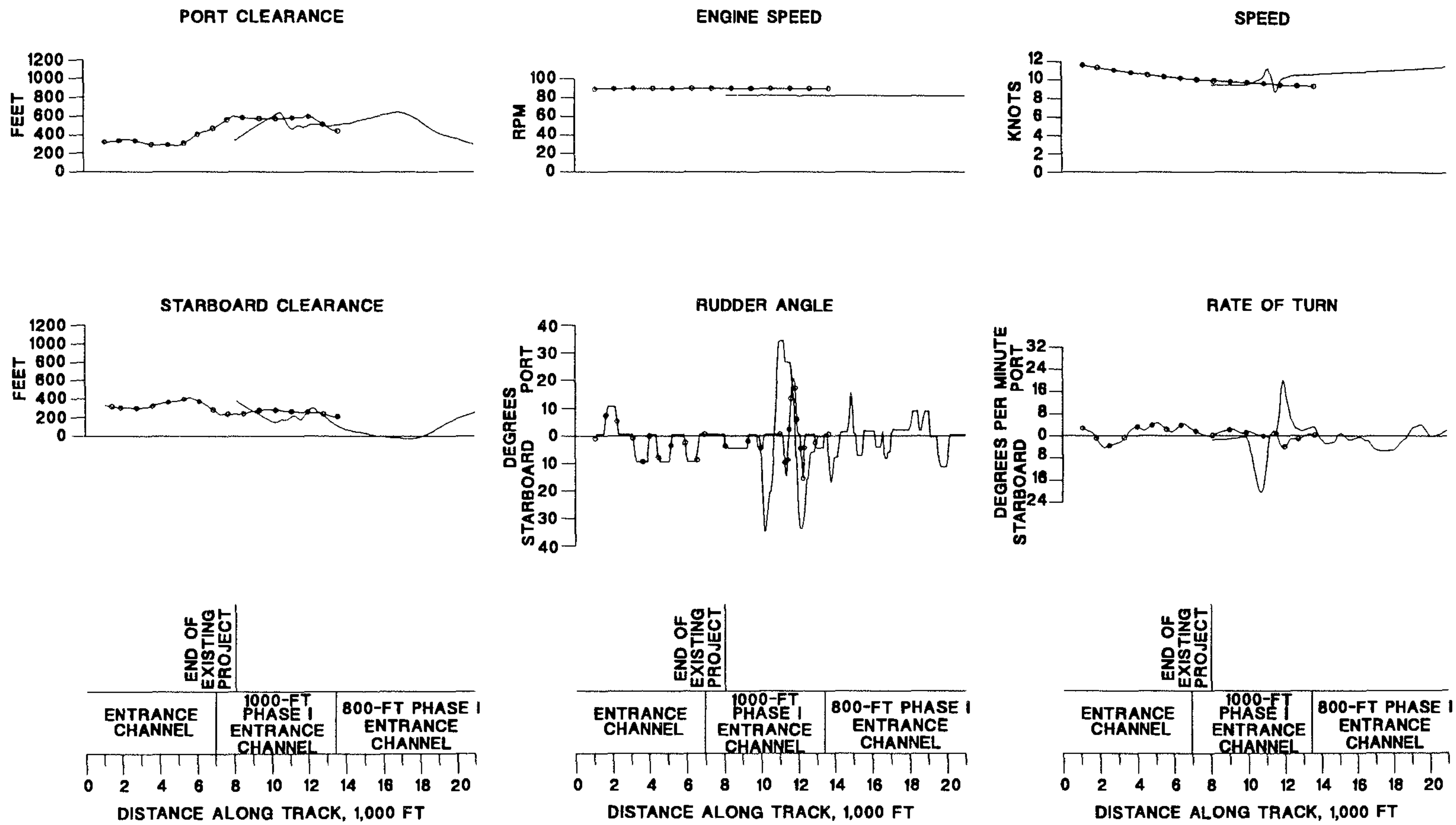


PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

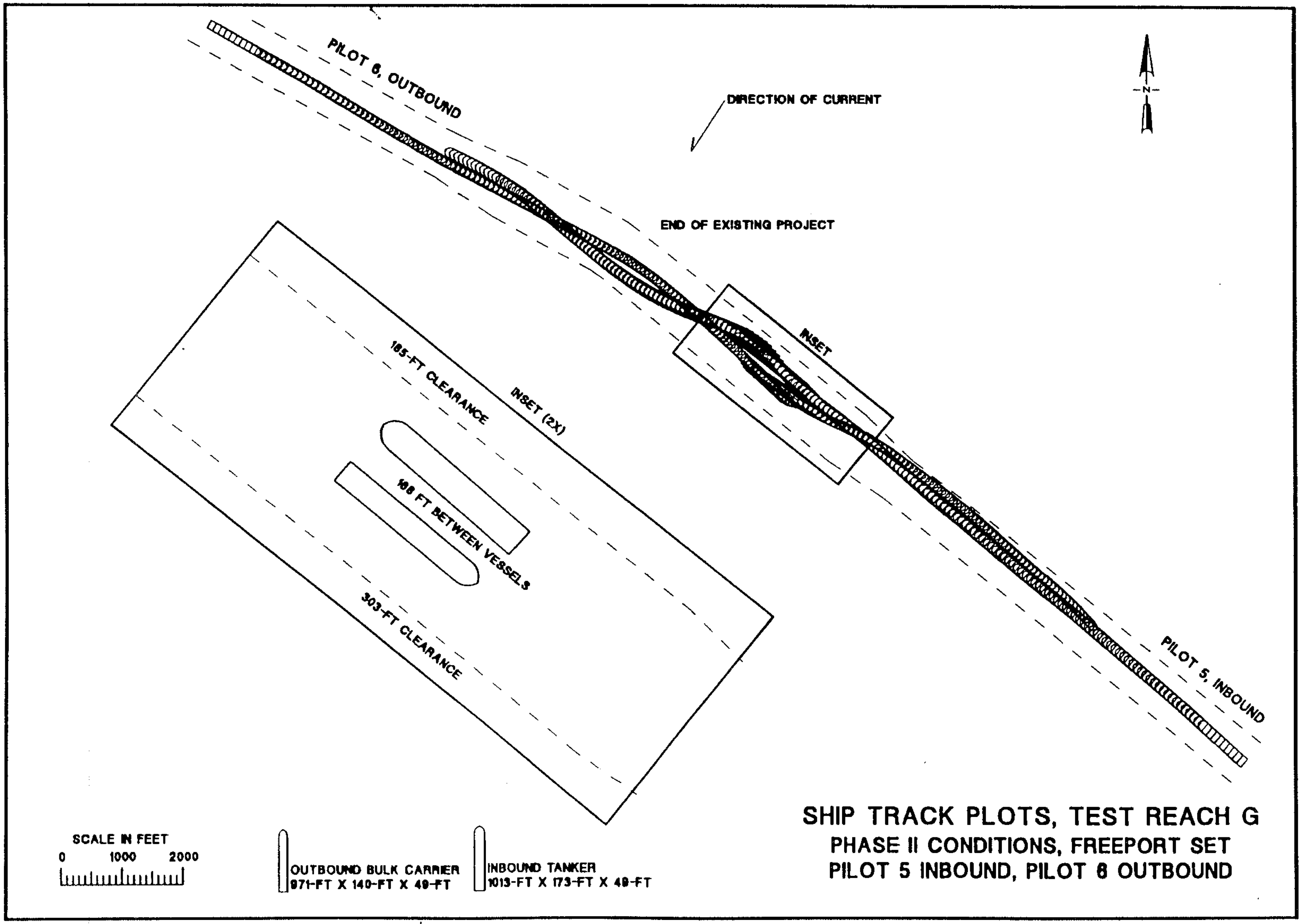


SHIP TRACK PLOTS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

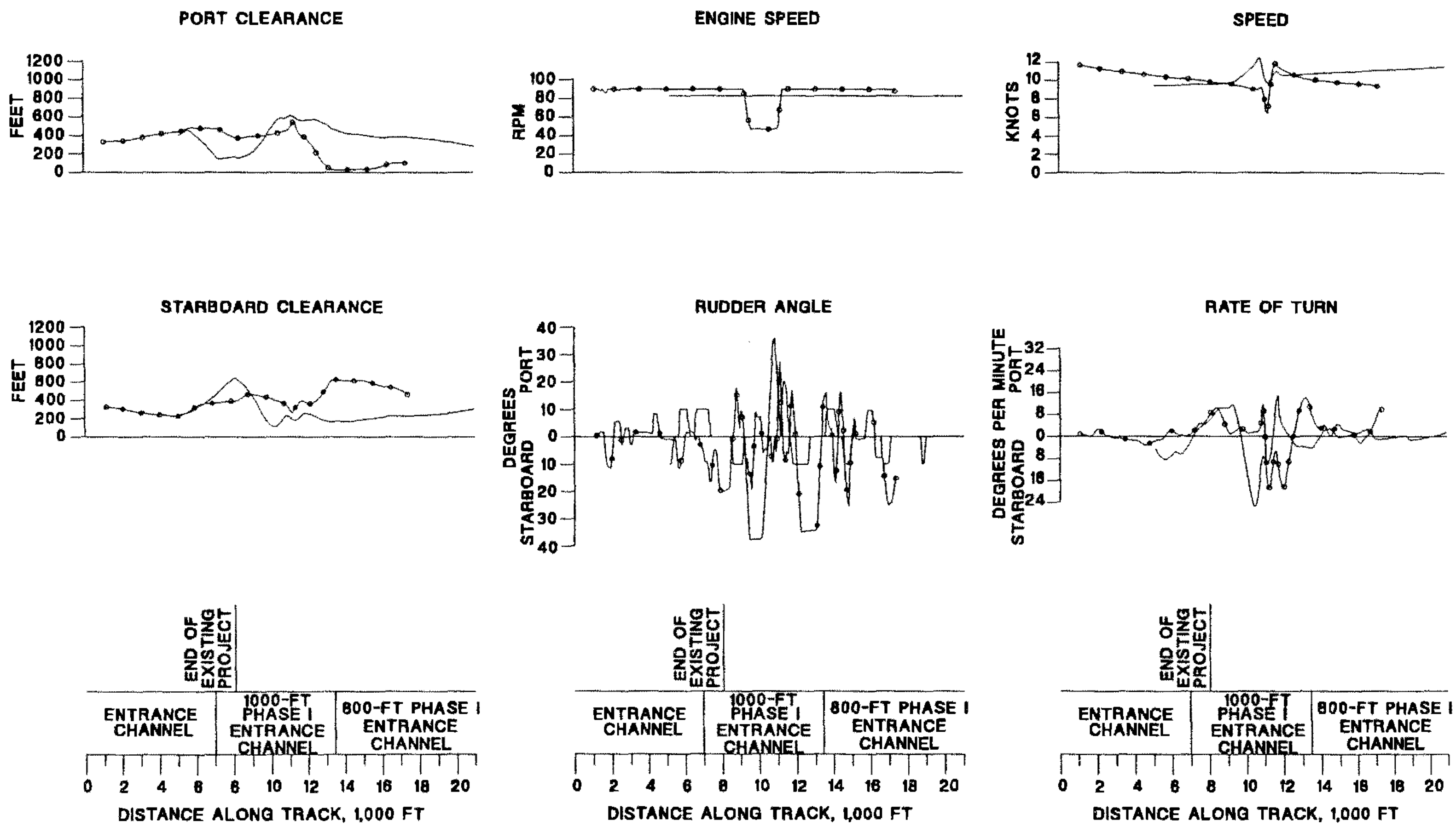


PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



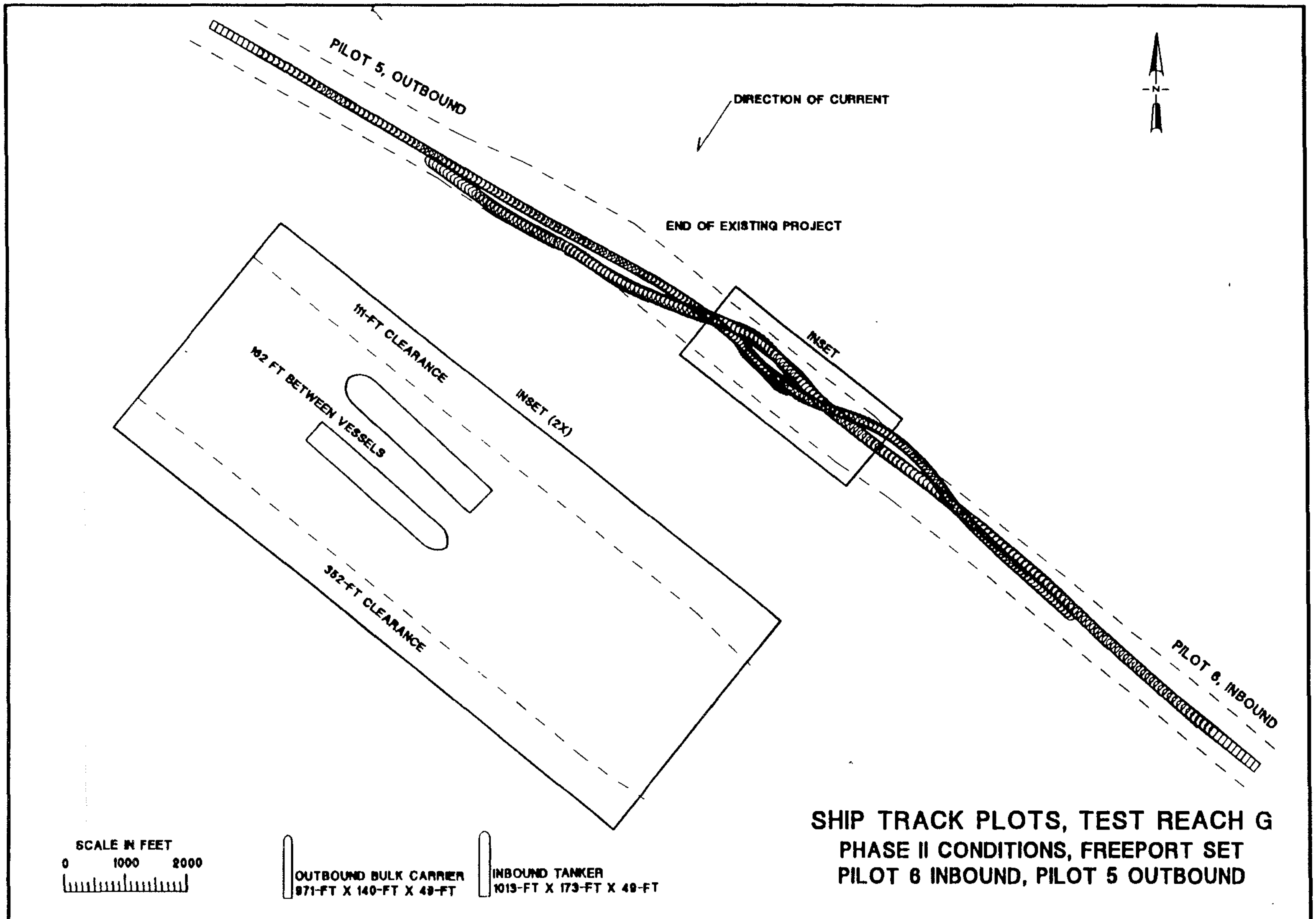
SHIP TRACK PLOTS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



PILOT 5 INBOUND

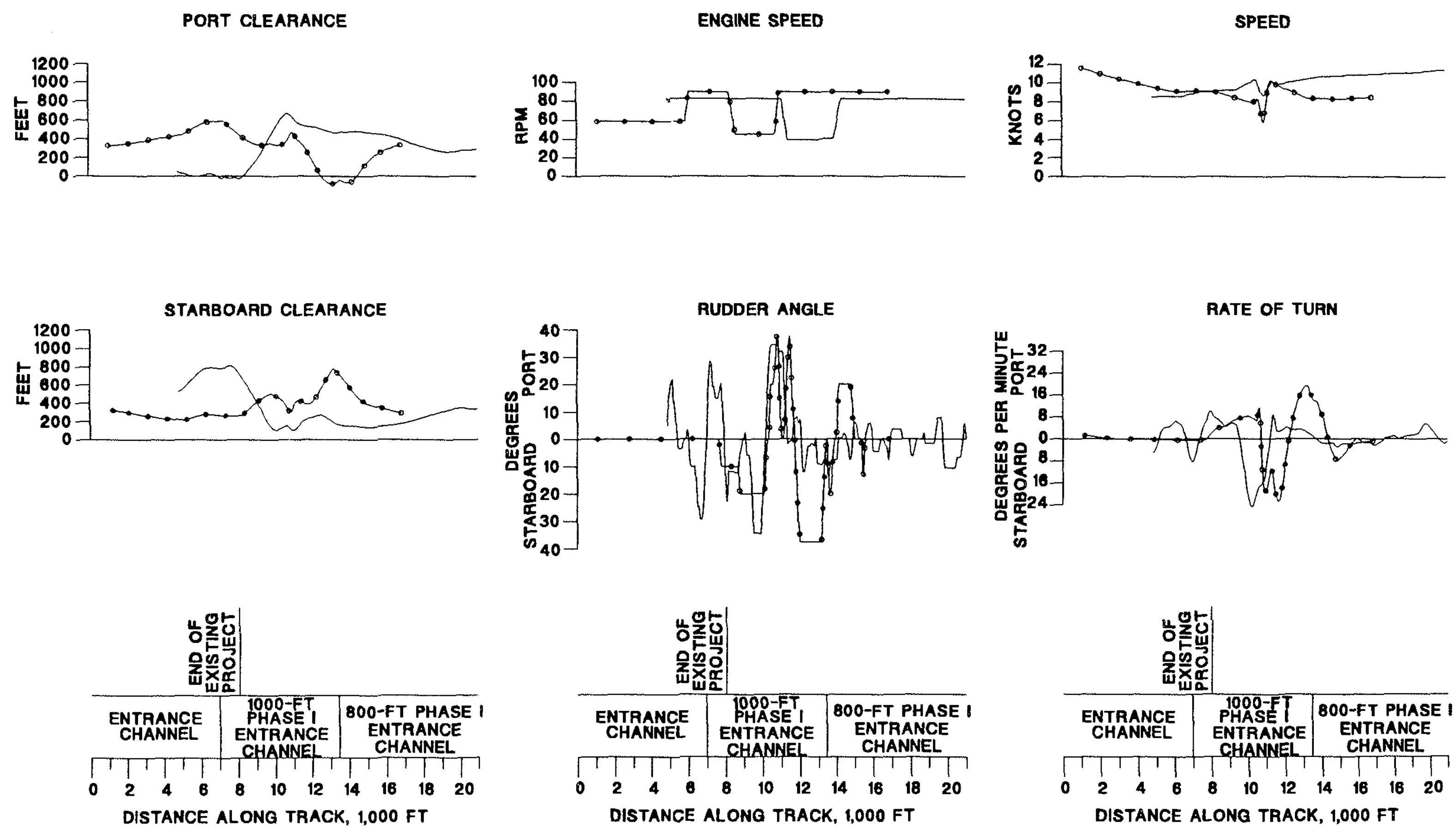
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



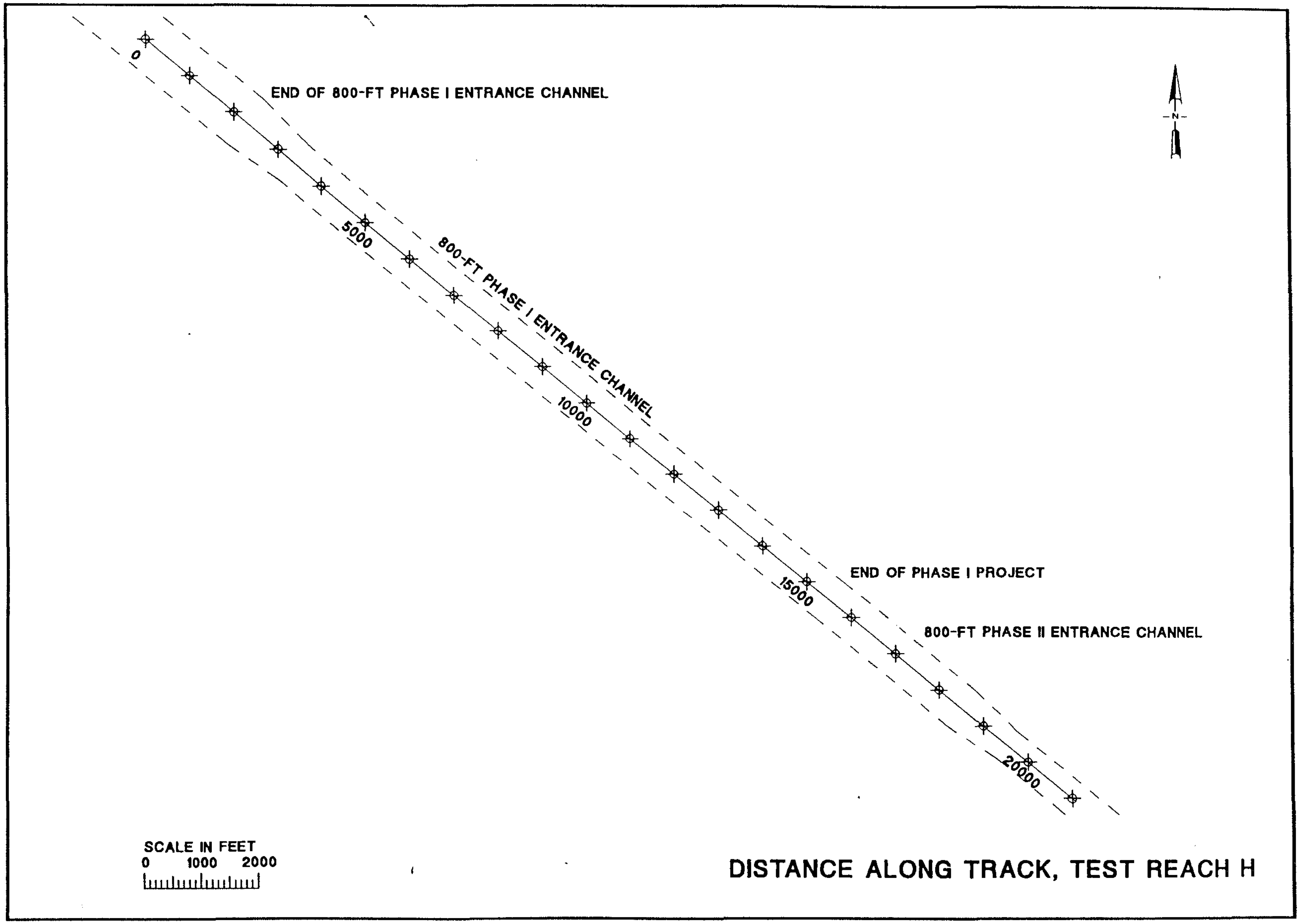
SHIP TRACK PLOTS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

Plate 190



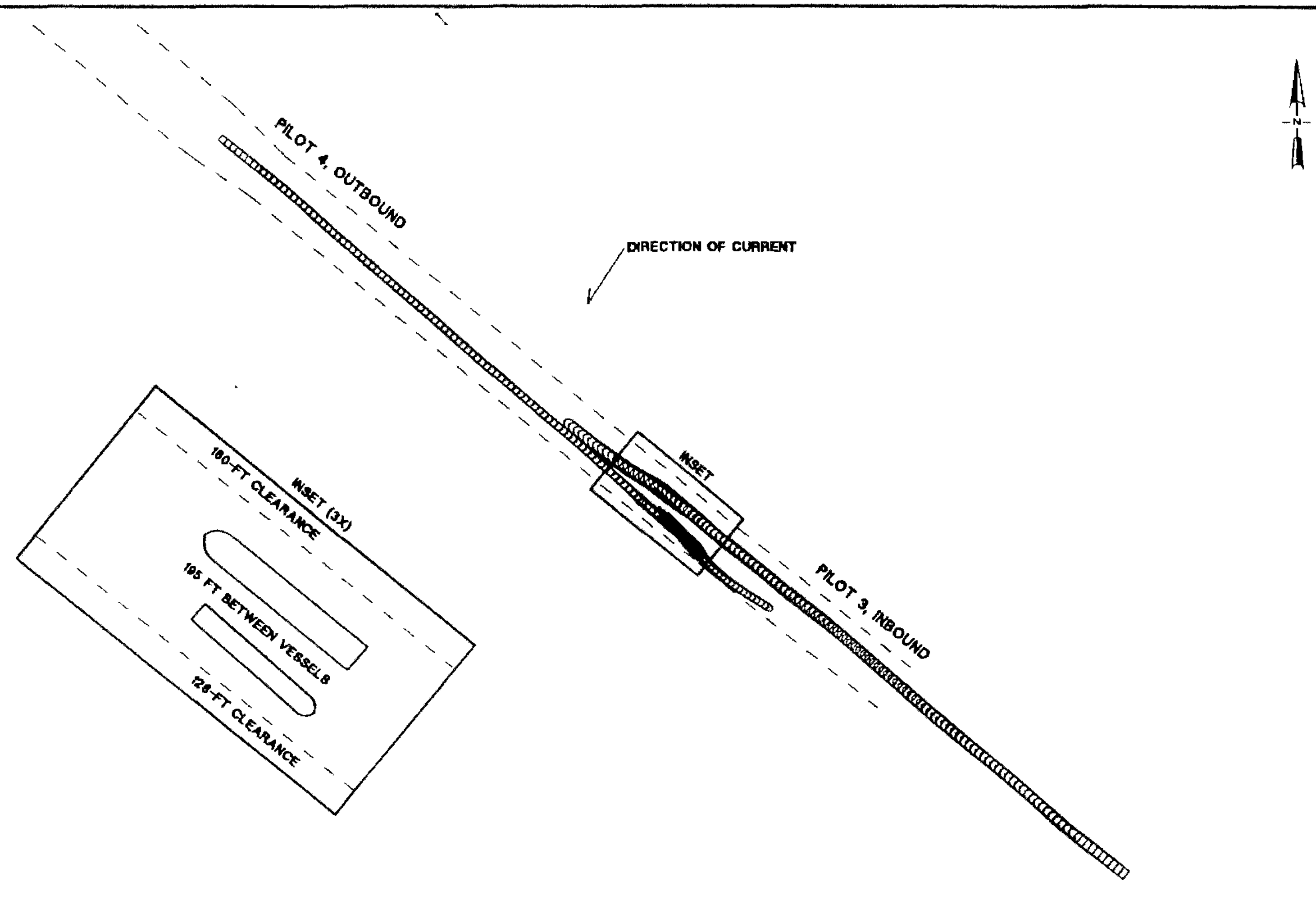
PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH G
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

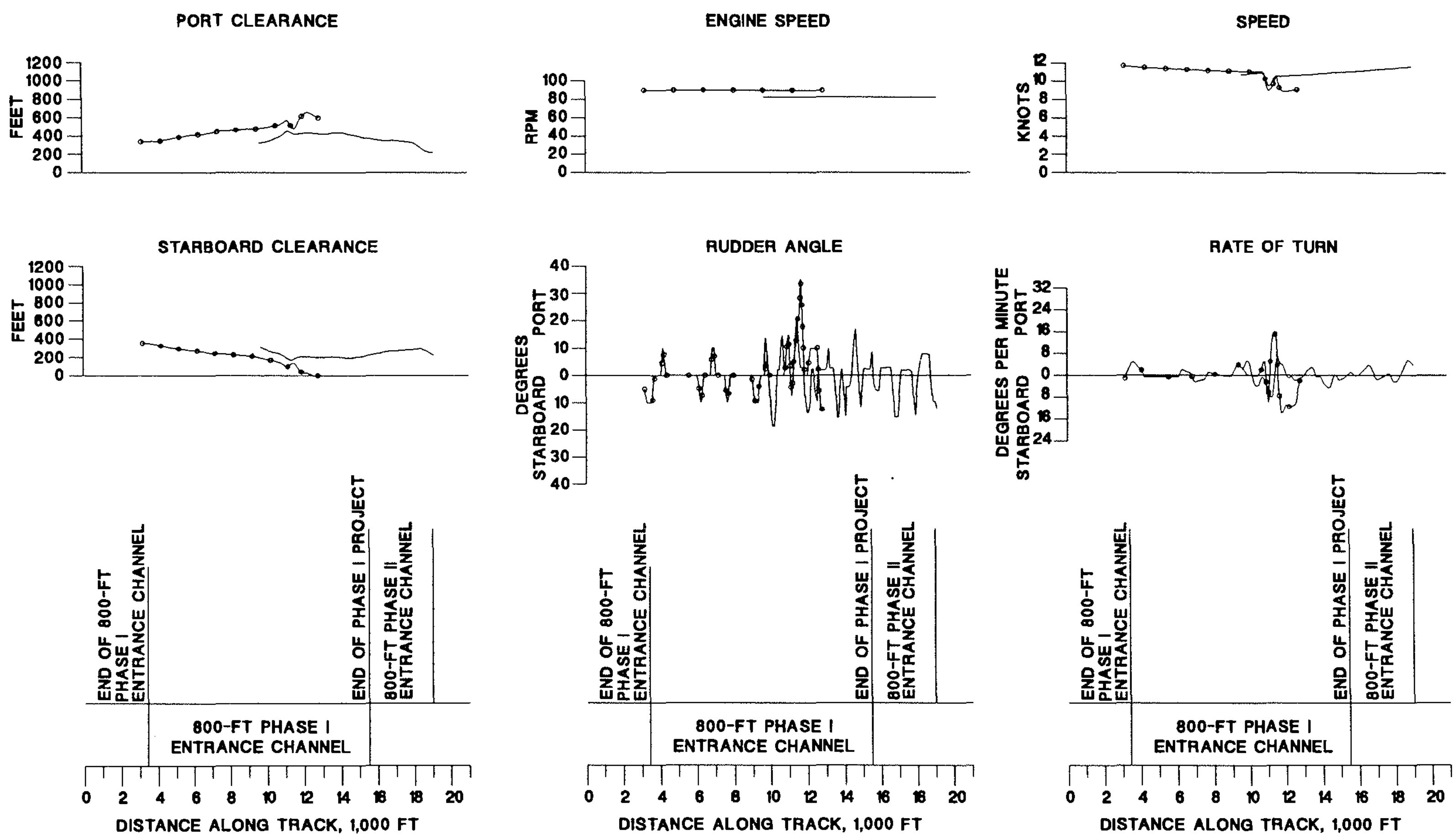


END OF 800-FT PHASE I ENTRANCE CHANNEL
800-FT PHASE I ENTRANCE CHANNEL
END OF PHASE I PROJECT
800-FT PHASE II ENTRANCE CHANNEL
N
0
5000
10000
15000
20000
SCALE IN FEET
0 1000 2000
DISTANCE ALONG TRACK, TEST REACH H

Plate 192

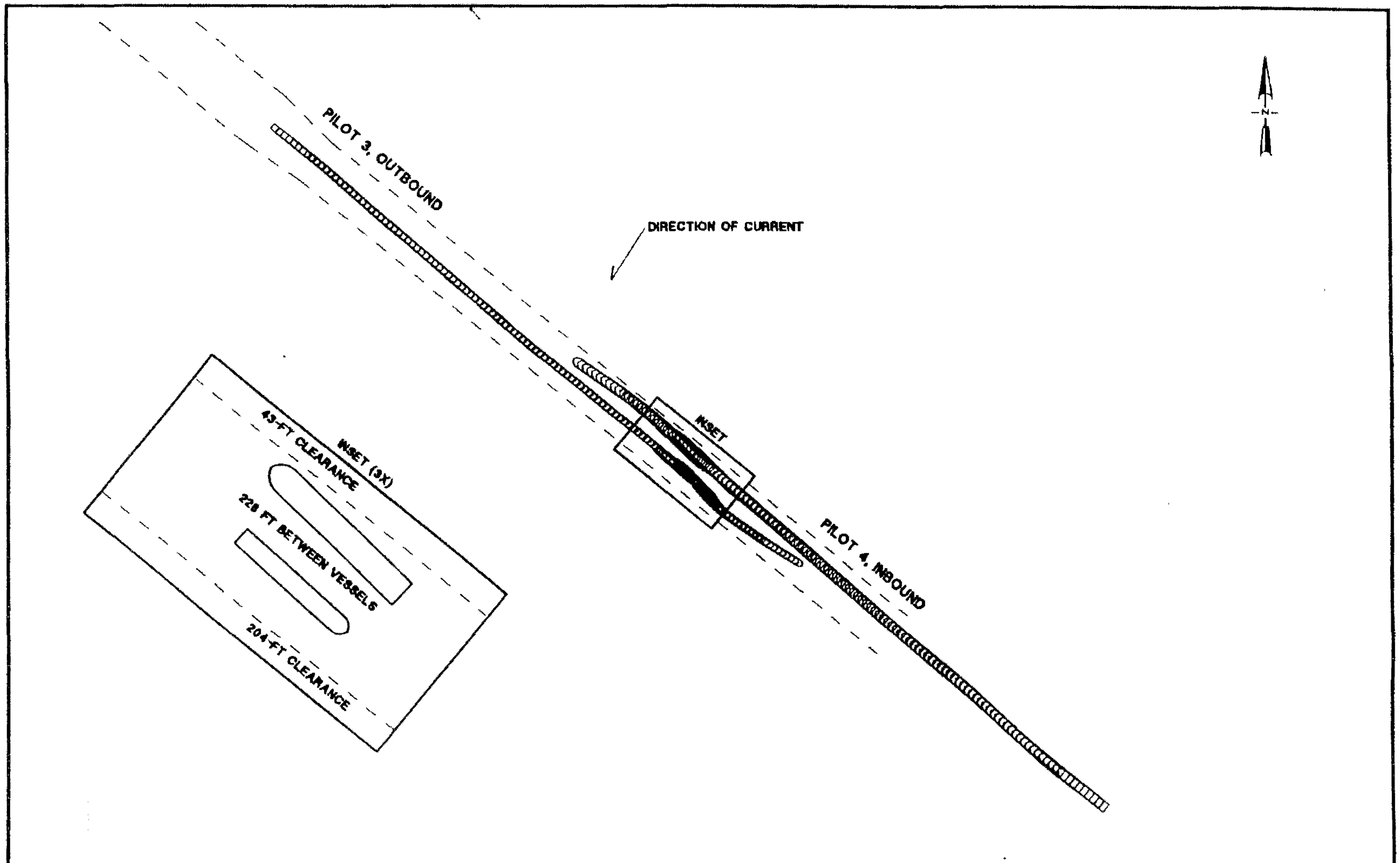


SHIP TRACK PLOTS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

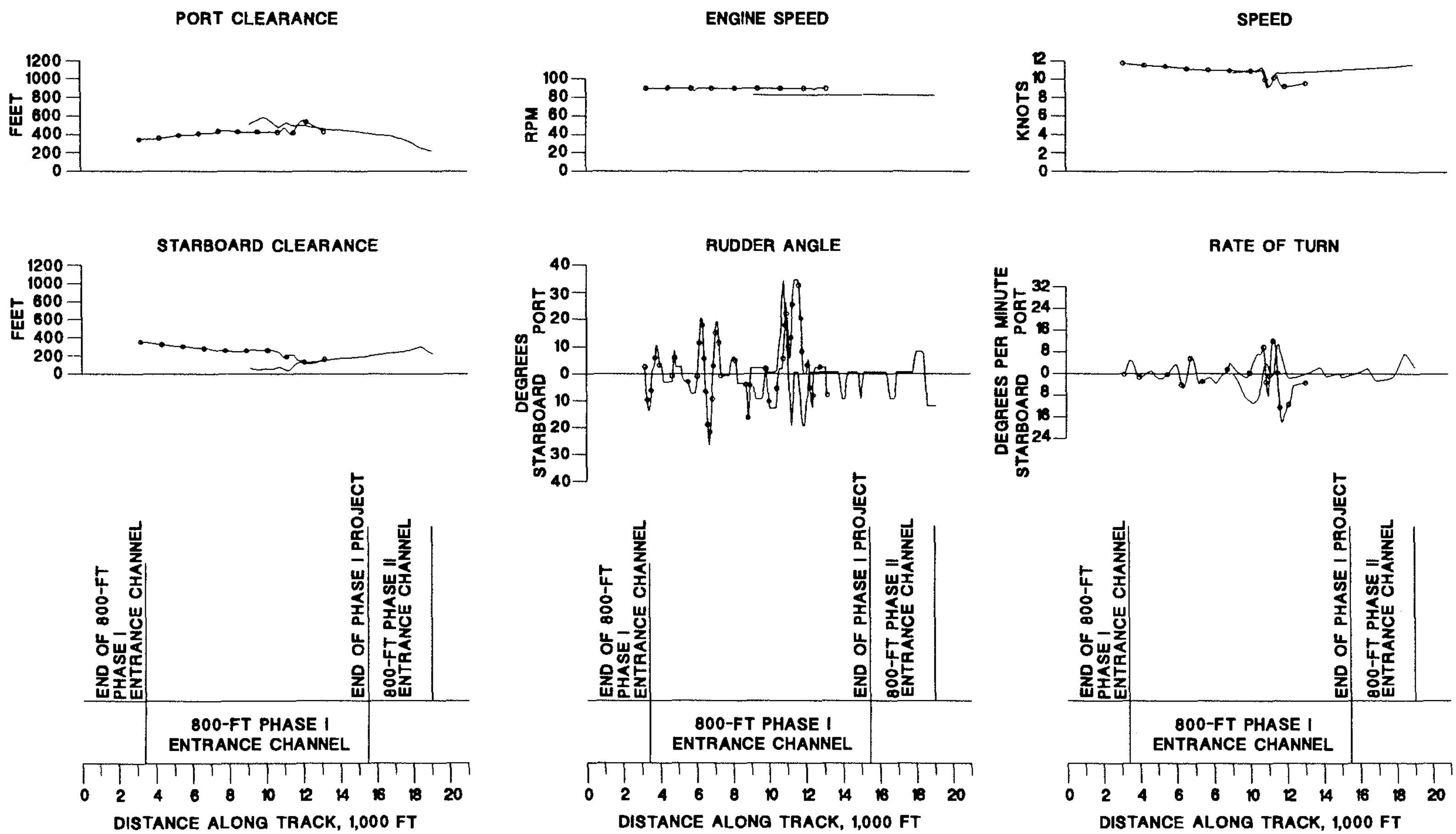


PILOT 3 INBOUND
PILOT 4 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



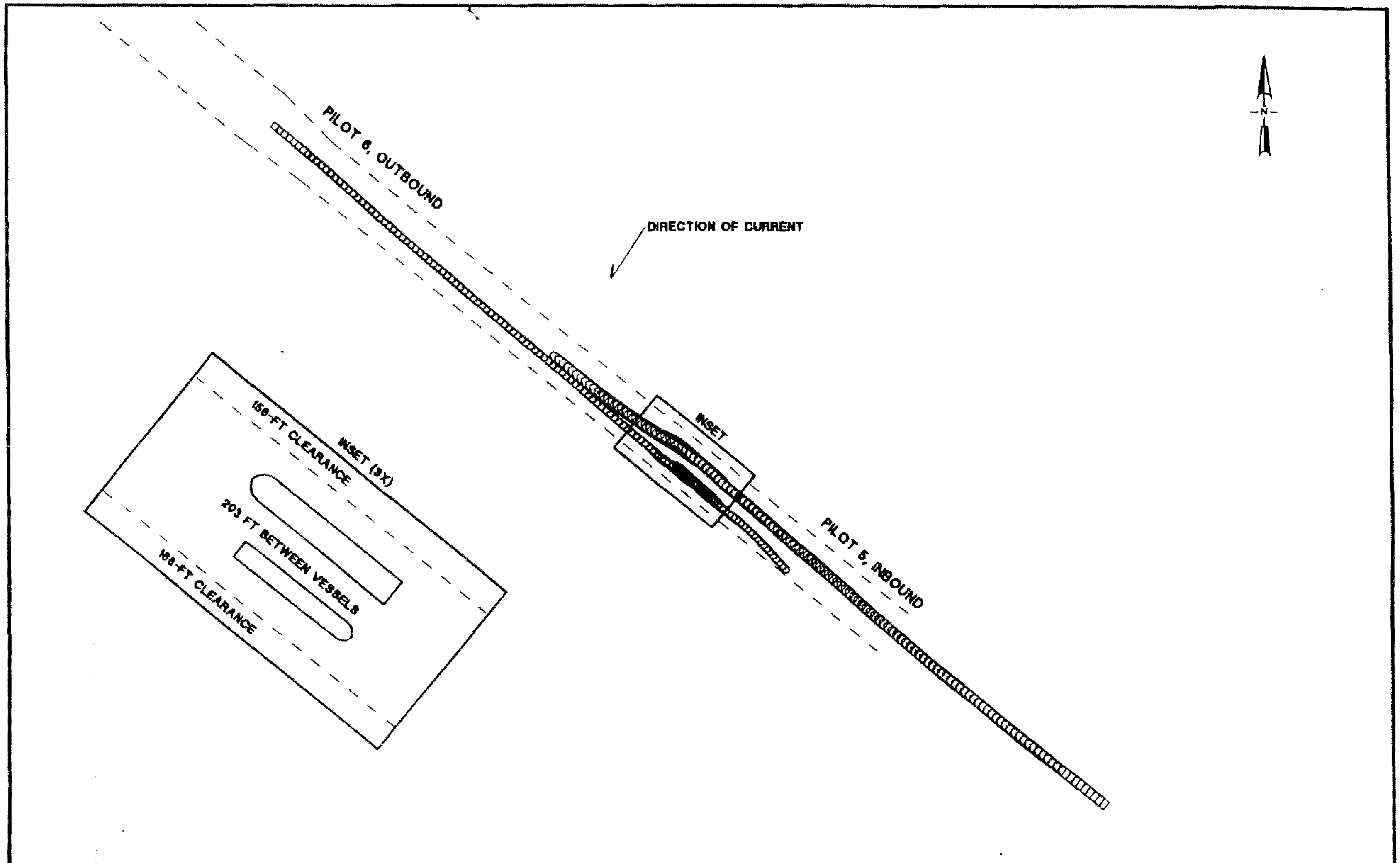
SHIP TRACK PLOTS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



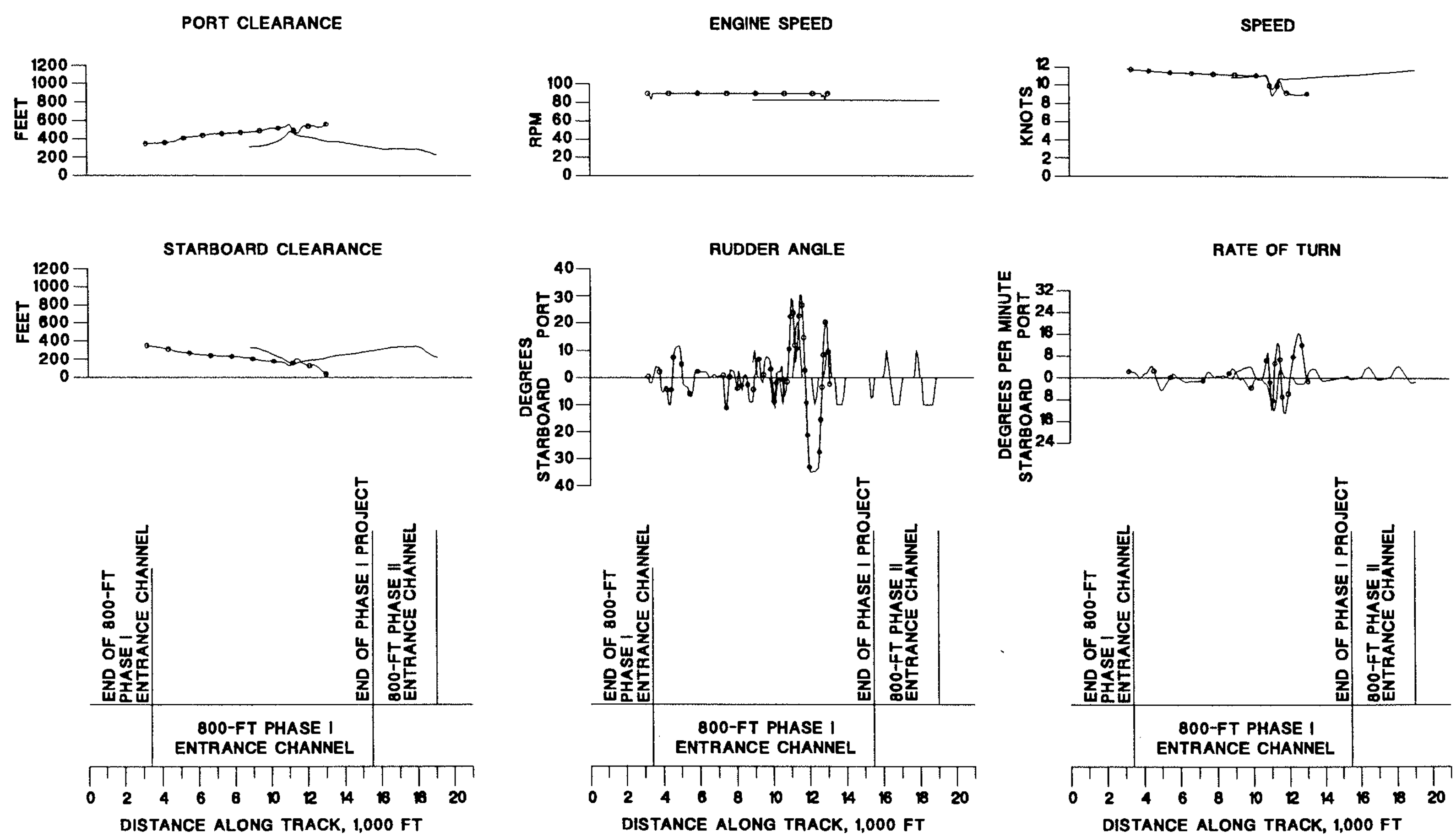
PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

Plate 196



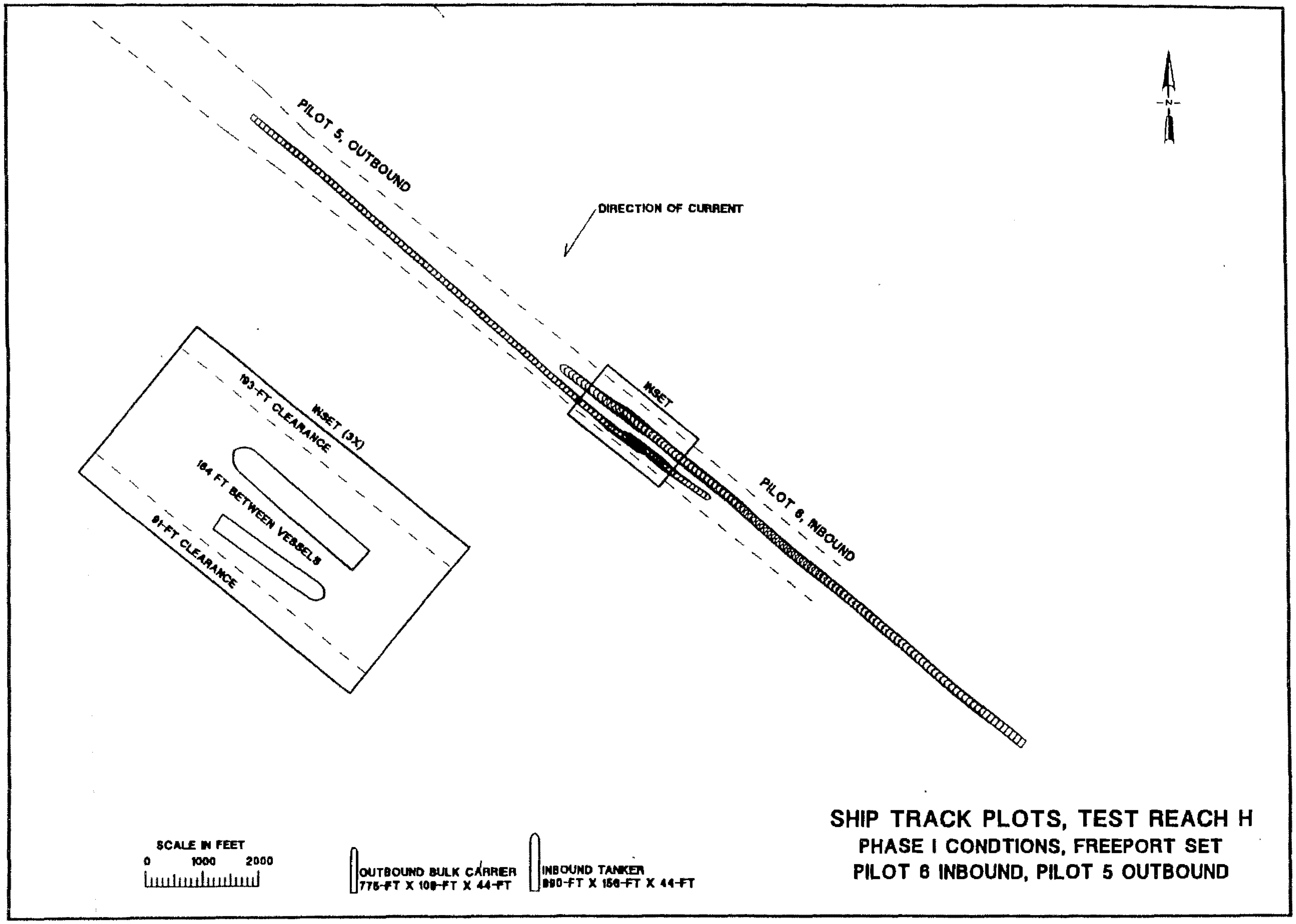
SHIP TRACK PLOTS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



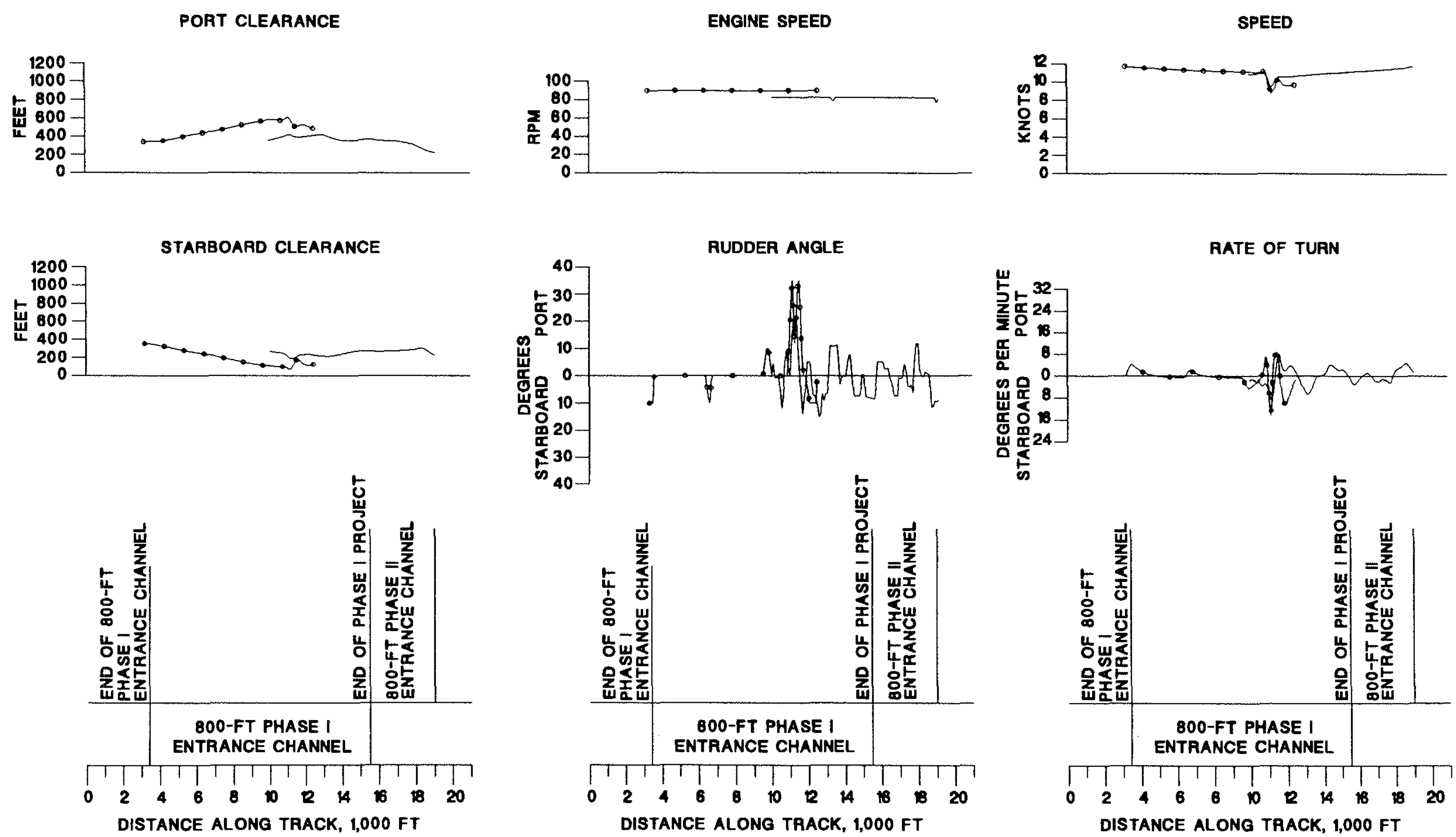
PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 198



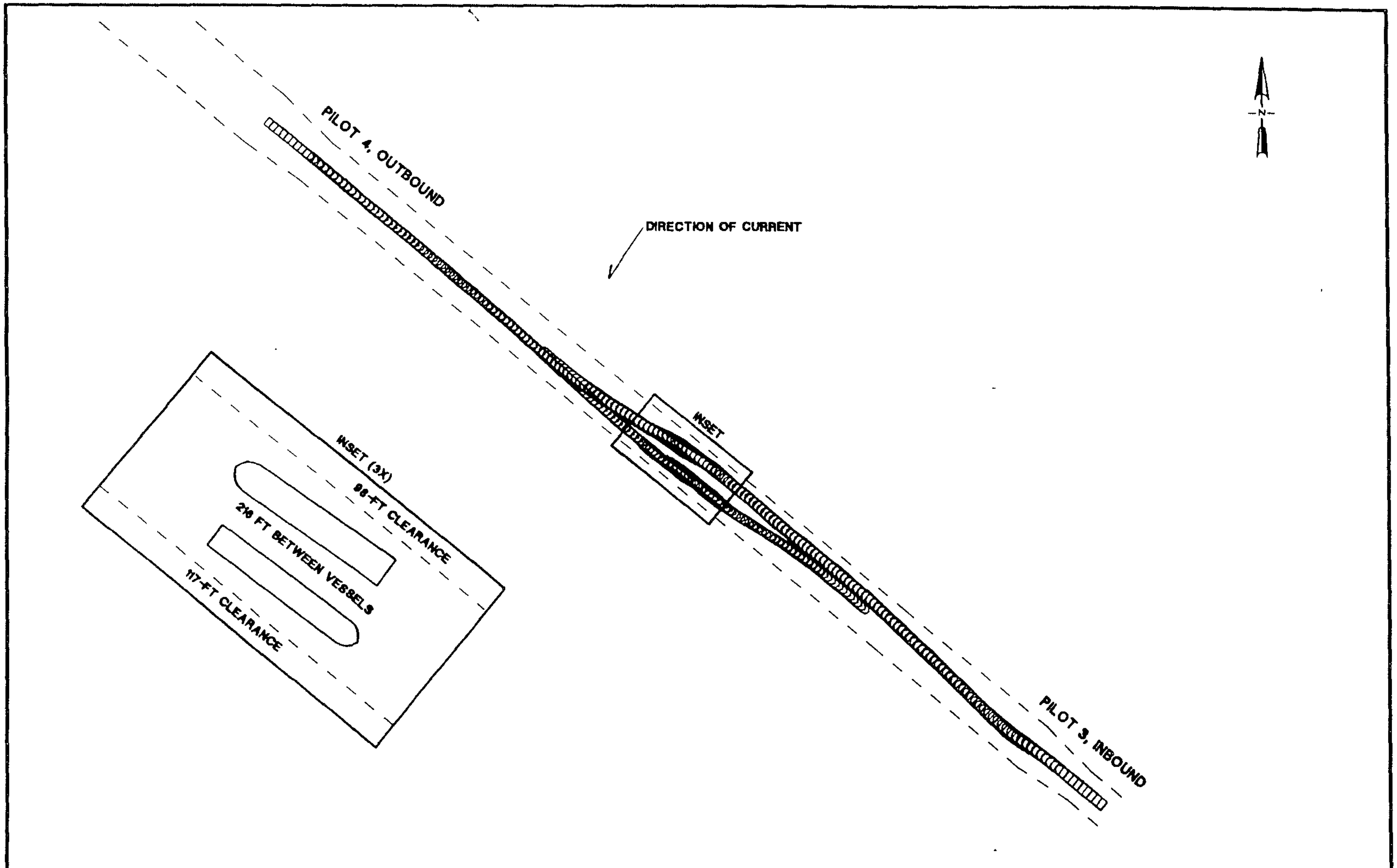
SHIP TRACK PLOTS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



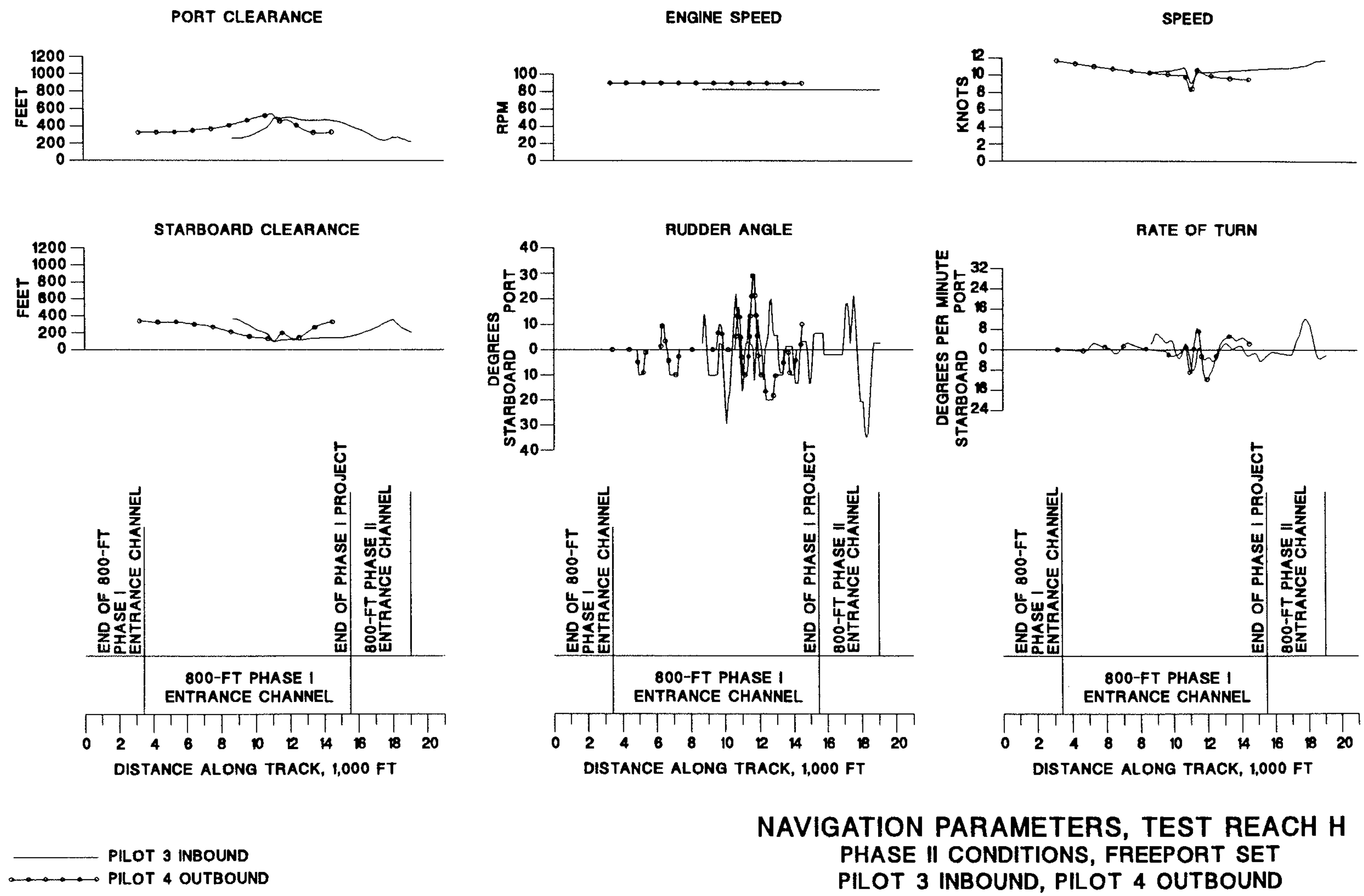
PILOT 6 INBOUND
PILOT 5 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE I CONDTIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

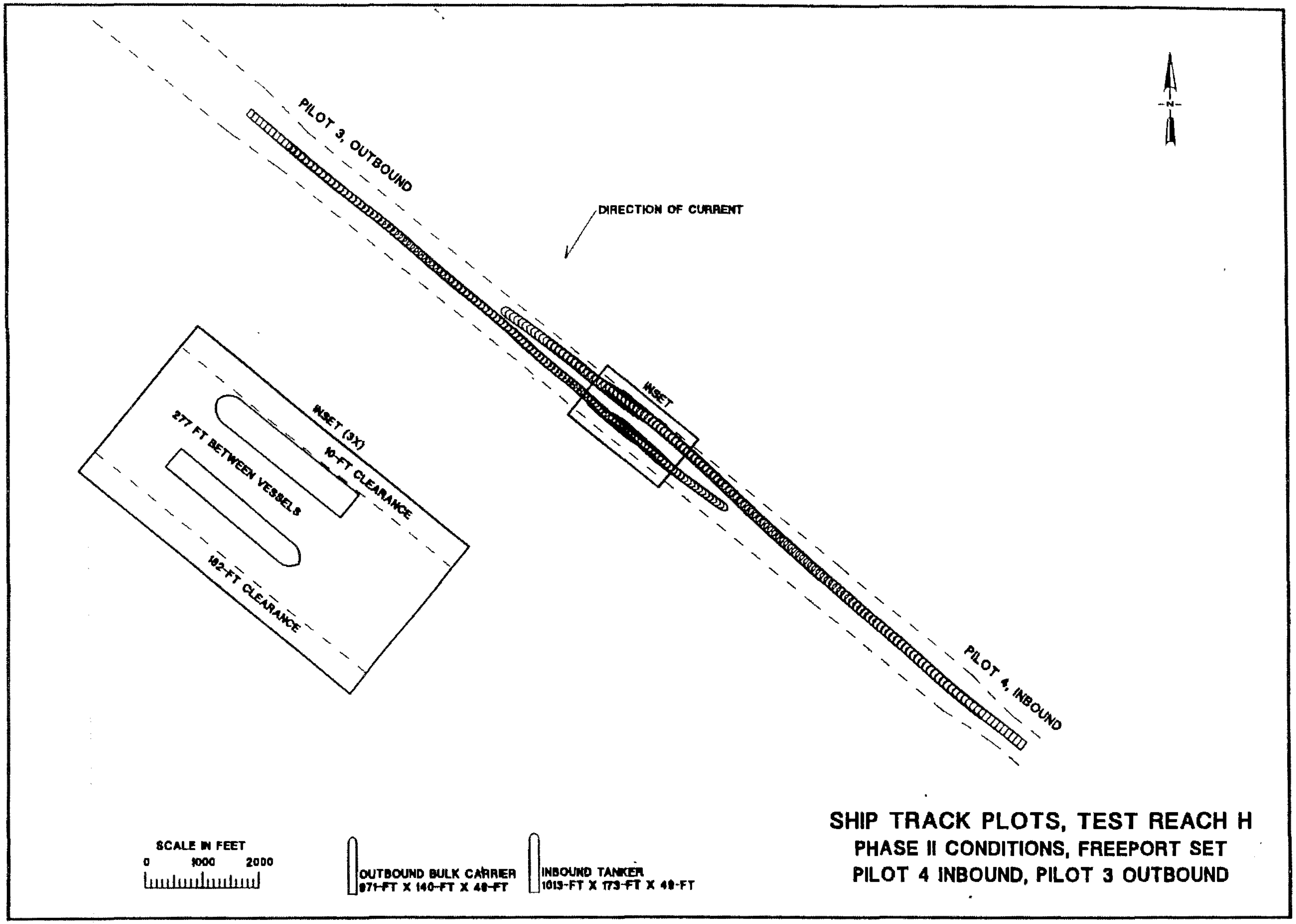
Plate 200



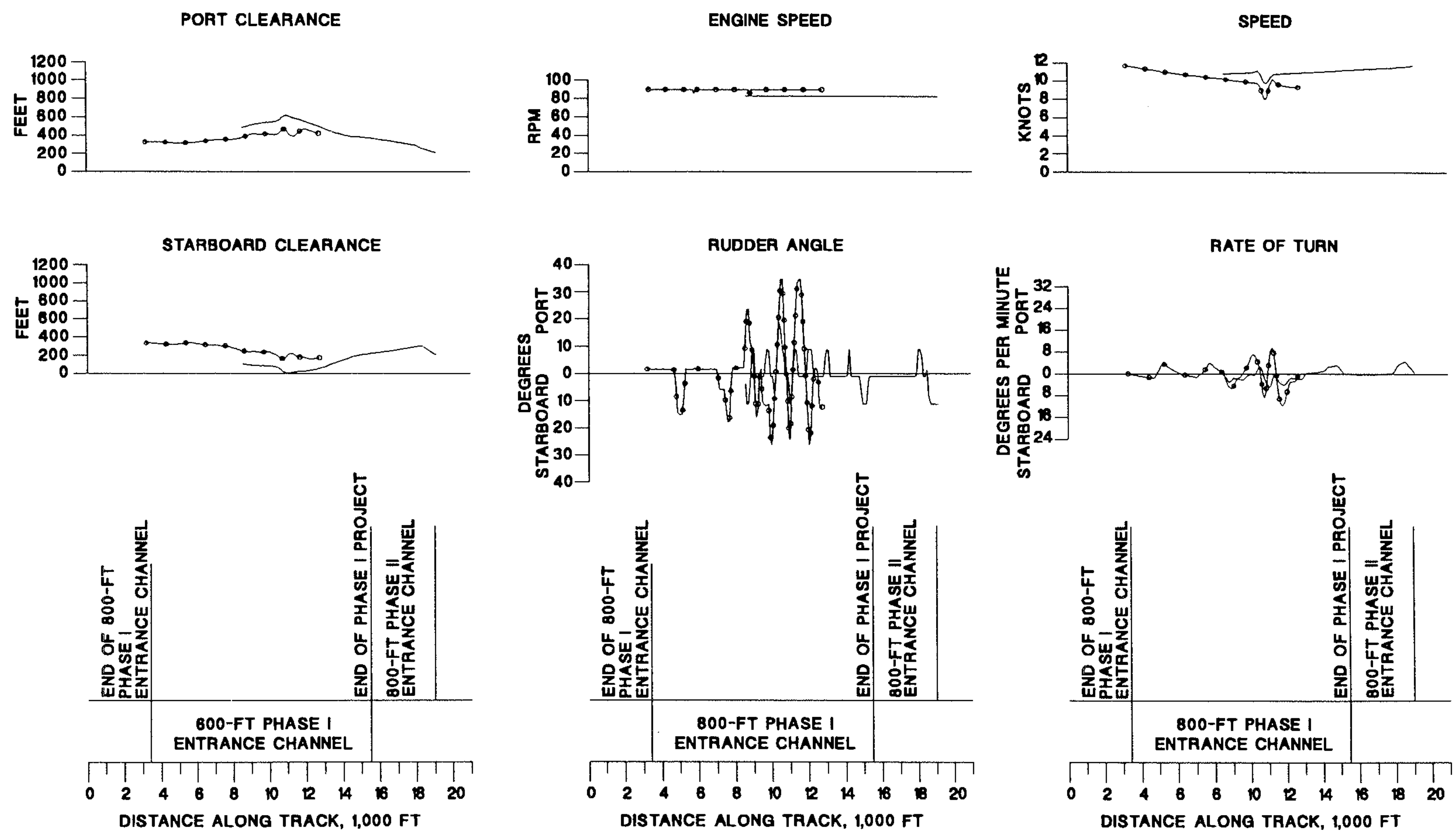
SHIP TRACK PLOTS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

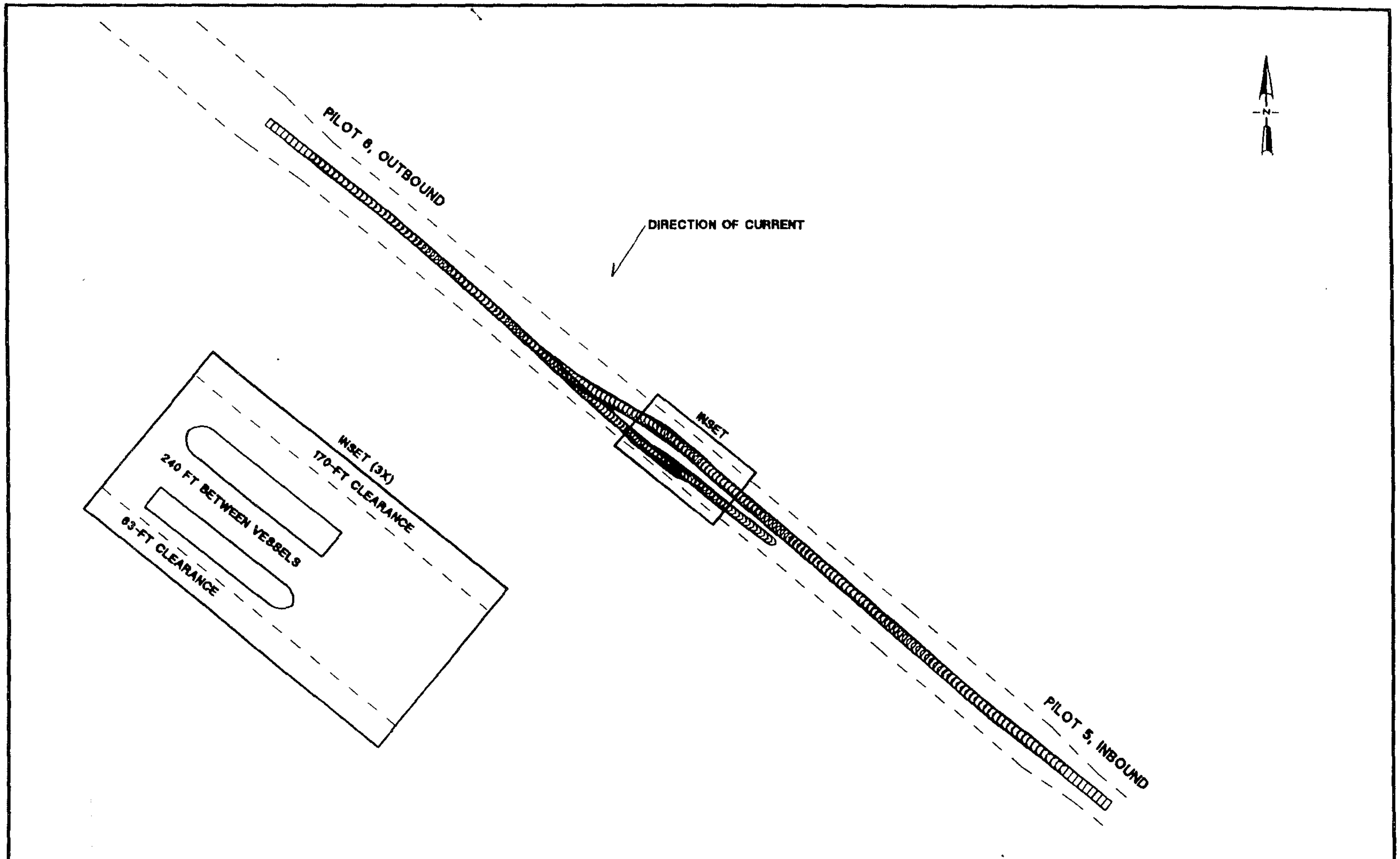


SHIP TRACK PLOTS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

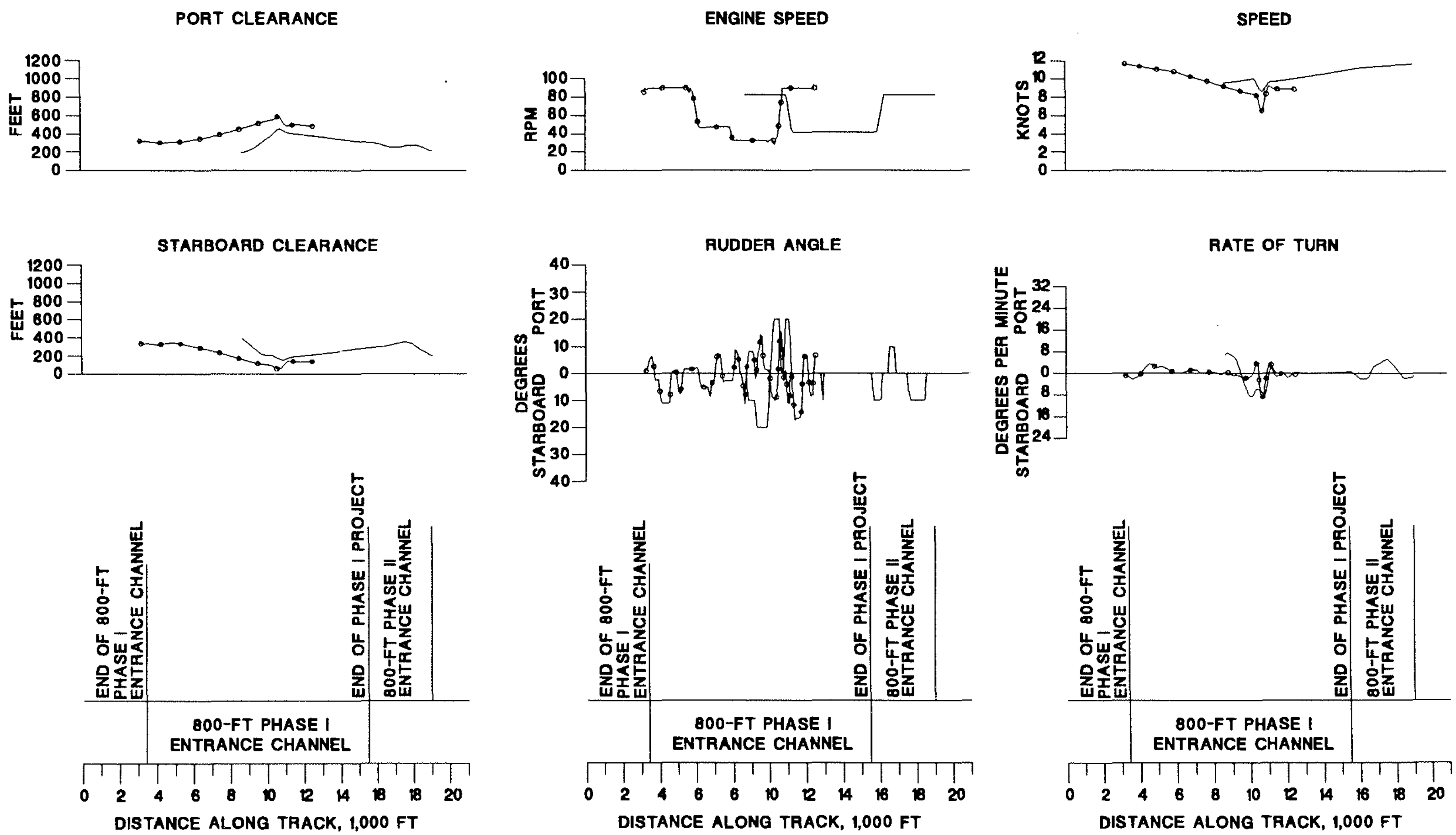


PILOT 4 INBOUND
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

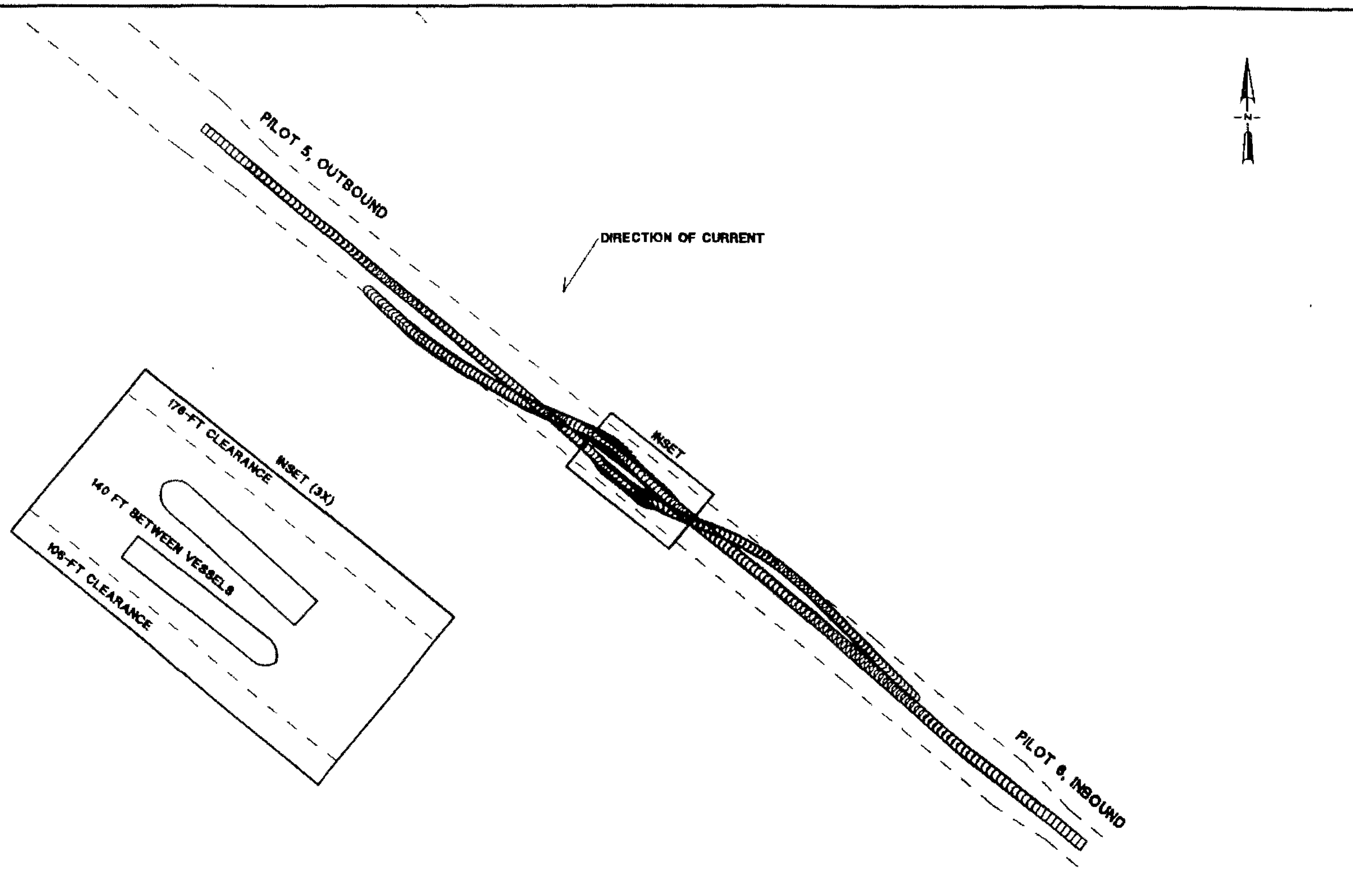


SHIP TRACK PLOTS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND



PILOT 5 INBOUND
PILOT 6 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

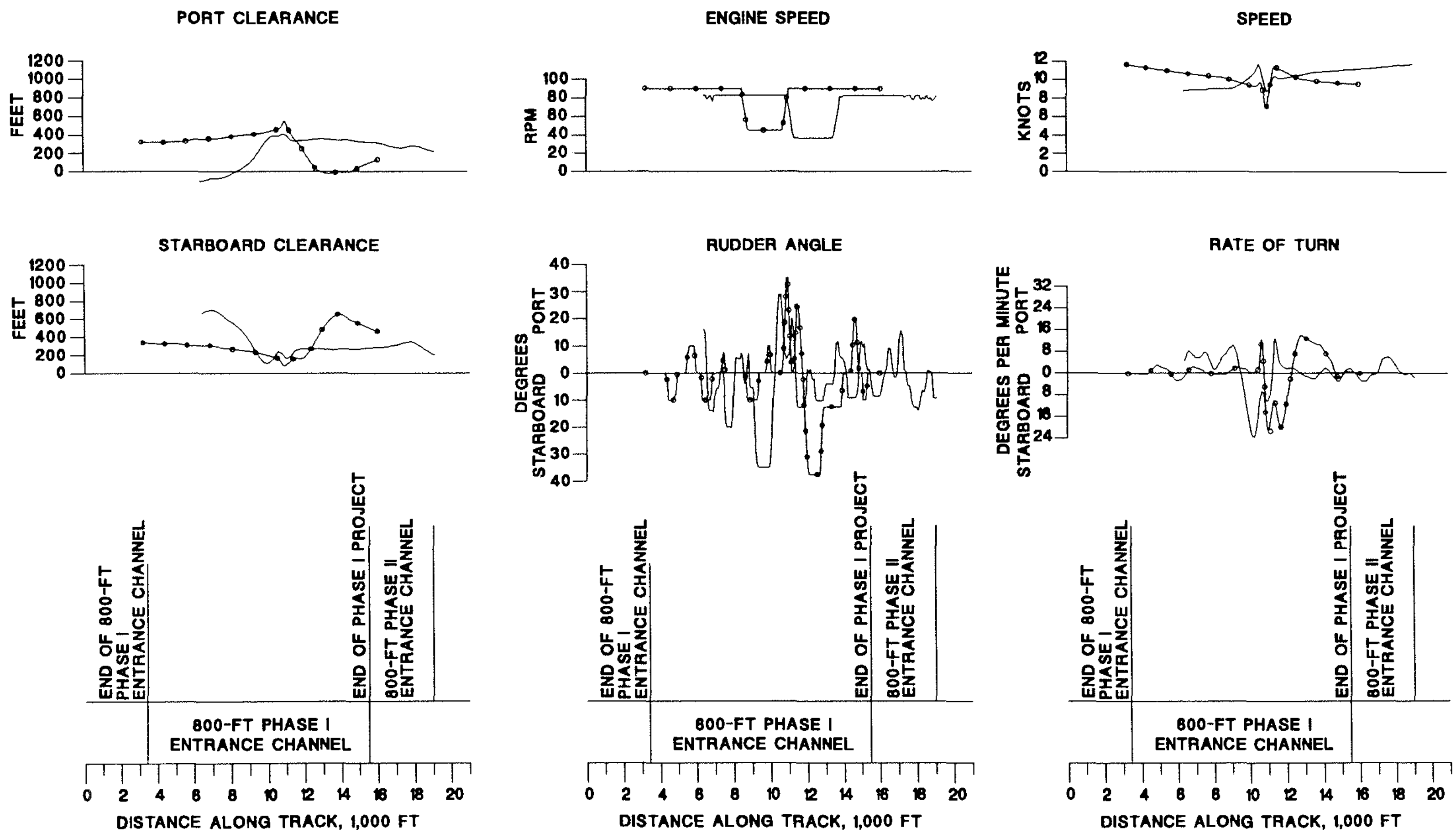


SCALE IN FEET
0 1000 2000

OUTBOUND BULK CARRIER
971-FT X 140-FT X 49-FT

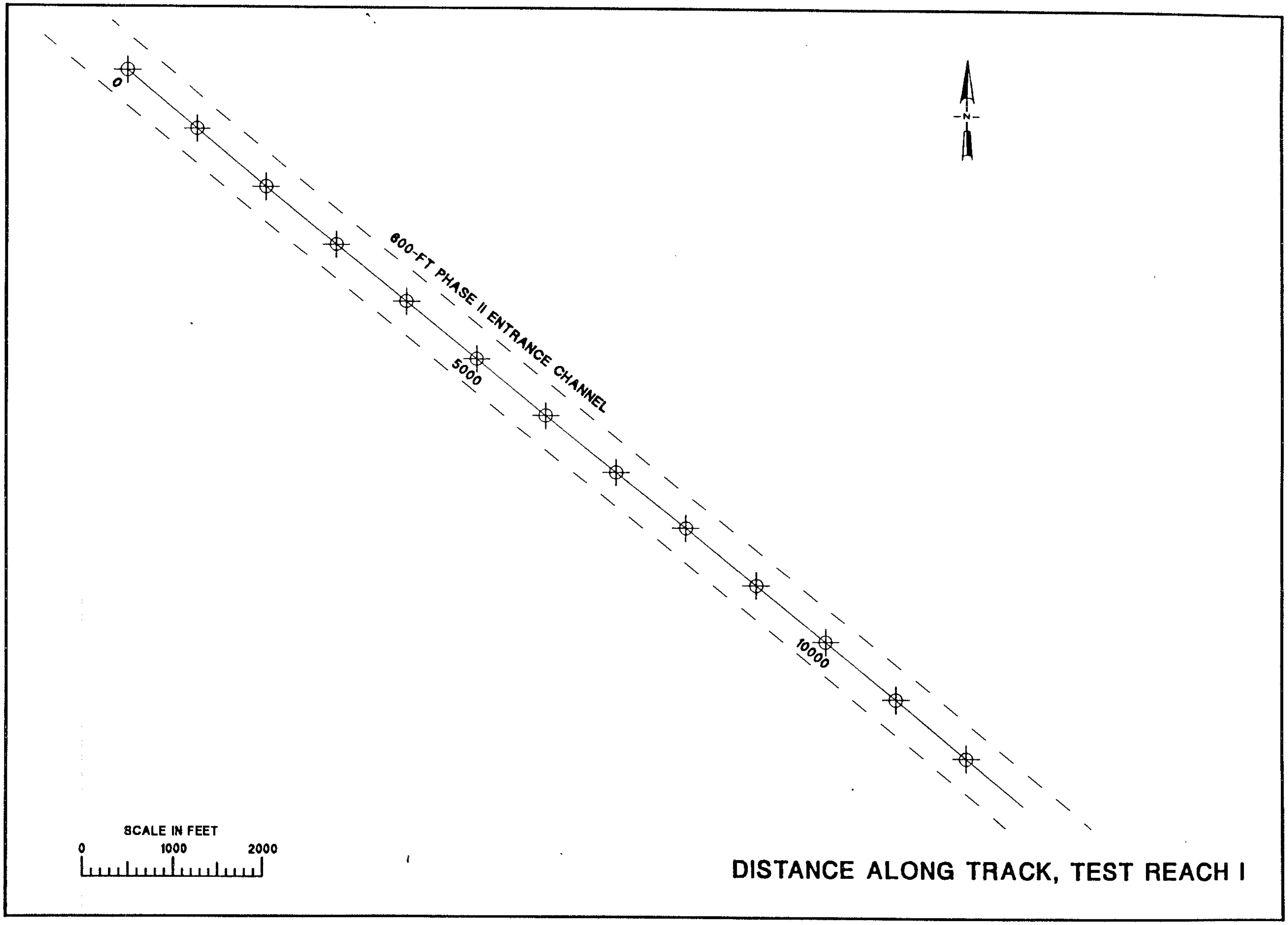
INBOUND TANKER
1013-FT X 173-FT X 49-FT

SHIP TRACK PLOTS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

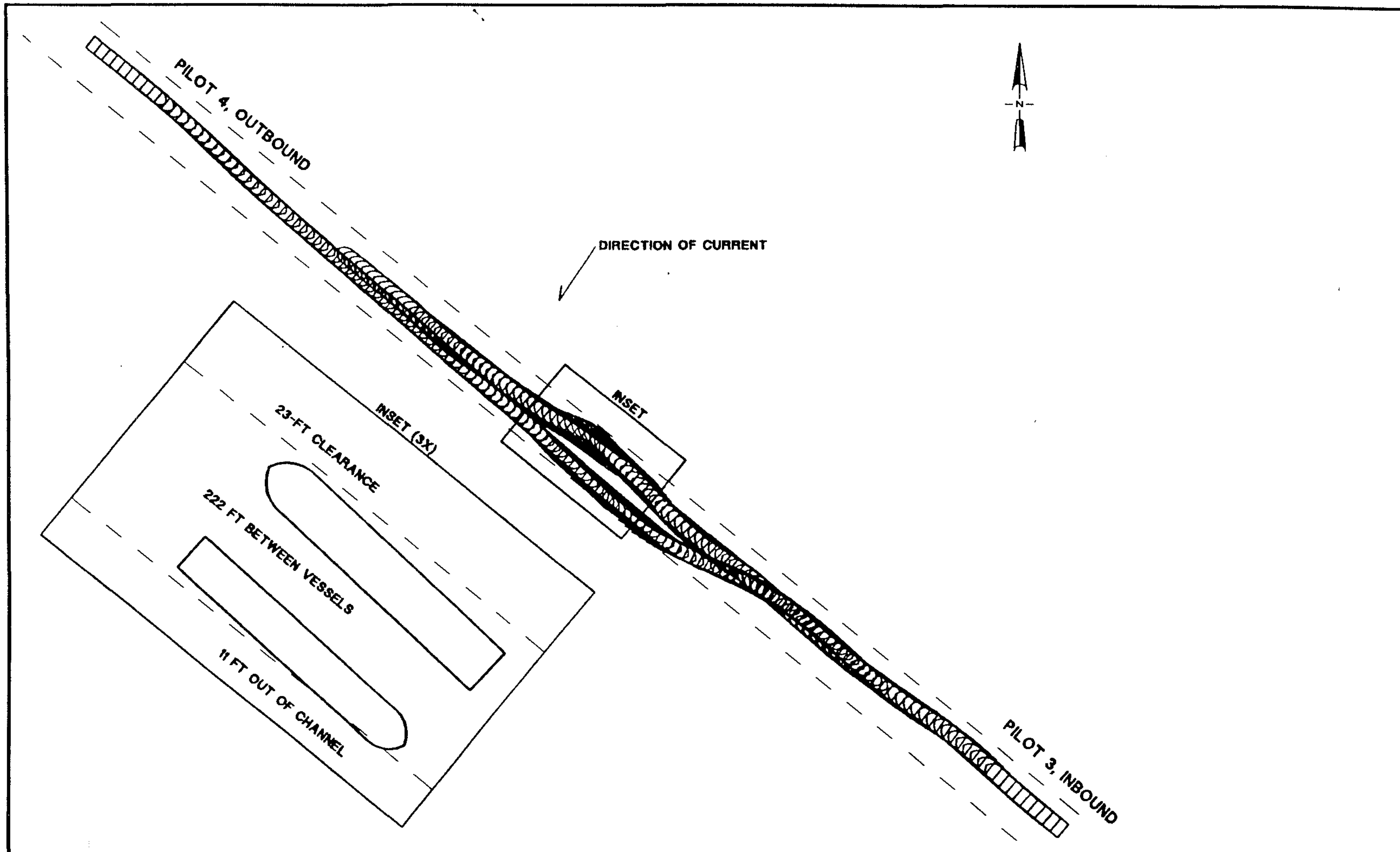


PILOT 8 INBOUND
PILOT 5 OUTBOUND

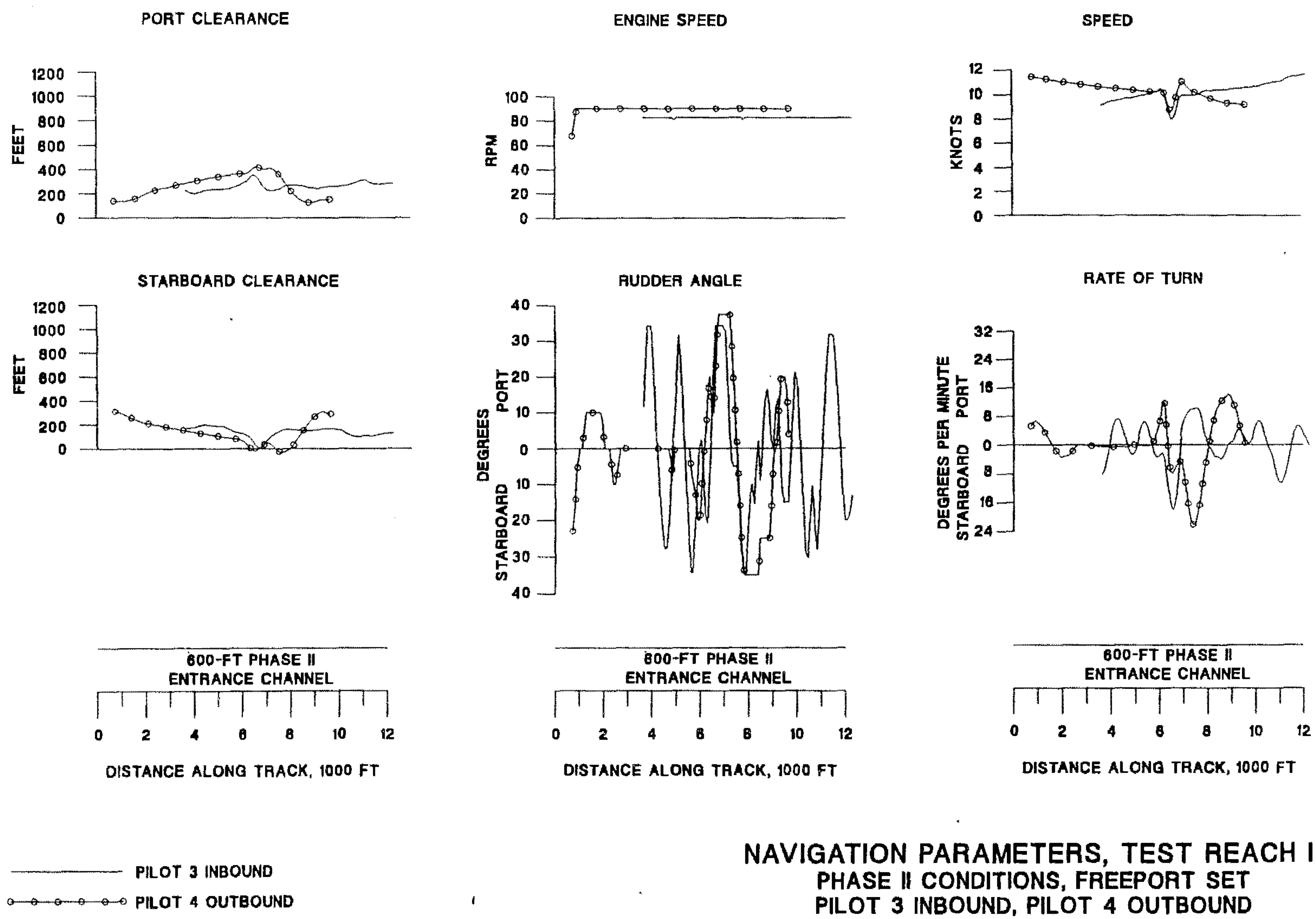
NAVIGATION PARAMETERS, TEST REACH H
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



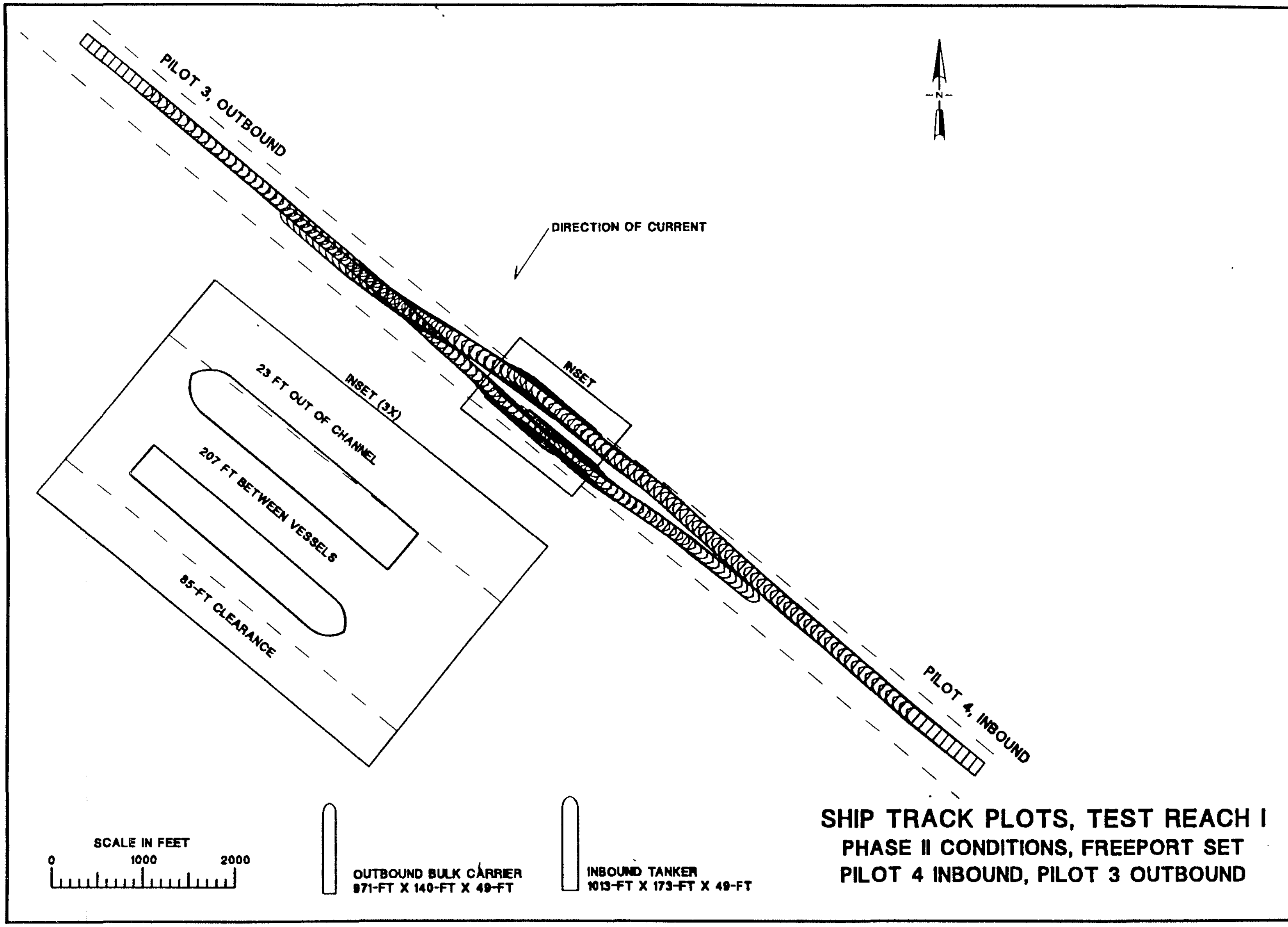
DISTANCE ALONG TRACK, TEST REACH I



SHIP TRACK PLOTS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND

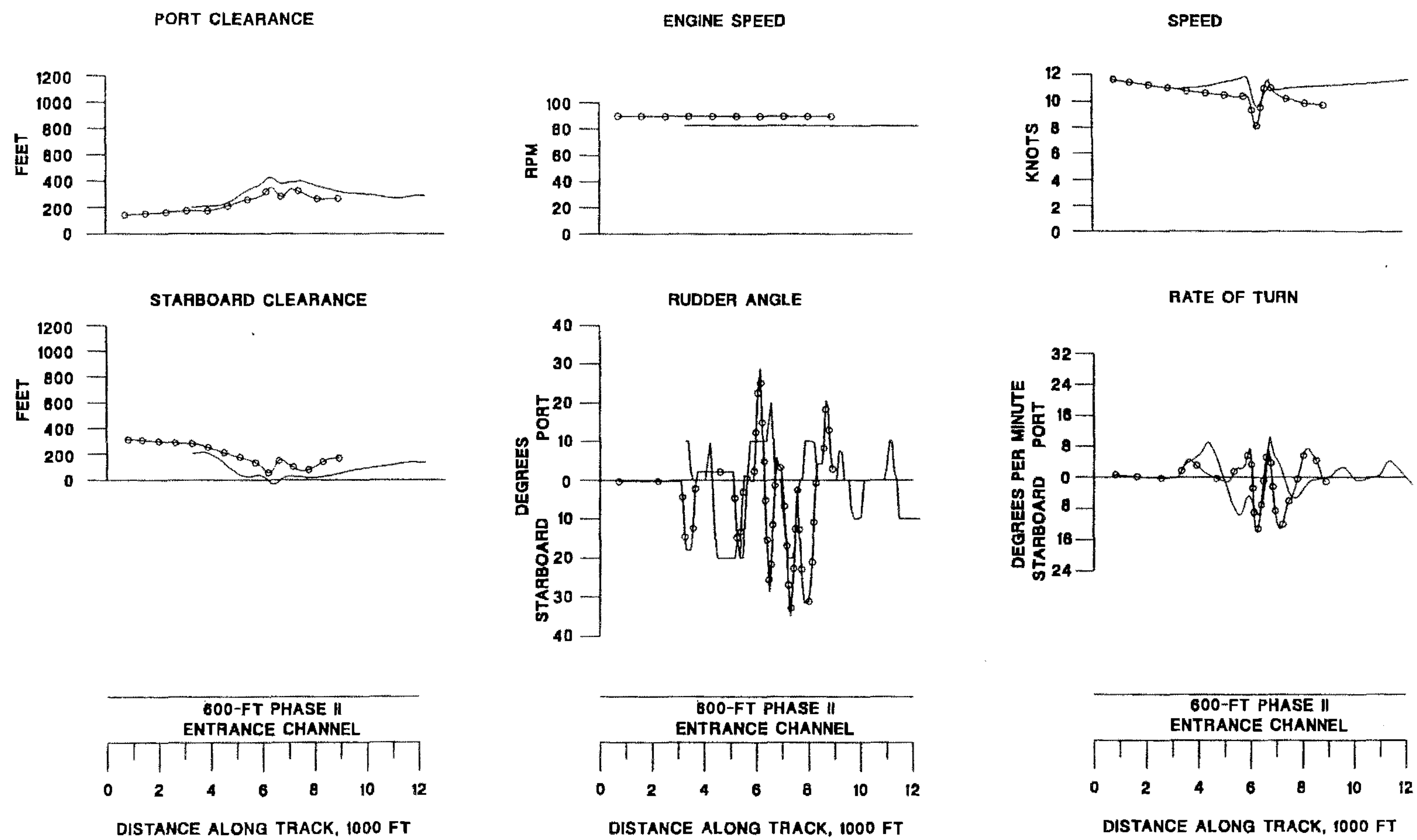


NAVIGATION PARAMETERS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 3 INBOUND, PILOT 4 OUTBOUND



SHIP TRACK PLOTS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND

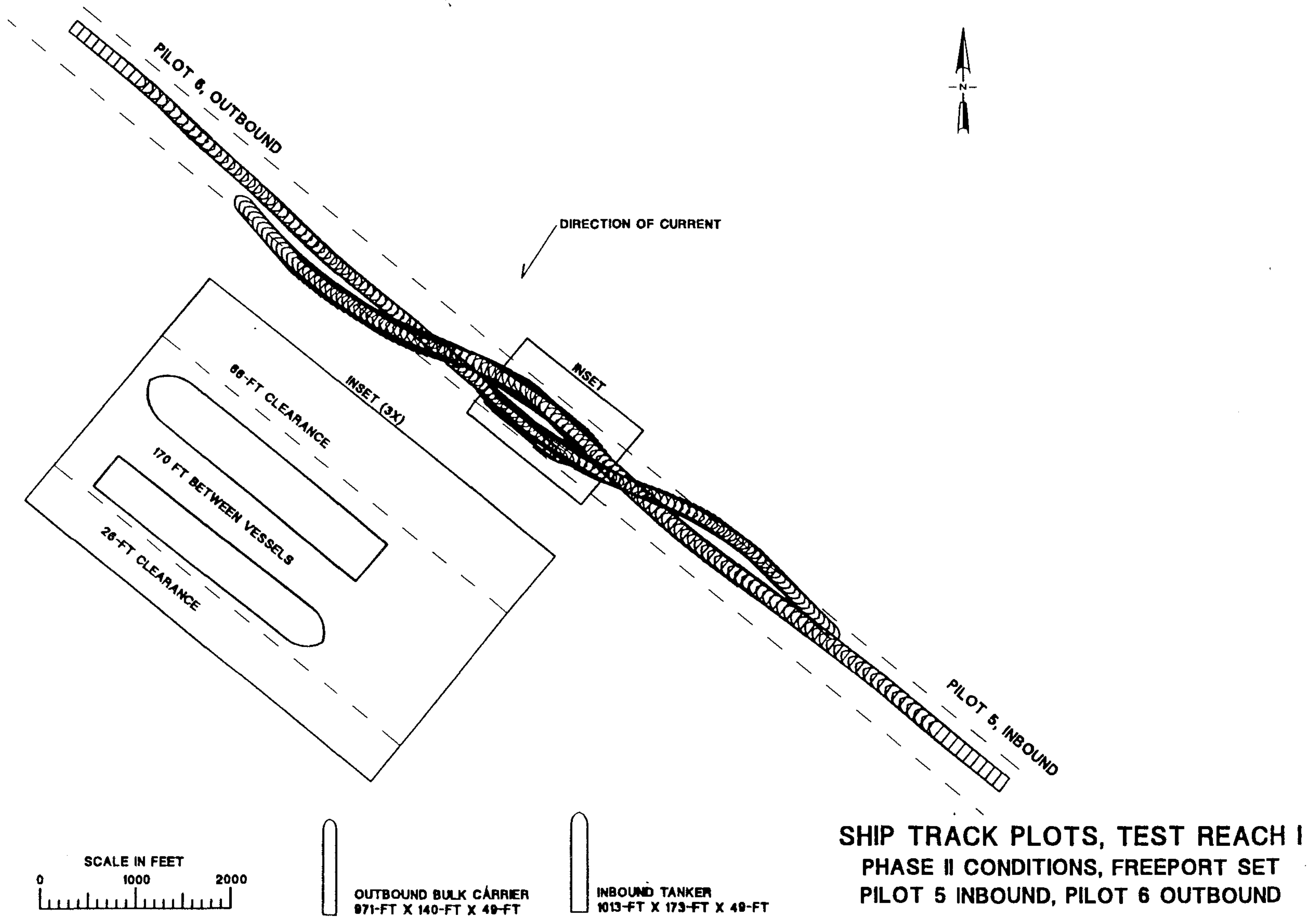
Plate 212



PILOT 4 INBOUND

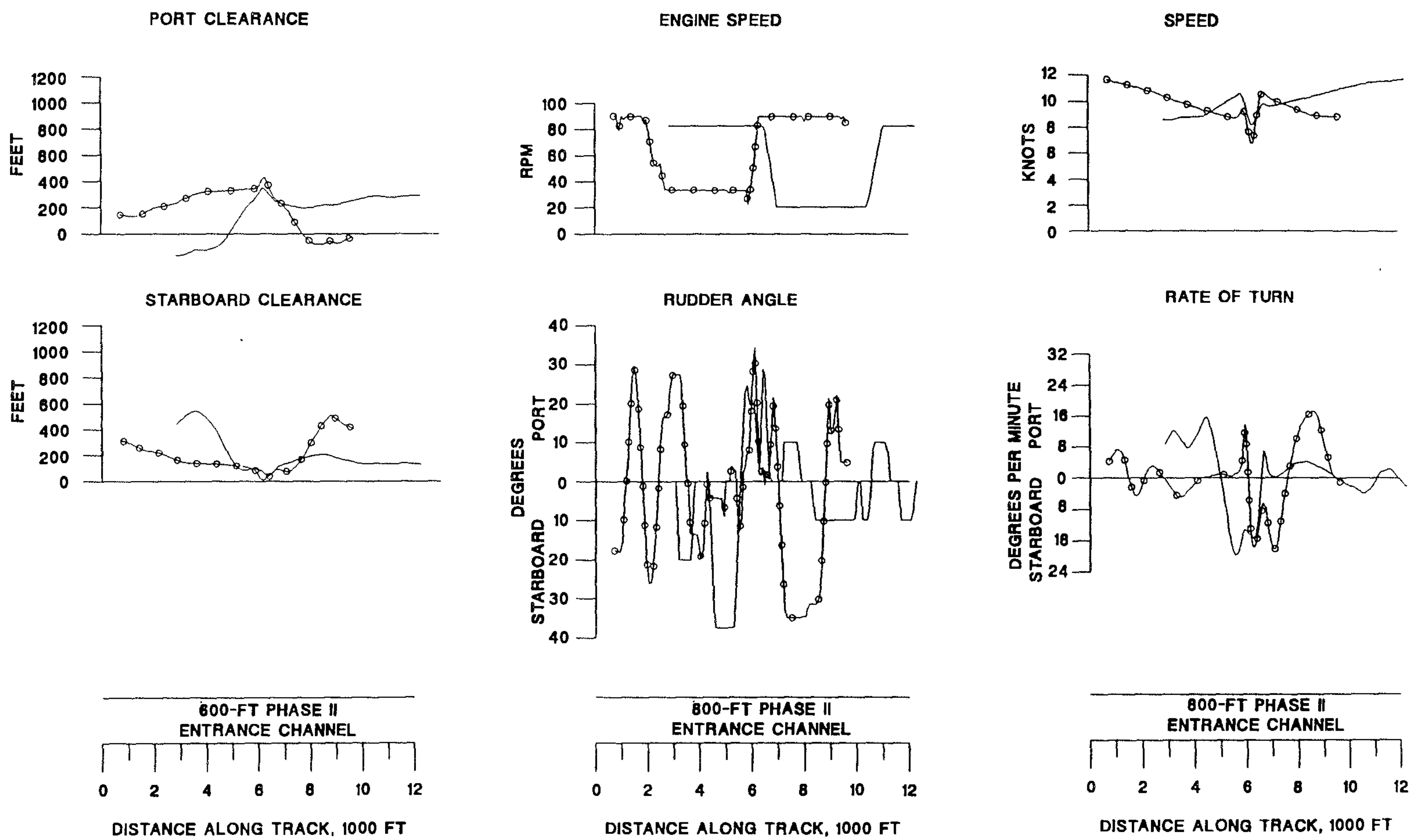
PILOT 3 OUTBOUND

NAVIGATION PARAMETERS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 4 INBOUND, PILOT 3 OUTBOUND



SHIP TRACK PLOTS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 5 INBOUND, PILOT 6 OUTBOUND

Plate 214



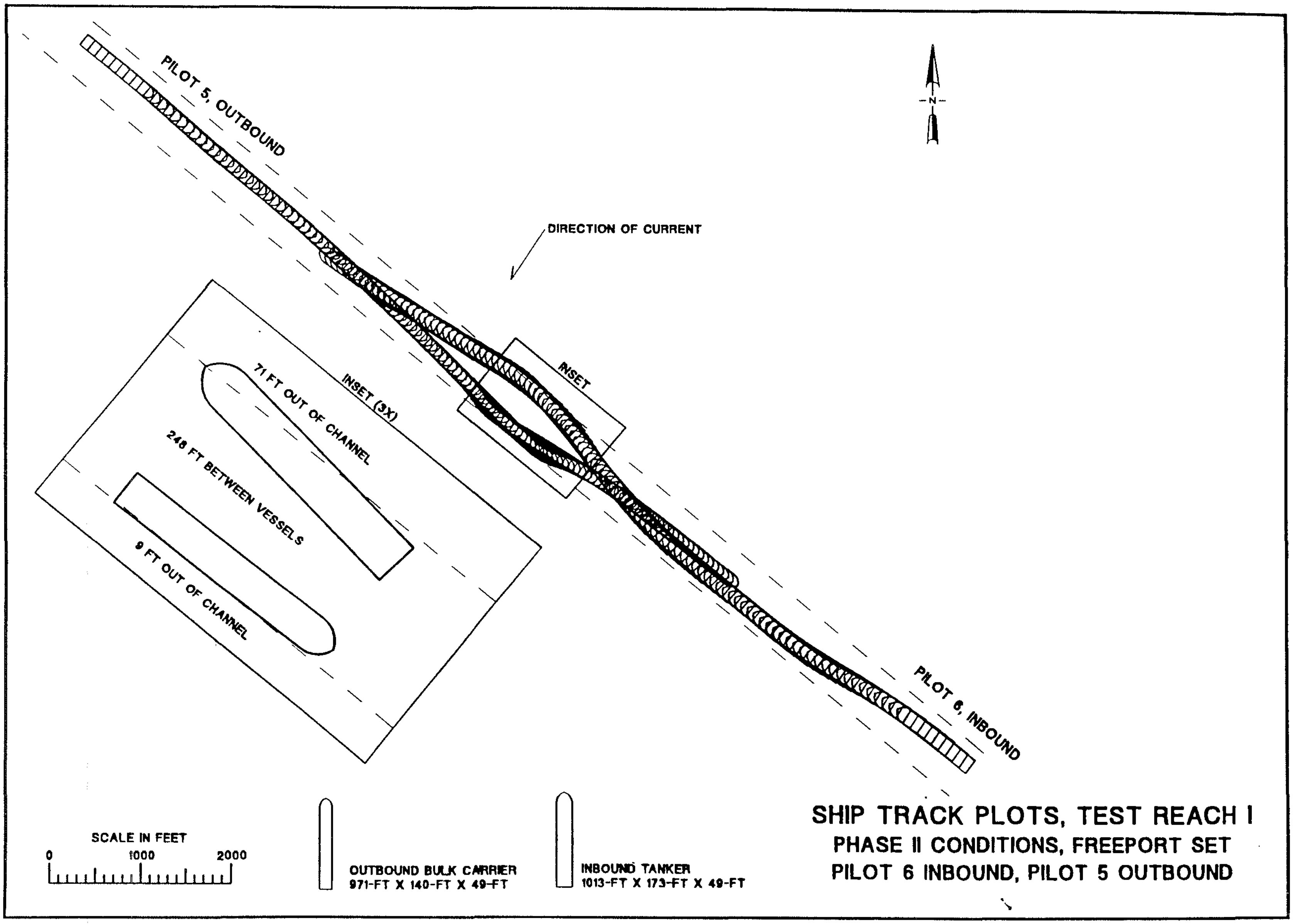
PILOT 5 INBOUND

PILOT 6 OUTBOUND

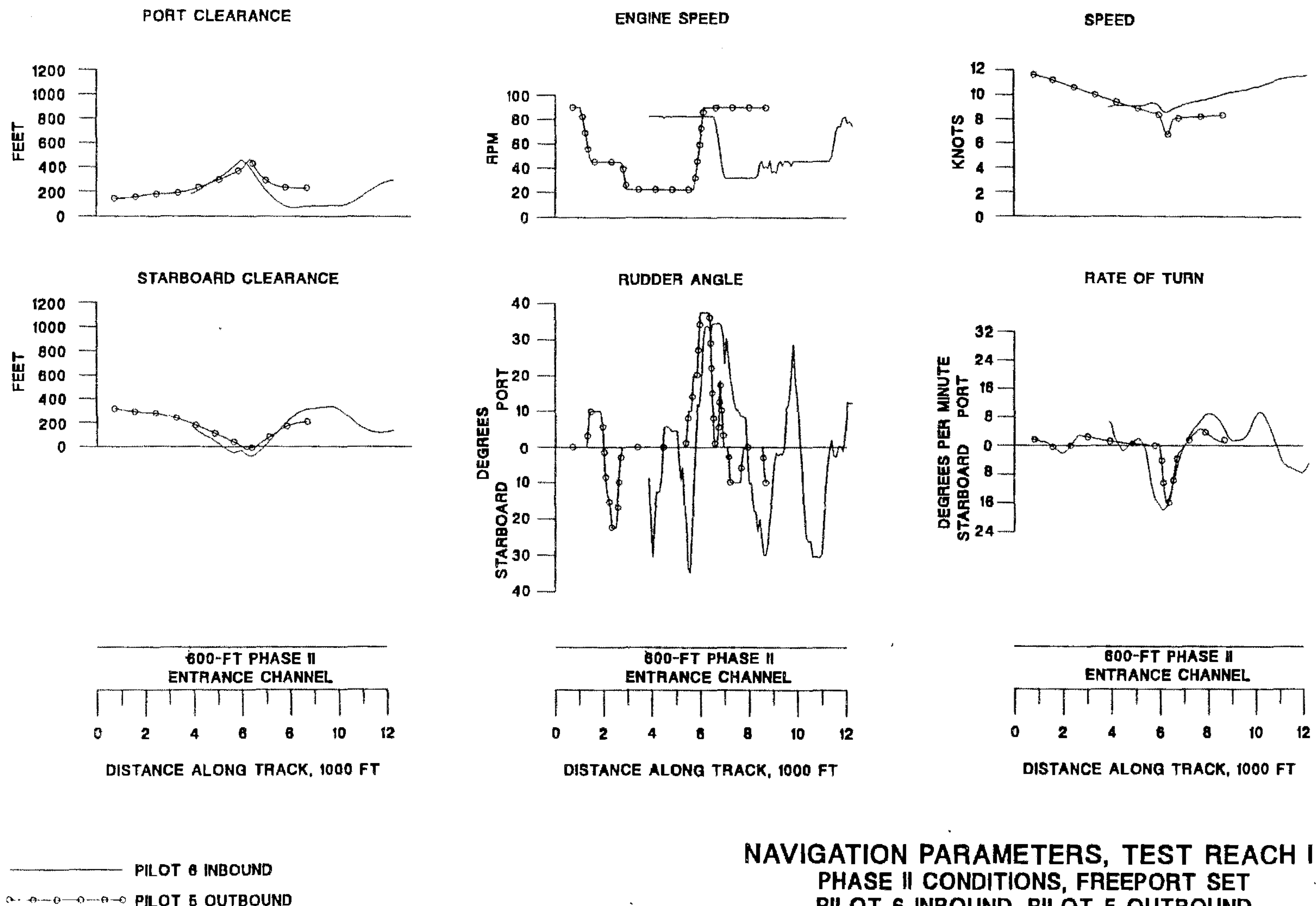
NAVIGATION PARAMETERS, TEST REACH I

PHASE II CONDITIONS, FREEPORT SET

PILOT 5 INBOUND, PILOT 6 OUTBOUND



SHIP TRACK PLOTS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND



NAVIGATION PARAMETERS, TEST REACH I
PHASE II CONDITIONS, FREEPORT SET
PILOT 6 INBOUND, PILOT 5 OUTBOUND

REPORT DOCUMENTATION PAGE

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Dennis W. Webb

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The Houston/Galveston Navigation Channels are located along the Gulf of Mexico Coast in eastern Texas. These channels include the Entrance Channels, the Bar Channels (Bolivar Roads Area), Galveston Ship Channel, Texas City Channel, the Gulf Intracoastal Waterway (GIWW), and the Houston Ship Channel (HSC), which branches off the Bolivar Roads Channel, traverses Galveston Bay, and ends in Houston.

The existing Entrance Channels are 42 ft deep and 800 ft wide. Phase I and Phase II of a proposed improvement project will deepen them to 47 ft and 52 ft, respectively. The Phase I and II Entrance Channels will be extended into the Gulf of Mexico to naturally deep water. The Galveston Ship Channel is presently 40 ft deep and 1,100 ft wide. Phases I and II of the proposed improvements will deepen the channel to 45 and 50 ft, respectively, while decreasing the width to 450 and 550 ft, respectively.

The U.S. Army Engineer Waterways Experiment Station conducted a navigation study to evaluate the effects of the proposed improvements on navigation. This study was conducted at WES using a "real-time" ship simulator.

14. SUBJECT TERMS
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Galveston Ship Channel
Houston Ship Channel
Ship simulation
Ship/ship interaction

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