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Report No. CG-D-10-90

The Effect of Ship Inherent Controllability on Piloted Performance: The Simulator Experiment

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INTERIM REPORT
JUNE 1990

Prepared for:

U.S. Coast Guard
Research and Development Center
Avery Point
Groton, Connecticut 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering, Logistics, and Development
Washington, DC 20593-0001

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Technical Report Documentation Page

1. Report No. CG-D-10-90	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle The Effect of Ship Inherent Controllability on Piloted Performance: The Simulator Experiment		5. Report Date October 1990
		6. Performing Organization Code
7. Author(s) M.W. Smith, J. Mazurkiewicz, and W.K. Brown		8. Performing Organization Report No. R&DC 16/90
9. Performing Organization Name and Address Ship Analytics, Inc. North Stonington Professional Center North Stonington, CT 06359		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTG23-86-20030
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Office of Engineering, Logistics, and Development Washington, DC 20593		13. Type of Report and Period Covered Interim Report
		14. Sponsoring Agency Code G-ER

15. Supplementary Notes This work was conducted as part of Project 2703, Waterway Performance, Design and Evaluation. R&DC Project Manager is Dr. Marc B. Mandler, 203-441-2615.

16. Abstract

The simulator experiment reported here is a component of the USCG Waterway Performance, Design and Evaluation Study, and was done for the development of a procedure to predict performance or risk in a waterway from the characteristics of user traffic.

A sample of seven commercial ships, ranging in size from a 33,000 deadweight ton (dwt) bulker to a 250,000 dwt tanker, made multiple transits, under similar channel and environmental conditions, controlled by commercial pilots, in a experiment conducted at the simulator at the USCG Academy in New London, Connecticut.

A preliminary analysis that found that piloted performance data grouped over all transits for a given ship varied as expected with ship size (displacement), but was not sensitive to controllability indices. A more detailed analysis by individual runs found that performance was sensitive to these indices.

The final analysis and the presentation of predictive formulas appears in an accompanying report entitled, "The Effect of Ship Inherent Controllability on Piloted Performance: The Evaluation and Prediction" by J. Mazurkiewicz and M.S. Smith.

17. Key Words Marine simulation, man-in-the-loop simulation, ship inherent maneuverability, piloted maneuverability, risk assessment, restricted waterways		18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161	
19. Security Classif (of this report) UNCLASSIFIED	20. Security Classif (of this page) UNCLASSIFIED	21. No. of Pages	22. Price

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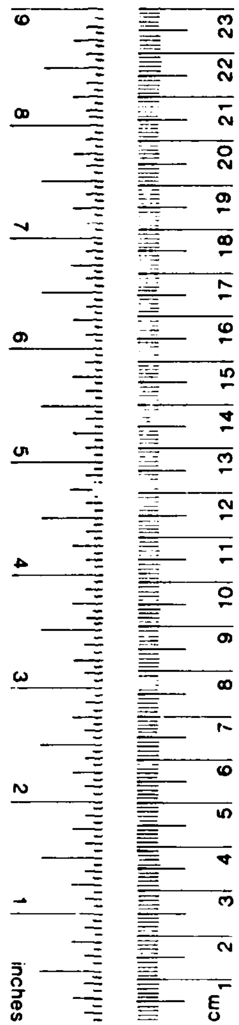
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

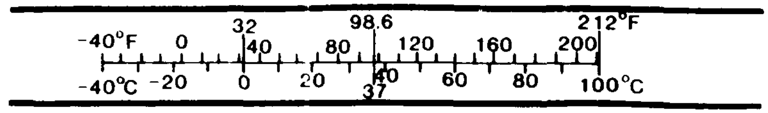
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures. Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

INTRODUCTION

The United States Coast Guard (USCG) has a requirement for a methodology that will predict ship performance in restricted waterways from the known characteristics of user traffic. The general approach being used to develop this methodology is as follows:

- Select a sample of large, commercial ships that are representative of the population of such ships on a number of parameters describing their size and controllability
- Collect a sample of performance data for these ships on the real-time man-in-the-loop shiphandling simulator at the USCG Academy in New London, Connecticut
- Use these data to develop a set of formulas that will predict the relation between ship parameters and performance in a waterway
- Incorporate these formulas in the Waterway Systems Design Manual

The first two steps are described in this report.

SHIPS AND SHIP PARAMETERS

The seven "ships" were selected to meet a number of criteria. Direction from the USCG was that they range in size up to 225,000 deadweight tons (dwt), with a preference for the inclusion of a 150,000 dwt bulker carrier. In keeping with the overall content of the Waterway Study, all the ships were of a type and size that would confine them to a dredged channel in restricted waterways and that would require a licensed, commercial pilot. Because the intended data analysis required that they be describable by common parameters, they all had conventional hulls and were allowed no external maneuvering assistance. The ships included the following: a 33,000 dwt bulk carrier, a 1000-foot Great Lakes ore carrier, a 76,000 dwt bulk carrier, three versions of a 150,000 dwt bulk carrier (varying in rudder effectiveness), and a 250,000 dwt tanker.

In designing the experiment, a variety of size and inherent controllability qualities were considered. Size parameters included displacement in long tons, length between perpendiculars, beam, and draft. A variety of parameters of maneuverability available in the literature were examined. Those used in the design of the experiment included a non-dimensional tactical diameter, calculated from the turning circle, and the Nomoto parameters, steering quality indices calculated from zig-zag maneuvers. Earlier USCG-sponsored research provided data on a sample of commercial ships that were used to ensure that the experimental ships represented the population of real-world ships on the parameters of interest.

DESIGN AND CONDUCT OF THE EXPERIMENT

In order to meet the experimental objective of measuring the contribution of the ship to over-all performance in restricted waterways, it was necessary to design an appropriate context of waterway and piloting conditions. All the ships were run in a narrow channel, outlined by buoys, with a single 35° turn. To add a realistic level of difficulty, there was a wind and current that varied within the run (but was the same between runs). Because the ships varied so much in size, the width of the channel was adjusted to each ship. Because channel width is a critical factor in the risk represented by ship size, channel width was treated as an experimental variable by running one mid-sized ship in three different widths of channel. Commercial pilots, experienced with the particular ship size, each made multiple runs with the ships assigned to him. Over all, 16 runs were made with each ship.

In anticipation of the planned analysis that would look for a dependence of the piloted maneuvers on the inherent controllability of the ships, the transit conditions and pilot instructions were planned to sample the maneuvers needed in a narrow channel. Each run was initialized with the ship to the right of the channel, approximately two nautical miles below the turn, with its heading equal to the course of the channel. The pilot was instructed to bring the ship to the centerline, to trackkeep until preparation for the turn, to make the turn by his own strategy, to bring the ship back to the centerline, and to trackkeep again with different wind and current conditions. These component maneuvers played an important part in the results and analysis.

PRELIMINARY ANALYSIS AND RESULTS

The analyses were begun using the techniques that are the bases of the Waterway Systems Design Manual's quantitative procedures. Group performance for a particular ship was represented by the crosstrack distribution of the 16 ship tracks for the length of the transit. The first examination concentrated on the most difficult and highest risk regions, turn and turn recovery. In those regions, there was a straightforward relation between ship displacement and crosstrack distance from the centerline, but there was not one between inherent controllability and distance. It was concluded that earlier procedures were not sufficiently sensitive and other methods were explored. Data for each single pilot's multiple runs with each ship showed that the pilots differed in their strategies and therefore in their tracks, interfering with a simple relation between ship characteristics and tracks.

For maximum sensitivity, each individual run was examined and, in each, the component maneuvers were identified and isolated. The maximum crosstrack distance from the centerline achieved during each maneuver was selected and these values were used to produce new distributions to represent each ship's performance in the channel. These distributions were used in the final analyses to develop the required procedures.

EVALUATION AND PREDICTION OF PILOTED PERFORMANCE

The further analyses and the resulting quantitative formulas are described in an accompanying report, "The Effect of Ship Inherent Controllability on Piloted Performance: Evaluation and Prediction," (Mazurkiewicz and Smith, in preparation). This second report describes the examination of candidate ship parameters to identify those which correlate best with the selected representations of piloted performance. The selected measures of ship characteristics and of piloted performance were used to develop regression models describing the relations for each of the component maneuvers.

REVISION OF THE DESIGN MANUAL

The last step in the development of a procedure to predict performance and risk in restricted waterways from the known characteristics of user traffic will be the incorporation of the new formulas and related findings in a revision of the "Short Range Aids to Navigation Systems Design Manual for Restricted Waterways," (Smith et al., 1985). As of this writing this revision is planned for calendar year 1991. This revision will allow district system designers to examine the effects of ships up to a maximum size to be expected in restricted waterways. In addition, the greater sensitivity provided by the inclusion in the process of parameters of ship controllability will allow a more confident use of risk management procedures involving the ship.

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Section 1

INTRODUCTION

1.1 SHIP PERFORMANCE IN RESTRICTED WATERWAYS

The United States Coast Guard (USCG) requires a methodology that predicts ship performance in restricted waterways from the known characteristics of expected traffic. This report describes a simulator experiment evaluating the performance of a sample of large commercial ships in narrow channels. The data from this experiment were used to develop a methodology that is presented in the accompanying report entitled, "The Effect of Ship Inherent Controllability on Piloted Performance: Evaluation and Prediction" (Mazurkiewicz and Smith, in preparation).

As an overview of the experiment reported here, the ships selected were large, commercial, conventionally-hulled ships, ranging in size from 33,000 deadweight tons (dwt) to 250,000 dwt. Ship displacement and indices of ship inherent maneuverability qualities served as independent variables during the experimental design and the data analyses. The "ships" were compared in transits of similar waterways under the control of qualified commercial pilots in an experiment conducted at the shiphandling simulator at the USCG Academy in New London, Connecticut. These piloted runs provided a variety of performance measures to serve as dependent variables for the data analyses.

After a preliminary examination and analysis, described in the present report, the data were used in an extensive analysis described in the later report (Mazurkiewicz and Smith, in preparation). In the later steps the empirically-measured relations between restricted waterway performance and ship characteristics were used generally to develop formulas that can be used to predict the performance of ships not included in the experiment.

1.2 SHIP PERFORMANCE IN THE WATERWAY PERFORMANCE, DESIGN AND EVALUATION STUDY

The efforts described in these two reports are components of the USCG Waterway Performance, Design and Evaluation Study. The Waterway Study has included previous analyses of the contribution of the ship to performance in restricted waterways. Earlier experiments have compared the performance of three sizes of tankers up to 80,000 dwt (Bertsche et al, 1981; Marino et al, 1984). Performance data from these experiments were used in the "Short Range Aids to Navigation Systems Design Manual for Restricted Waterways" (Smith et al., 1985) to develop a ship size "correction factor." The correction factor allowed the generalization of the Design Manual's performance data, which were collected for a great variety of waterway conditions with a 30,000-dwt tanker, along a dimension of deadweight tonnage to other ship sizes.

The primary objective of the new effort is to replace that ship size correction factor. The advantage of the new procedure over the old will be the greater range of ship sizes, the specification of ships by a parameter(s) with more general application than deadweight tonnage, and the use of data collected within one experiment designed for the purpose. This final use of the data will be in a revision of the 1985 Design Manual, expected as of this writing in 1991.

The revised Design Manual, incorporating the findings of the present experiment, will provide the system designer with the following:

1. A refined aid system design and waterway evaluation process, allowing the calculation of performance measures for specific ships. It is not anticipated that there will be any qualitative differences in resulting aid system design, but associated quantitative values will be different.

2. An increased scope of the risk management processes suggested by the Design Manual. A more exact procedure for quantifying performance for specific ships will allow more accurate comparisons between the relative safety of transits by different ships and will more appropriately support decisions about the assignment of resources to waterways visited by them.

1.3 THE SHIP CONTROL AND NAVIGATION TRAINING SYSTEM (SCANTS)

The Ship Performance Experiment was run at the Ship Control and Navigation Training System (SCANTS) at the USCG Academy in New London, Connecticut. This simulator is one of a number built by Ship Analytics (SA) with the capacity to support both training and operational research. Its advantages for the present study include its compatibility with simulators used earlier in the project. The techniques used at SCANTS for scene generation, hydrodynamics, data collection and a variety of other functions are similar to those of its prototype, the USCG/SA simulator originally developed for this project in an earlier phase. The use of that prototype for the evaluation of waterway performance was supported by a Validation Experiment (Smith et al, 1984), comparing at-sea and simulator data under similar conditions. SCANTS is briefly described in Appendix A.

Section 2

SHIPS AND SHIP PARAMETERS IN THE DESIGN OF THE EXPERIMENT

2.1 OBJECTIVE

The primary objective of this experiment was to investigate the relative performance of a variety of ships subjected to the same environment. A number of factors were considered in selecting ship models to be used. General guidelines, also used in previous Waterway Study experiments, were that the ships be of types which normally require a licensed pilot in restricted waters, and that they have drafts which prohibit their passage outside channel boundaries. Since the focus of this experiment was the controllability of the ship itself, no outside aids controllability, such as tugs, were used. Since the intention was to iden.ify the ship parameters that would most effectively predict narrow channel performance, only conventionally - hulled ships, that were expected to be adequately described by the same parameters, were included.

The United States Coast Guard directed that ships of at least 225,000 dwt be included in the Study. This was based on the current interest in large deep-draft ships now calling on U.S. ports. The U.S. Army Corps of Engineers has made it their policy to dredge some channels to 40-50 feet in order to accommodate large ships. (See Appendix B.) Since interest in large ships is high, four of the seven ships chosen were large. Three ships included were smaller, both to ensure applicability of the findings to those that more frequently visit U.S. ports and to provide a wide range of parameter values for the purposes of the analyses.

2.2 SHIP SELECTION BY SIZE

Ships from the SA library of proprietary ship models were reviewed and candidate ships were tested off-line to compare their performance in standard maneuvers with each other and with published performance data. These ships, developed with different types of source data and for different objectives, were modified as needed to better represent published generic performance data for their types. After some preliminary consideration of the range of controllability these ships would provide, five ships were selected to represent the required size range. Their dimensions are summarized in Table 2-1 in order of their displacement (in long tons).

1. 33,000 Dead Weight Ton (dwt) Bulk Carrier. This ship was originally based on model tests conducted at the Stevens Institute for a Series 60 Class vessel. It was used at the Maritime Administration's (MARAD) Computer Aided Operations Research Facility (CAORF) at Kings Point, New York in a design study done for the Panama Canal Commission (D'Amico, 1985). For that study, it underwent extensive "validation," or comparison with specially-collected at-sea data.

Table 2-1: Physical dimensions and indices of controllability for selected ships

Ship (k dwt)	Displ. (k LT)	Length (ft)	Beam (ft)	Draft (ft)	Dt/L (1)	K' (2)	T' (3)
Bulker: 33	42	574	85	37	3.8	1.7	2.8
G.L. Ore Carrier: 1000'	78	990	105	28	3.2	1.0	1.8
Bulker: 76	86	855	106	40	3.3	2.1	4.1
Bulker: 150 (R)	171	915	145	52	2.8	2.8	5.3
Bulker: 150 (D)	171	915	145	52	3.0	8.1	21.4
Bulker: 150 (U)	171	915	145	52	2.4	1.8	2.1
Tanker: 250	283	1085	170	61	2.6	2.9	5.6

Ship: 1,000 deadweight tons
Displacement: 1,000 long tons
Length between perpendiculars: feet
Beam: feet
Draft: feet
(1) Non-dimensional tactical diameter
(2) Non-dimensional turning ability (from 10° /10° zig-zag tests)
(3) Non-dimensional quickness of response to helm (from 10° /10° zig-zag tests)

2. 1000-Foot Great Lakes Ore Carrier. This ship model was originally developed at the Stevens Institute, with partial data published by them (Eda et al, 1982). Such a vessel is designed with dimensions that can be accommodated by the Great Lakes and the associated rivers and locks. The model is used at the Maritime Training and Research Center (MTRC) in Toledo, Ohio where much of the work done involves Lakes shiphandlers.

3. 76,000 dwt Bulk Carrier. This ship was originally based on model tests conducted by N.H. Norrbin at the Swedish Maritime Research Center (SSPA). It was a second ship used at CAORF in the Panama study (D'Amico, 1985).

4. 150,000 dwt Bulker Collier. This ship is similar to one used at CAORF in design studies done for the United States Army Corps of Engineers, in support of dredging projects in Norfolk and Mobile (Williams et al, 1982; O'hara, 1984). It is included here because of USCG interest in a ship of such a draft. (See Appendix B.)

5. 250,000 dwt Tanker. The original model of this ship was used in a number of generic waterway experiments done for MARAD at CAORF. For the present experiment it was modified to match published ship model performance (Roseman, 1987). It is similar to a ship that was used in a simulator analysis of the requirements for deepwater ports done for the USCG (Cook et al, 1980). Note that the present and near-term expectation is that a very large crude carrier (VLCC) like this one would off-load or lighter offshore and be brought into a harbor by tugs. Its inclusion here, where the only allowance for its size is increased channel width, is meant only to provide an extreme point for the data analysis. It is not meant to offer any analysis of such operations with such a ship.

The experimental evaluation was done on the seven ships listed in Table 2-1. The development of three versions of the 150,000 dwt bulker, varying in controllability (the last three columns in Table 2-1), are discussed in Section 2.3 below.

2.3 SHIP SELECTION BY INHERENT CONTROLLABILITY

On the assumption that inherent controllability is a major factor in performance in narrow channels, the controllability of the experimental ships was a major consideration in the design of the experiment. The first requirement for the design was a review of the literature to identify a set of descriptive parameters for possible use. Narrowing the set of parameters to those most likely to be effective, required preliminary planning of the analysis described in the related report (Mazurkiewicz and Smith, in preparation). Earlier USCG-sponsored research was a valuable resource to the experimental design process, providing data on the controllability of a sample of 600 commercial ships (Barr et al, 1981; Landsburg et al, 1983; NKF Engineering, 1989). The experimental ships were selected and modified as required to represent the sample of real-world ships.

During the design of the experiment, some of the available ships were modified to extend the range of variations available and to allow the independent variation of size and controllability. For variation in controllability the original 150,000 dwt bulker, indicated by an "O" in Table 2-1, was joined by two "sister" ships: one with an upgraded rudder, indicated by a "U", and one with a degraded rudder, indicated by a "D". To provide variation in size, the original 150,000 dwt bulker and the 250,000 dwt tanker were made as similar in controllability as was consistent with published test data. The characteristics of these ships are discussed below.

The first example of a controllability index used to describe the experimental ships is the non-dimensional tactical diameter. Simply, this is the diameter of the ship's turning circle, divided by the ship's length in the same units. The final values for the experimental ships are presented in Table 2-1 and are plotted in Figure 2-1. In the figure non-dimensional tactical diameter is plotted against displacement, with a background of published data for a sample of commercial ships (Barr et al, 1981). This presentation shows that the experimental ships represent the densest part of the larger distribution, along both dimensions. The three symbols, representing experimental ships, arranged in a vertical stack are the three 150,000 dwt bulkers. (A brief description of the turning circle appears in Appendix C Pilot Briefing. The index is discussed in the accompanying report, Mazurkiewicz and Smith, in preparation.)

The primary effort in the design of the experiment used Nomoto's indices, calculated from zig-zag maneuvers (Nomoto, 1960). K' is a non-dimensional measure of turning ability; T' is a non-dimensional measure of quickness of response to the helm. Final values of these indices for the experimental ships are presented in the last two columns of Table 2-1 and are plotted in Figure 2-2. K' is plotted against T' with a background of published data for commercial ships (Barr et al, 1981; Landsburg et al., 1983; NFK Engineering, 1989). As a general interpretation of this plot, increased values of K' represent improved turning ability and increased values of T' represent slower response to the helm. The two experimental ships very close together in maneuverability are the original 150,000 dwt bulker and the 250,000 dwt tanker, two ships that differ considerably in size, as measured by displacement. The experimental ships in the far upper right hand corner is the 150,000 dwt bulker with the degraded rudder. From the figure it can be seen that the experimental ships represent a considerable range and generally the high risk portion of the distribution. (A brief description of the zig-zag maneuver appears in Appendix C Pilot Briefing. The indices are discussed in the accompanying report, Mazurkiewicz and Smith, in preparation.)

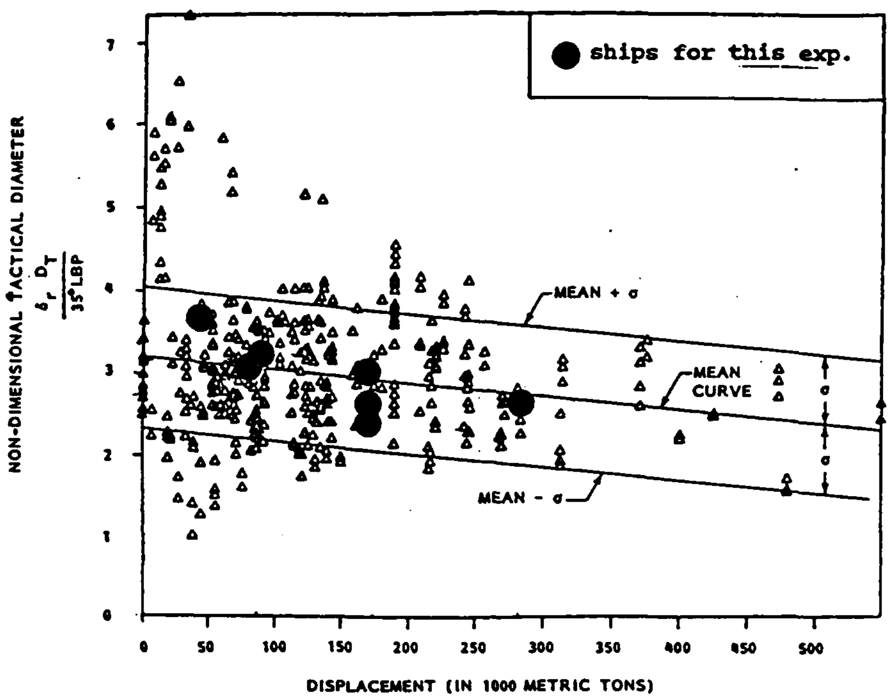

Figure 2-1. Distribution of ships by tactical diameter and displacement.

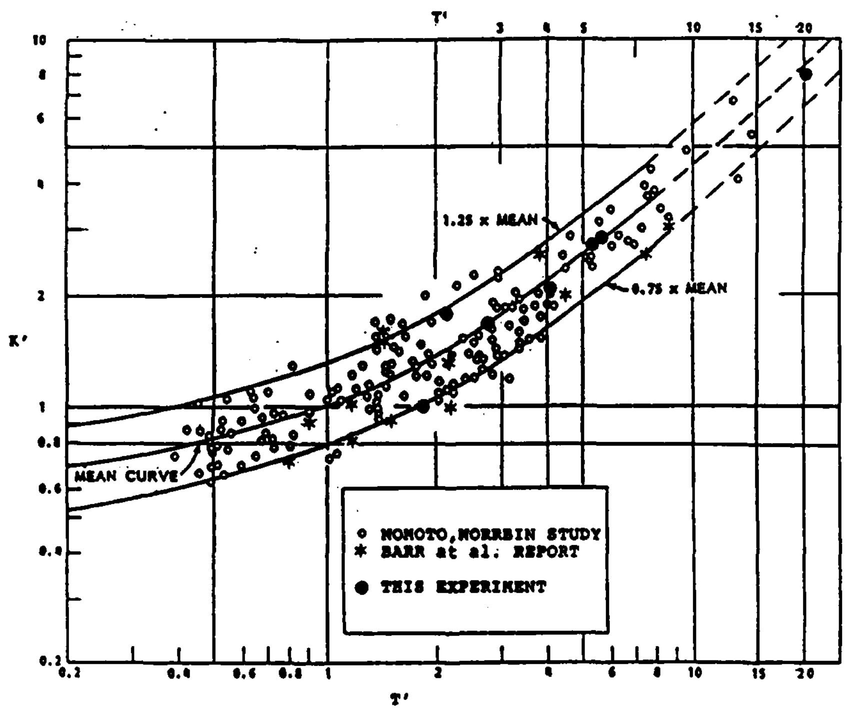

Figure 2-2. Distribution of ships by controllability indices, K' and T'.

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Section 3

DESIGN AND CONDUCT OF THE EXPERIMENT

3.1 THE DESIGN

A simulator experiment provides controlled conditions for the measurement of the performance of a ship/waterway/pilot system. The examination of the contribution of the ship to the performance of the total system is the objective of this experiment. The selection of the ships and their characteristics was described in Section 2. The ship characteristics provide the primary experimental "variable" and determine the principal differences among scenarios, as shown in Table 3-1.

In order to make a controlled evaluation of the contribution of the ship to the system, it was necessary to plan appropriate waterway and pilot contributions. With this experiment's emphasis on ship size, the channel width was an especially critical factor. Because the ships varied so greatly in over-all size, it was necessary to adjust the channel width for each ship. To provide performance data on the effect of channel width as an independent experimental variable, one mid-size ship transited three different widths of channel. The selected widths for each ship and the additional variations for one ship appear in Table 3-1. The logic of these widths is discussed in Section 3.2 below, along with additional discussion of the waterway conditions. The pilots and the procedures that influenced them are discussed in Sections 3.3 and 3.4.

3.2 THE WATERWAY AND THE ENVIRONMENT

3.2.1 Waterway Design

The waterway, adapted from one used in earlier Waterway Project experiments, consisted of two channel legs, having courses of 341 and 306 degrees true respectively, joined by a 35-degree, noncutoff turn to the left (Figure 3-1). The channel boundaries are marked by gated pairs of buoys with three buoys at the turn. Previous experiments have shown this arrangement to be an effective, self-contained aid system (Smith et al., 1985). Changes in channel width between scenarios were simulated by moving buoys farther out in a direction perpendicular to the centerline. The navigational channel existed only as the region between the buoys; that is, the channel was visual only, having no bank or sidewall effects nor any bottom effects. No land was visible, but all scenarios took place during daytime in unlimited visibility. In this way, pilots were given adequate information for navigating the waterway by the aids alone, without any additional information from bank effects or land-based objects.

3.2.2 Ship Size and Channel Width

Past research has shown that the relative widths of the ship and the channel affect the pilots' perceptions of their position in the channel and/or their standard of the precision needed; and, therefore, the resulting ship track performance (Marino, Smith, and Moynehan, 1984). The objective

Table 3-1: Conditions for Experimental Scenarios

Scenario	Ship	Displacement (Light tons)	Length (Feet)	Beam (Feet)	Draft (Feet)	Rudder	Channel Width (Feet)
1	33,000 dwt bulk carrier	42,072	574	85	37	regular	489
2	1,000 - foot Great Lakes ore carrier	77,500	990	105	28	regular	757
3	76,000 dwt bulk carrier	86,174	855	106	40	regular	685
4	150,000 dwt bulker (R)	171,240	915	145	52	regular	798
5	150,000 dwt bulker (D)	171,240	915	145	52	degraded	798
6	150,000 dwt bulker (U)	171,240	915	145	52	up-graded	798
7	250,000 dwt tanker	282,924	1085	170	65	regular	943
8	76,000 dwt bulk carrier	86,174	855	106	40	regular	543
9	76,000 dwt bulk carrier	86,174	855	106	40	regular	400

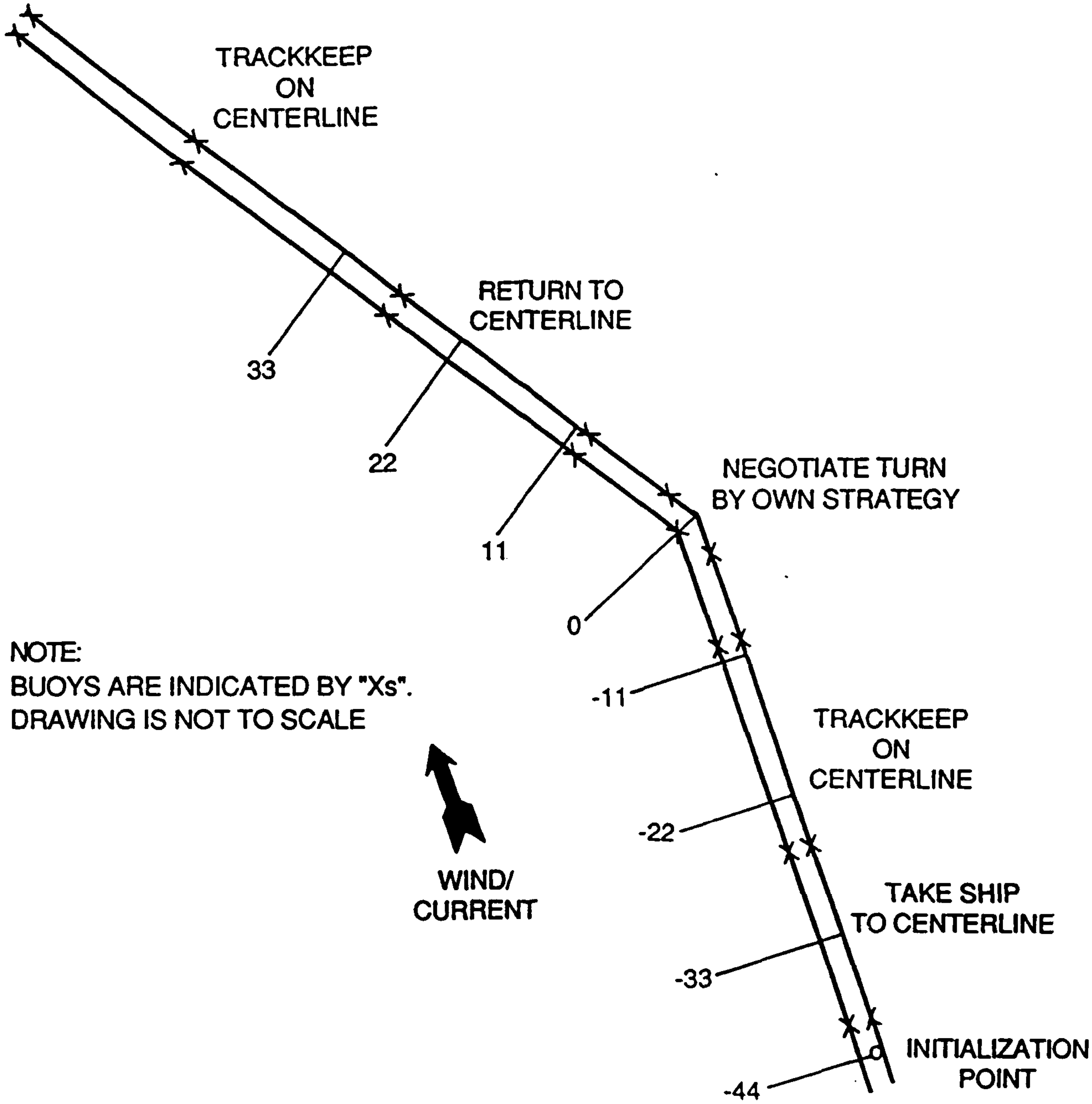

Figure 3-1: Maneuvering requirements and datalines

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of comparing performance as a function of ship size required that the channel size have a constant relationship to ship size in the pilots' subjective evaluation of the situation. Pilots in past experiments have not been very concerned with the amount of space available for recovery or trackkeeping, but they have been concerned with the amount of room available to make a relatively-severe 35-degree turn with a large ship. Therefore, it was assumed that for them the critical ship's width is not the ship's beam when it is perpendicular to the channel centerline, but the distance perpendicular to the channel centerline taken up by the ship when it is maneuvering to make the turn.

To find a baseline relationship between this maneuvering width and channel width, a sample of existing data (Gynther and Smith, 1989) for a very similar scenario was examined to find the maximum crab angle (the angle formed by the difference between the channel centerline and the ship's longitudinal axis) assumed by the ship during the transit. The maximum was 15 degrees at one ship's length before the turn apex. At that point the total channel width was 2.12 times the "swept path," or the width between the extreme points of the ship. In planning this new experiment, it was assumed that the ships would take the same track. The channel width for each ship in Scenarios 1 through 7 was 2.12 times the swept path when the ship assumed a position 15 degrees off the channel centerline. Inspection of the ships and their channels in Table 2-1 will show that the channel width calculated by this method was sensitive to both the beam and the length of the ships. Note that the unusual length of the Great Lakes ore carrier resulted in quite a wide channel. The channel width for the 150,000 dwt collier, which is shorter relative to its other dimensions, was not much greater.

Because the effect of channel width on piloted ship performance is a component of the relative risk factor computation (Smith et al., 1985), scenarios were added to allow the independent evaluation of this additional factor. As summarized in Table 3-1, Scenarios 8 and 9 were added, placing one of the ships, the 76,000 dwt bulk carrier, in two narrower channels than that calculated by the method above. The objective of evaluating the effect of the channel width in relation to ship size was met by running this ship in three channel widths: 685, 543, and 400 feet. This objective was given a lower priority in the experiment and these additional two scenarios were given only one half the number of replications (n=8) given the ship performance scenarios (n=16). The comparison of performance as a function of channel width for the same ship is to be used for a replacement of the channel width correction factor in the Design Manual (Mazurkiewicz and Smith, in preparation).

3.2.3 Environmental Effects

As in past experiments, there were variations in wind and current within the scenario. The effects used are illustrated in Figure 3-1 and in Appendix C Pilot Briefing. A gusting wind and decreasing current followed in Leg 1, contributing little to the difficulty of the transit. As the ship came around the turn, the wind and current were on the port quarter, increasing the difficulty of the recovery. The current continued to decrease, requiring frequent adjustment of the ship's heading to achieve and maintain a centerline track in Leg 2. The pilots were required to maintain a relatively slow speed, increasing the difficulty of the transit in this environment. The objectives of this level of difficulty were to ensure a "conservatism" in the resulting performance data. Test scenarios in an earlier experiment (Marino, Smith, and Bertsche, 1981) showed that these effects were necessary to measure differences among scenario conditions.

3.3 THE PILOTS

3.3.1 Pilot Qualifications

The shiphandlers were pilots with both federal and state licenses and with recent experience with commercial ships in narrow channels. The two groups who participated were as follows.

1. The Northeast Marine Pilots, Inc. with headquarters in Newport, Rhode Island, frequently handle ships up to approximately 80,000 dwt in their biggest harbor, Providence, Rhode Island. This group has participated in a number of project experiments, including the recent Radio Aids experiment at SCANTS (Gynther and Smith, 1989). For this experiment the four participating pilots were assigned to the three smallest ships, those comparable to their experience.

2. The Virginia Pilots Association, handle 150,000-dwt colliers loaded to 50 feet in several 600-foot wide channels. They handle ships as large as the 250,000 dwt tanker, but not loaded to a 65-foot draft in a channel. This group never before participated in this project, but they have participated heavily in port design experiments done at CAORF for the USACOE (Williams et al., 1982). Four pilots from this group, with experience most comparable to the experimental 150,000 dwt collier in the experimental channel, were assigned to the larger ships.

3.3.2 Pilot Briefing

As has been the case in every Waterway experiment, the pilots were briefed before they stepped onto the bridge, this time emphasizing the ship characteristics. The briefing package included "Pilot Cards" describing each of the ships to which the pilot had been assigned. Excerpts from the briefing package with complete Pilot Cards are included in Appendix C. Each Card included an illustration of the ship, the vessel particulars (physical dimensions), a table of maneuvering speeds, and the maneuvering characteristics. The last were specified by the turning circle, as required by USCG regulations, and the zig-zag maneuver, as recommended by the Society of Naval Architects and Marine Engineers (SNAME) (Landsburg et al., 1980). To ensure that the pilots were aware of the information available to them and to determine what they considered helpful, the experimenter went over the entire package before-hand, and discussed it during the day.

In the expectation that they might identify the parameters that would best predict the piloted performance of the experimental ships, the pilots were questioned as to what concepts they typically use to characterize a ship. All of them mentioned one or more of ships' physical dimensions--length, draft, and beam--as telling them what to expect of a ship's performance. They do not typically expect deadweight tonnage or displacement to predict performance. They use only the most general, qualitative terms to describe performance characteristics. All the pilots were familiar with turning circles and knew that they were posted on ship's bridges, but they all reported that they did not typically refer to them or make use of them: "there is not time." (A pilot from another association, who discussed the experiment by telephone but did not participate, reported that his group had recently adopted the non-dimensional tactical diameter in their practice.) Only one of the pilots had any previous familiarity with the zig-zag maneuver. That these pilots practice without the use of any quantitative parameters of controllability is consistent with the point made in the accompanying report (Mazurkiewicz and Smith, in preparation), that there is little agreement on standard maneuvers and indices in the engineering domain.

3.4 CONDUCT OF THE EXPERIMENT

3.4.1 The Events of the Experimental Day

1. The pilot's day began with the formal briefing outlined in Appendix C. The discussion included the ship characteristics, the "waterway," the maneuvering instructions, and an overview of the questions he would be asked during the course of the day. (There was no formal debriefing.)

2. The pilot was introduced to the bridge and did a familiarization run, using one of the ship models assigned to him. He was given the option of repeating the run or a part of it before continuing with the experimental conditions. The data from this run were not used in the analysis.

3. A pre-planned sequence of experimental scenarios followed. Each pilot did eight experimental runs on each of two days as described in Section 3.4.4.

3.4.2 Shiphandling Requirements

The transit requirements, illustrated in Figure 3-1, were designed to require a sequence of component maneuvers that could be examined in relative isolation. The instructions to the pilot are summarized along the right-hand side of the channel out-line. Each scenario was initiated with the ship inside the channel, to the right of the centerline, on a heading parallel to the course of the channel. The ship's speed through the water was 9 knots with a following wind and current. The pilot was asked to maneuver the ship to the centerline and trackkeep. The pilot negotiated the turn by his own strategy, changing the engine speed, if he thought it appropriate. After the turn, he brought the ship back to the centerline, with the varying wind and current on the port quarter. These instructions, as they were presented to the pilot, appear in Appendix C. The required maneuvers form the basis of the maneuvering regions discussed in some detail in Section 4 that follows.

3.4.3 Data Collection Techniques

During an experimental run, one of the simulator's computers recorded various performance parameters and environmental data at regular intervals. These data were later used in off-line analyses. Data recorded were of three general types:

1. Computer-Recorded Measures. The ship's crosstrack position as a function of alongtrack position was recorded as the ship transited the length of the channel. These measures form the primary data of the experiment. Analyses conducted using crosstrack position are discussed in Section 4. Other ship status descriptors recorded include speed, yaw rate, heading, course, rudder angle, and engine revolutions per minute.

2. Terminal-Entered Measures. The pilot's orders to the helmsman were recorded by the simulator operator at the operator's terminal. These orders included: course, rudder, and engine order telegraph. A computer program incorporated these comments into the file of data described above so that they could be referred to during data analysis.

3. Pilot's Subjective Reactions. The pilot's comments and reactions to all aspects of the simulation were noted by the researcher. A questionnaire was used to guide the discussions. This provided another source of data to use in evaluating the effectiveness of the simulation.

3.4.4 Replications

For the purposes of the data analysis, the maximum possible number of replications of each scenario was desirable. To derive the most benefit from each pilot, each made two runs with each of the ships assigned to him on each of the two days he was available. The planned sequence of runs for the experiment appears in Table 3-2. A sample sequence for one pilot appears in Table 3-3. (Note that the extra channel-width scenarios, 8 and 9, receive half the number of runs.)

With repeated runs for a single pilot, it was necessary to control the contribution of unwanted order effects: practice, fatigue, or carry-over. Table 3-1 shows a counterbalanced sequence of runs such that each scenario appears equally often in each position in each block of four ships, and equally often before and after every other scenario within the smaller/larger ship split. This counterbalancing is based on a design technique known as a "Latin Square" (Lindquist, 1953). The counterbalanced sequence makes it possible to either ignore any possible order effects, assuming that they would average out over scenarios, or to analyze for them as separate factors. (Preliminary analyses showed that there were no significant order effects and this possibility was not considered in the later steps of analysis.)

Table 3.2 Experimental Run Sequence

		DAY 1		DAY 2	
		MORNING	AFTERNOON	MORNING	AFTERNOON
	FAM	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
PILOTS	SMALLER SHIPS				
1	1	1 2 3 9	2 1 8 3	3 8 1 2	9 3 2 1
2	2	2 1 8 3	3 9 1 2	9 3 2 1	1 2 3 8
3	3	3 9 1 2	8 3 2 1	1 2 3 8	2 1 9 3
4	9	8 3 2 1	1 2 3 9	2 1 8 3	3 9 1 2
	LARGER SHIPS				
5	4	4 7 6 5	7 4 5 6	6 5 4 7	5 6 7 4
6	7	7 4 5 6	6 5 4 7	5 6 7 4	4 7 6 5
7	6	6 5 4 7	5 6 7 4	4 7 6 5	7 4 5 6
8	5	5 6 7 4	4 7 6 5	7 4 5 6	6 5 4 7

Table 3.3 Sample Sequence of Scenarios: Pilot 1

	MORNING				AFTERNOON			
FAM	1	2	3	4	1	2	3	4
	DAY 1							
1 33K bulker	1 33K bulker	2 1,000-F Laker	3 76K bulker	9 400F channel	2 1,000-F Laker	1 33K bulker	8 543F channel	3 76K bulker
	DAY 2							
	3 76K bulker	8 543F channel	1 33K bulker	2 1,000-F Laker	9 400F channel	3 76K bulker	2 1,000-F Laker	1 33K bulker

3.5 SUMMARY TO THIS POINT

The following is a summary of the design and conduct of the experiment that produced the data discussed in the following section.

1. The primary differences among the scenarios were in the characteristics of the seven ships, which were specified by both size and controllability parameters. These characteristics are summarized in Table 2-1.

2. The ships were run in a narrow waterway with adequate visual aids and moderate environmental effects. The channel is illustrated in Figure 3-1 and in Appendix C.

3. Because of the extended range of ship sizes, the channel width was adjusted for each ship. Channel width was also treated as an experimental variable with one mid-size ship run in two additional widths of channel. The ship-size/channel-width combinations that were run are summarized in Table 3-1.

4. Commercial pilots, with qualifications appropriate to the ships and operations simulated, participated as shiphandlers.

5. The waterway and the shiphandling requirements were designed to sample the maneuvers that make up a transit of a narrow channel. These requirements are summarized in Figure 3-1 and in Appendix C.

6. The primary data were the crosstrack distance of the ship's center of gravity as it moved alongtrack during the transit. A variety of other ship-status and human-factor data were also collected and were available to support the analysis described in Section 4 and the accompanying report (Mazurkiewicz and Smith, in preparation).

7. Each of the eight pilots made multiple runs with the ships and channel widths assigned to him. In total, there were 16 replications for each ship size and eight replications of each of the two additional channel widths for one of the ships. The sequence of replications is shown in Table 3-2.

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Section 4

PRELIMINARY ANALYSES AND RESULTS

4.1 OVERVIEW

The analyses were begun using techniques that had been developed over the numerous experiments of the Waterway Performance, Design and Evaluation Study, as had been proposed in the Presimulation Report (Brown, Mazurkiewicz, and Smith, 1989). The primary data have generally been the crosstrack distribution of the group's ship tracks for each set of scenario conditions, distributions which form the bases of the Design Manual's quantitative procedures (Smith et al., 1985). Because the findings of the present experiment are intended to be incorporated into those procedures, the previously-employed techniques were an appropriate starting point.

Examination of group data showed the presence of performance trends with ship size (displacement). However, these analytical procedures using grouped data were not sensitive enough to distinguish performance trends with controllability. A number of more sensitive methods of examining data were identified and are described here. Techniques and results discussed in this section are intended as preparation for the final analysis and results presented in the follow-on to this report (Mazurkiewicz and Smith, in preparation).

4.2 EXAMINATION OF GROUP DATA

4.2.1 The Methodology

Basic measures used to describe performance in the experimental waterway are calculated following a simulator run, using data from "history" files recorded in real time during a run. Values calculated provide measures of crosstrack position (distance from the ship's center of gravity to the channel centerline), heading, rudder angle, speed, etc. as functions of alongtrack position. Alongtrack position is defined by a "data line" number. Data lines are imaginary lines spaced at 475-foot intervals along the length of the experimental waterway and oriented perpendicular to the channel centerline, as illustrated in Figure 3-1. Parameters of interest are sampled as the ship "crosses" each data line.

Measures of crosstrack position for all transits of a particular scenario were combined to obtain the mean (MN) and standard deviation (SD) values over the length of the waterway, indicating general performance for that scenario. This evaluation is based on the assumption that an infinite number of runs would form a normal distribution in terms of ship crosstrack position. MN and SD values by data line for all scenarios are provided in Appendix D.

Values for the relative risk factor (RRF) were calculated by the method shown in Table 4-1, which is reproduced from the Design Manual (Smith et al., 1985; Bertsche et al., 1982). The Design Manual bases its RRF calculation on empirical values of the MN, SD, and nominal values of the

TABLE 4-1. SAMPLE CALCULATION OF RELATIVE RISK FACTOR (RRF) IN THE RECOVERY REGION

SHIP PARAMETERS	
Ship size	30,000 deadweight tons
Ship length	590 feet
Ship beam	85 feet
Crosstrack current velocity	0.25 knots
Transit speed	6 knots
B' (feet)	54.79 feet
CHANNEL PARAMETERS	
Channel width	500 feet
SAMPLE CALCULATION OF RRF: Crab angle, 2-5 degrees; gated aids; day	
[W/2) - (MN) - (B')]/(SD) = (NS)	reminder:
[(500/2) - (97) - (54.79)]/(34) = (2.89)	W: channel width
	MN: mean
	B': adjusted beam/2
[(W/2) + (MN) - (B')]/(SD) = (NP)	SD: standard deviation
[(500/2) + (97) - (54.79)]/(34) = (8.59)	NS: SDs to starboard
	NP: SDs to port
	PS: prob to starboard
(PS) + (PP) = (RRF)	PP: prob to port
(0.0019) + (0.0000) = (0.0019)	RRF: relative risk factor

adjusted beam. The "adjusted beam" is the swept path of the ship or the crosstrack distance between the extreme points when the ship assumes a crab angle to the channel course. In an effort to expose even subtle differences between scenarios in this experiment, the adjusted beam was calculated using actual data. The adjusted beam for a particular pilot for a scenario was calculated from the average ship heading at each data line over the runs (usually 4) made by the pilot. This value was then used in calculating the RRF. Unlike the method used in past experiments, the RRF was calculated for all data lines over the length of the waterway, allowing accurate identification of regions having the highest RRFs. Values calculated are provided in Appendix D.

4.2.2 Sample Findings From Group Data

This experiment required that performance results for all ships be compared on the basis of ship size, controllability, or other identifying characteristics. (The characteristics of the ships are summarized in Table 2-1.) As an initial step in this process, group data for ships having varying displacements were compared; that is, the two additional versions of the 150,000 dwt bulker were excluded. Figure 4-1 shows the MN of the ship tracks for five ships: the 33,000 dwt bulker, the 1000-ft Great Lakes ore carrier, the 76,000 dwt bulker, the 150,000 dwt bulker (regular rudder), and the 250,000 dwt tanker. Since the region surrounding the turn has been shown to have the highest risk of grounding (Smith et al., 1985), only this area is plotted here for the purpose of this discussion. The legend in the figure lists the ships in order by displacement. In the region immediately following the turn (approximately Data Line 5), a definite trend with displacement is apparent. Distance from the channel centerline is proportional to displacement in this region.

Displacement, however, is not necessarily equivalent to controllability as can be seen in the Table 2-1. If crosstrack position is taken as a measure indicative of how well the pilot is able to control the ship, one would expect a similar trend with some measure of controllability. Figure 4-2 shows the MN ship tracks as shown in Figure 4-1, with the addition of the tracks for the 150,000 dwt bulker, upgraded-rudder version and degraded-rudder version. A trend with controllability would be most visible in the three versions of the 150,000 dwt bulker. In the region where the trend with displacement was identified, no clear trend with ship controllability is apparent. In fact, ship tracks from the upgraded- and degraded-rudder versions of the 150,000 dwt bulker are quite different from the other ship tracks, suggesting that these ships may have been handled differently by the pilots or that some other factors are involved.

Examination of corresponding SD data in Figure 4-3 shows very high values for the upgraded- and degraded-rudder versions in the region following the turn. As was the case in Figure 4-1, the ships of varying displacement show a trend toward larger SD values with larger displacement. However, in terms of controllability, no trend is immediately apparent. That the ship with the poorest controllability characteristics would have the largest SD is not surprising; however, some of the smallest SD values belong to a ship (the 1000-foot ore carrier) with poorer-than-average controllability indices (see Table 2-1).

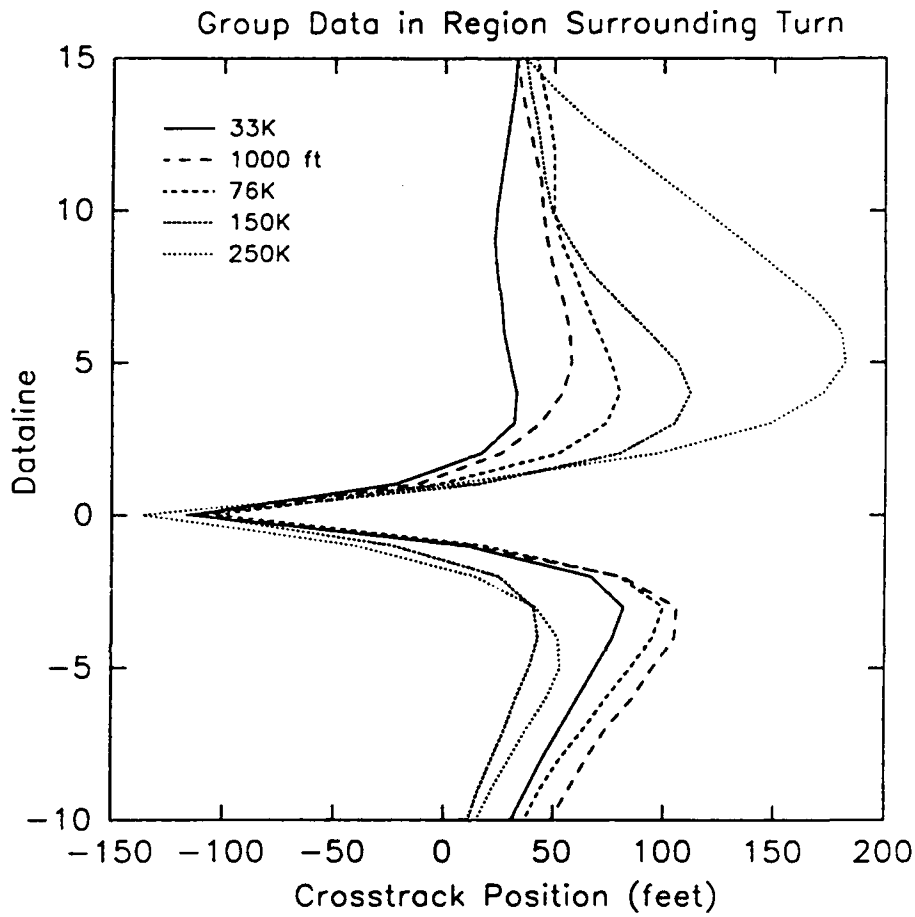

Figure 4-1: Means for five ships differing in displacement

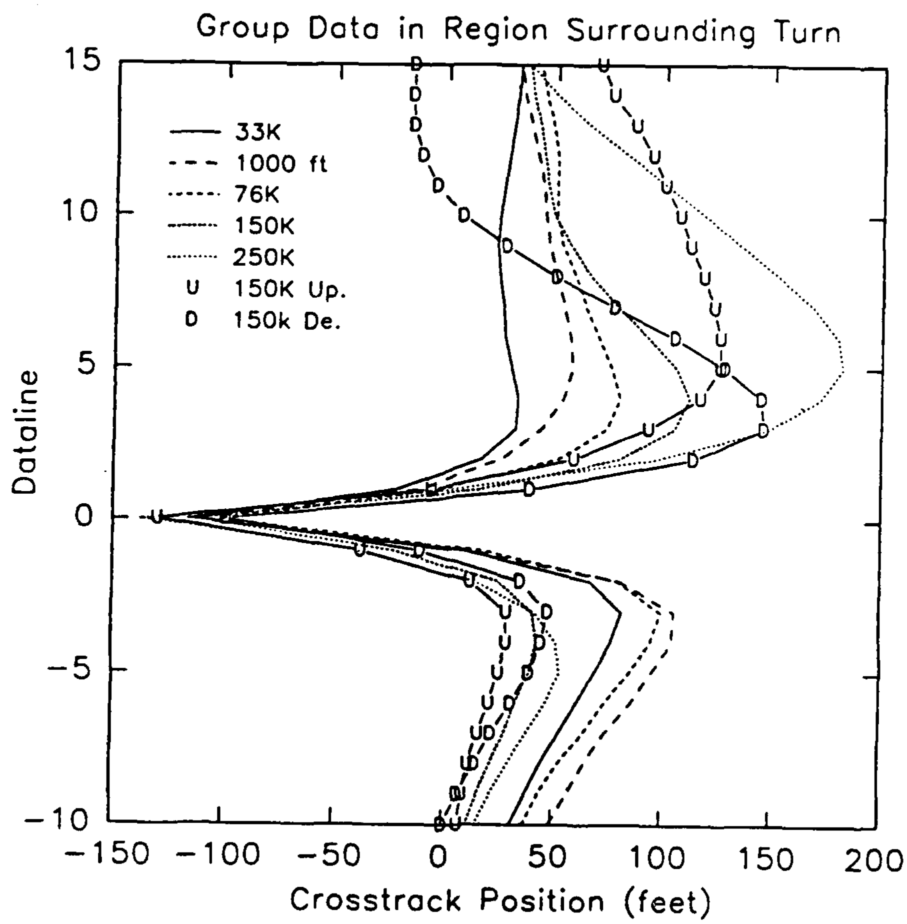

Figure 4-2: Means for seven ships differing in displacement and controllability

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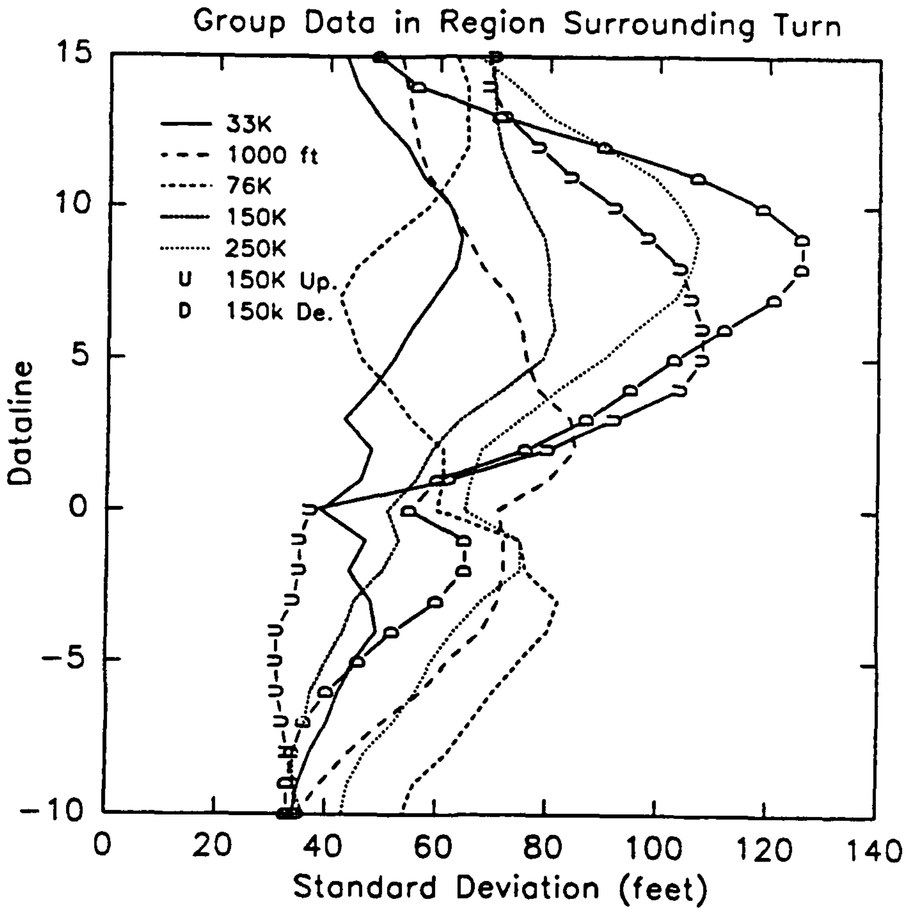

Figure 4-3: **Standard deviations for seven ships differing in displacement and controllability**

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Empirically-calculated RRF values, listed in Appendix D and plotted in Figure 4-4, indicate that the areas of the highest RRF values are at the turn apex (Data Line 0) and over a number of data lines following the turn (Data Lines 3-7, approximately). An interesting feature of the data shown in Figure 4-4, is that some ships exhibit their highest RRF values in the turn while others show high values in the region following the turn. This may be due to different handling techniques used with different ships, or to the ships' inherent characteristics. As in Figures 4-2 and 4-3, no obvious trend with controllability was found in the group RRF data.

4.2.3 Sample Finding from Data Grouped by Pilot

Since the overall group data proved to be insensitive to ship differences due to controllability, other methods of examining the data were investigated. Since each pilot had made four runs with each ship, it was possible to calculate the crosstrack MN, SD, and RRF values for each pilot for each ship. Using these data, ships could be compared without the potentially-complicating effect of pilot differences. This technique could not provide the final analysis tool because all ships had not been driven by the same pilot. (See Table 3-2.)

Data grouped by pilot were examined for differences between pilots and for each pilot's contribution to the overall statistics for a ship. As an example, Figure 4-5 shows MN ship tracks for the 33,000 dwt tanker for each pilot, along with the overall MN track. An interesting feature of these data is that the MN tracks of three of the pilots are fairly similar while the fourth is quite different. The MN ship track for Pilot 3 (P3) is very close to the channel centerline before the turn and immediately after the turn, but is farther from the centerline than the other ship tracks in the area from Data Lines 7 to 12. Overall, Pilot 3's MN track is good in terms of distance from the centerline of the channel, but it is different in form from the other tracks and this is reflected in the overall MN track (and, of course, the SD). One explanation for the variation among pilots shown in Figure 4-5, is that pilots may use different techniques in piloting the ships, especially in making turns. For instance, Pilot 3 uses a technique that does not involve swinging wide to the right in preparation for the turn as the other three pilots do. The turn recovery technique employed by Pilot 3 also appears to be different than that used by the other pilots.

MN tracks made with the 250,000 dwt tanker by four pilots along with the overall MN track are shown in Figure 4-6. As in Figure 4-5, in the region following the turn, three MN tracks are very similar in terms of distance from the channel centerline, while one is much closer. However, unlike Figure 4-5, the patterns of the four ship tracks following the turn are very similar. In this case it is difficult to identify any differences in piloting techniques, but the resulting tracks differ greatly. Looking at runs in this way, grouped by pilot, supports a conclusion that averaging all runs for a particular ship incorporates pilot differences and makes identification of differences due strictly to ship characteristics difficult.

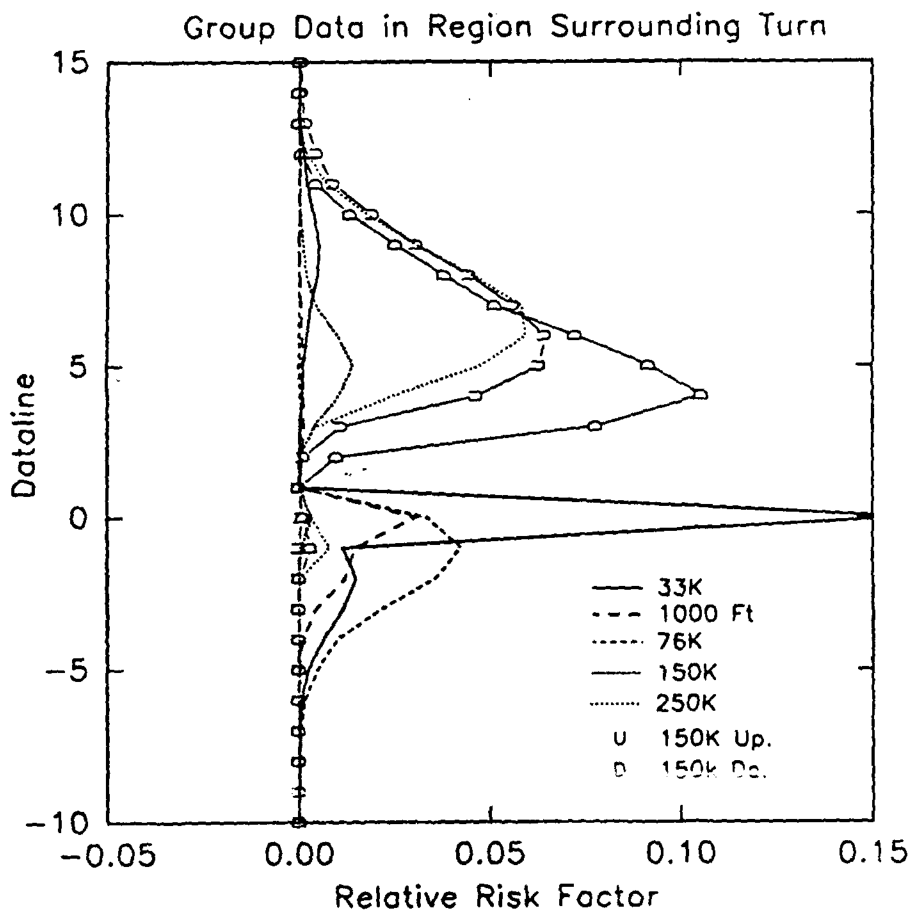

Figure 4-4: Empirical relative risk factor for seven ships

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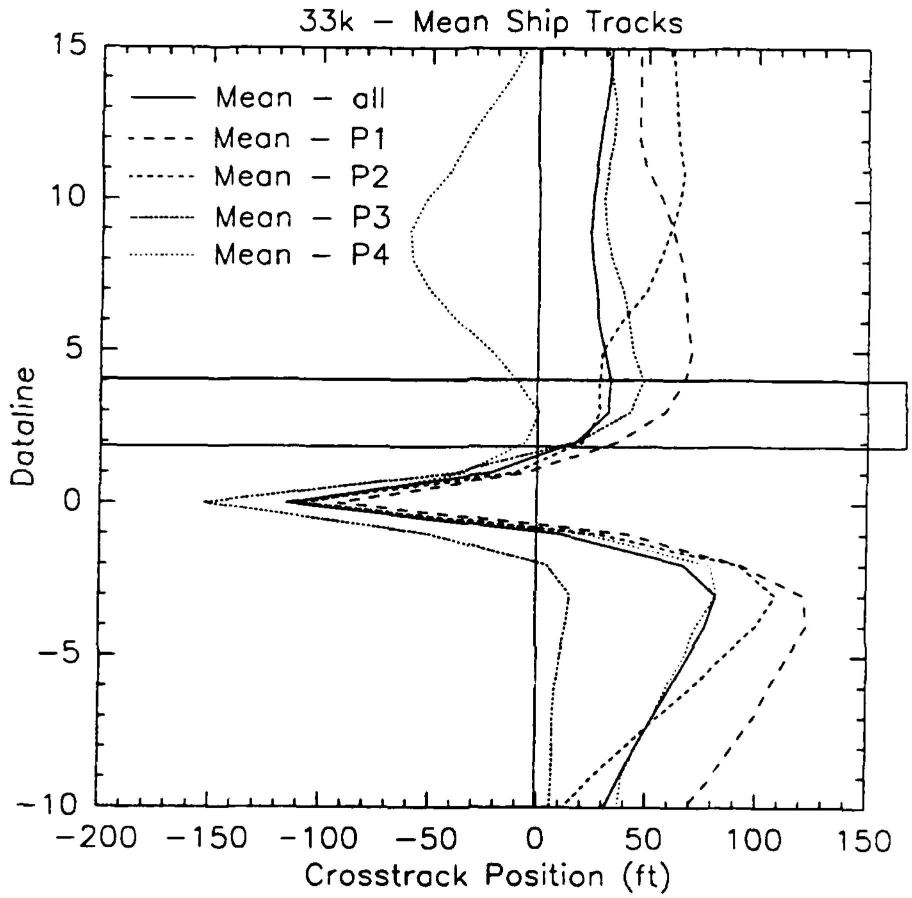

Figure 4-5: Group mean (n=16) and pilot mean (n=4) for 33,000 dwt bulker

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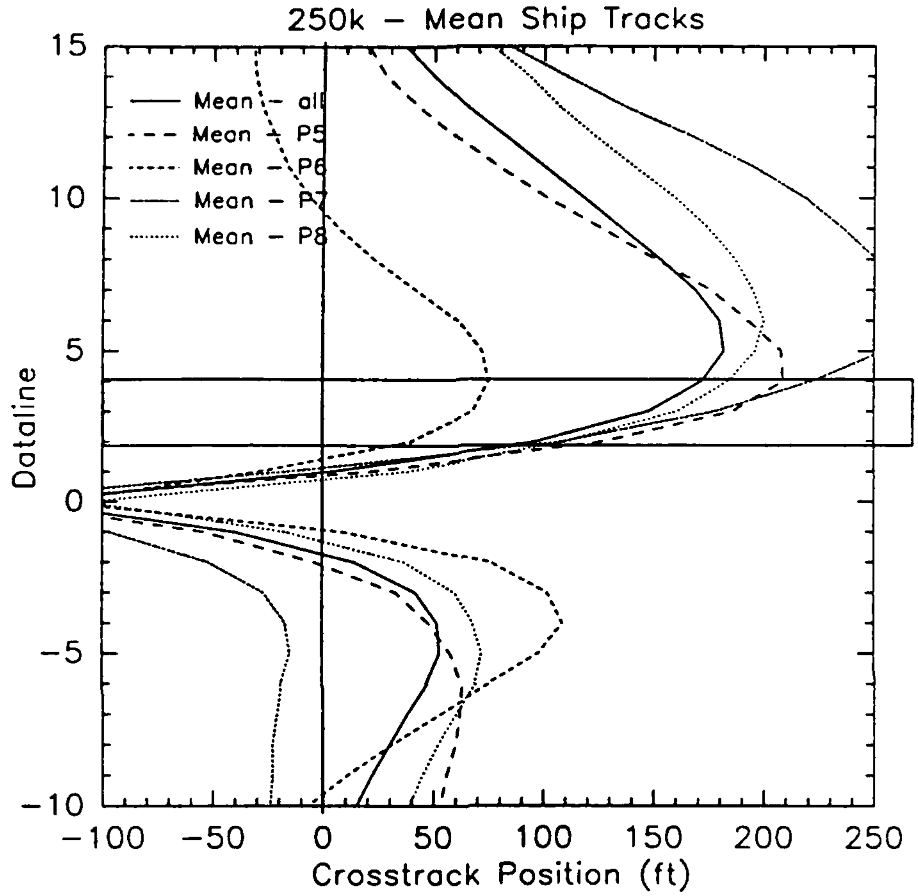

Figure 4-6: Group mean (n=16) and pilot mean (n=4) for the 250,000 dwt tanker

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Another example of data grouped by pilot appears in Figure 4-7. In this case, the four ships driven by Pilot 6 were compared using a different format, showing the MN and SD values over the length of the waterway. The MN values plotted in Figure 4-7 for the three versions of the 150,000 dwt bulker and the 250,000 dwt tanker do not differ greatly, although the MN values for the 150,000 dwt ship having a degraded rudder are definitely larger than the others following the turn. Based on the indices of controllability for these ships (T' and K' in Table 2-1 and Figure 2-2), one can rank these four ships in order of decreasing controllability: 1) 150,000 dwt, upgraded rudder; 2) 150,000 dwt, regular rudder; 3) 250,000 dwt; and 4) 150,000 dwt degraded rudder, (the distinction between 2) and 3) being somewhat arbitrary). According to this ranking, one might expect the MN values to generally increase with decreasing ship controllability. In the example shown however, MN values are fairly constant among ships but SD values tend to increase with poorer controllability. This is especially true in the region following the turn (Data Lines 0-20 in the figures).

This finding indicates that careful grouping of ship performance data by pilot may increase the sensitivity of the basic performance measures. It also indicates that the SD values may be more sensitive to differences in ship controllability that MN crosstrack position measures. The mechanism for this is unclear; it is possible that pilots may try different control techniques to compensate for the poor maneuvering characteristics of a ship, leading to inconsistencies between runs. A relationship between controllability and SD is implied by the data presented. However, SD values vary greatly over the length of the waterway and, therefore, could be difficult to use in predicting performance in some regions. Identification of a performance measure--the SD--which showed sensitivity to ship controllability was an important result of this exercise.

4.2.4 Effectiveness of Group Data

Analyses of group data by previously-developed techniques show some trends with ship displacement. However, these techniques did not appear to be sufficiently sensitive in identifying ship performance differences due to controllability characteristics. Performance differences related to controllability were present but apparently subtle. Grouping of data in smaller categories (i.e., by pilot) exposed some differences apparently related to controllability characteristics. However, in general, analyses using grouped data did not appear to be sufficiently sensitive to show the differences expected. For this reason, further analyses of the data were made by examining data from individual runs.

4.3 EXAMINATION OF INDIVIDUAL RUNS

4.3.1 The Methodology

Performance in individual runs was examined by a number of methods, methods that did result in a sensitive and systematic relation to ship characteristics. In this section these methods are described briefly, using sample data that serve the additional purpose of illustrating transit events. Section 4.3.2, that follows, describes the use of such events to

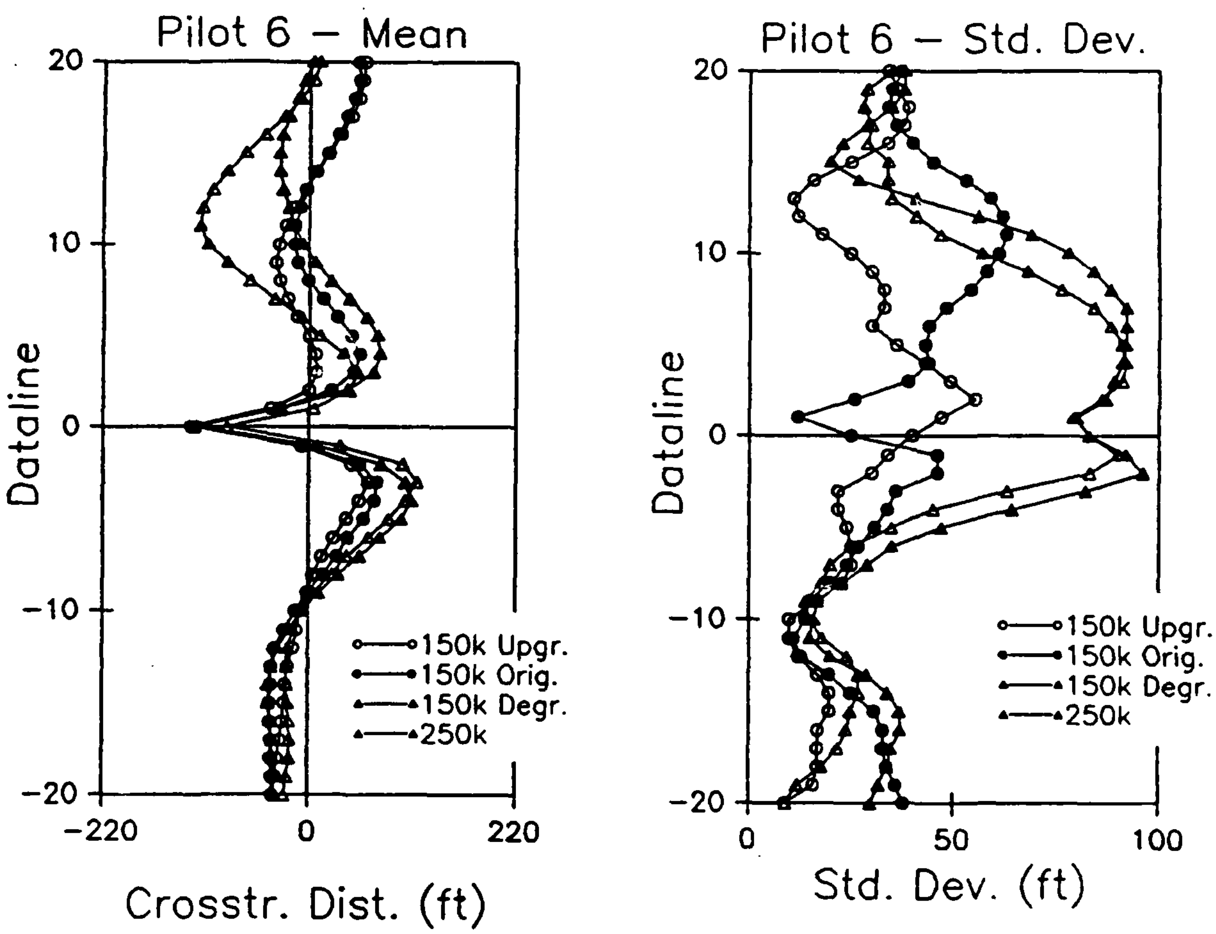

Figure 4-7: Data for one pilot (n=4) for each of the four larger ships

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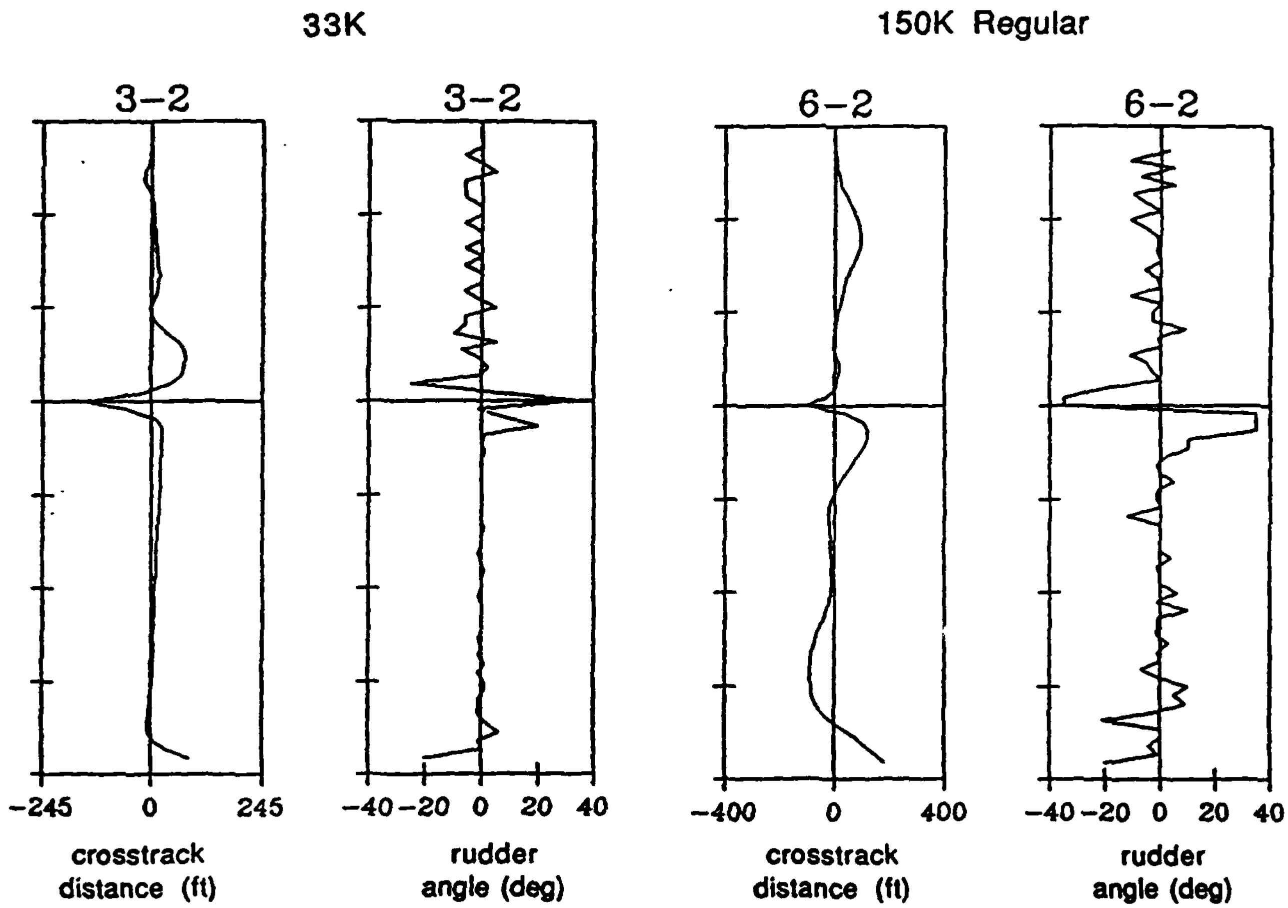
select the regions of the transit that will represent critical ship maneuvers. These ship maneuvers form the bases of the final analysis and prediction methodology that are described in the accompanying report (Mazurkiewicz and Smith, in preparation).

The first treatment of individual runs was the calculation and plotting of the track of the ship's center of gravity for the length of the transit. (Obviously, these are the single cases that make up the group distributions discussed in Section 4.2 and listed in Appendix D.) Two sample plots, one each from the sets of smaller and larger ships, appear in Figure 4-8. The x-axis represents the crosstrack position of the center of gravity, with zero at the centerline of the channel. The y-axis is the alongtrack distance at data lines along the channel for the entire transit, with zero at the midpoint of the turn. (See Figure 3-1 for an illustration of the transit, with maneuvering requirements and selected data lines indicated.) Figure 4-8 also contains plots of rudder angle for each of these runs.

The general conclusion from the analysis of individual runs--that there are substantial qualitative similarities among transit, despite the substantial differences in ship size and controllability--is illustrated by Figure 4-8. An an example, in both cases the pilots moved the ship's center of gravity to the right as the ship approached the left-hand turn. In both cases, they had on maximum left-hand rudder while the center of gravity approached the turn apex, and had on reverse rudder as the center of gravity passed the apex. The events of the transit are discussed in greater detail in the following sections. A complete set of individual center-of-gravity plots appears in Appendix E.

The RRF does not depend on the distribution of the ship's center of gravity alone. The sample calculation in Table 4-1 shows the contribution of the "adjusted beam," the crosstrack distance taken up by the ship's hull when it assumes a crab angle to the channel axis. The transit regions with the largest RRF values are generally those with the largest adjusted beam. To maximize the sensitivity of the present analysis, instead of using a nominal beam adjustment, the "extreme points" of the ship's hull were calculated directly from the raw data for each run. The extreme points and their usefulness in the analysis are illustrated in Figures 4-9 and 4-10. In Figure 4-9, a drawing of the outline of a ship (the 1000-foot ore carrier) as it makes the turn in the experimental waterway, the extreme points of the hull are marked 1 through 4. While the center of gravity is very close to the channel centerline at Data Line -1, Extreme Point 1 at Data Line 0 is very close to the left-hand boundary of the channel. This region of the transit is associated with some of the highest RRF values in the transit.

Another illustration of the contribution of the extreme points to risk appears in Figure 4-10. In this figure, the outline of a ship (the 150,000 dwt bulker with regular rudder) is shown as it approaches and completes the turn. In the region just after the turn, the ship's right rear extreme point nearly exceeds the channel boundary. This figure illustrates the sensitivity of the extreme point data to ship maneuvering such as in the turn recovery region, another region associated with high RRF values.



Note: Distances to the right of centerline are shown to the right in plot. Rudder angles to left are to right on plot.

Figure 4-8: Sample plots of individual runs with the 33,000 dwt bulker and the 150,000 dwt bulker (with regular rudder)

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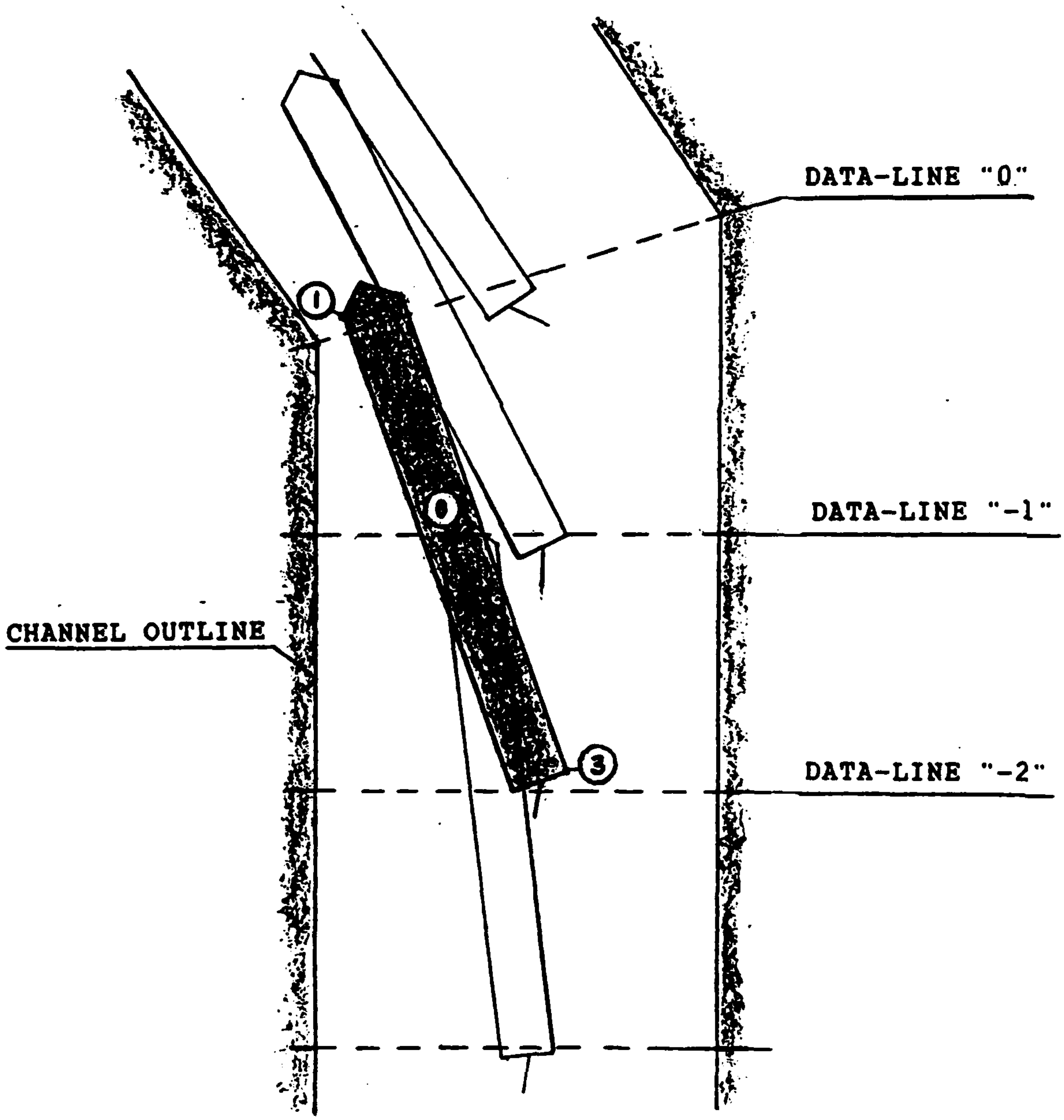

Figure 4-9: Ship's extreme points in the turn region

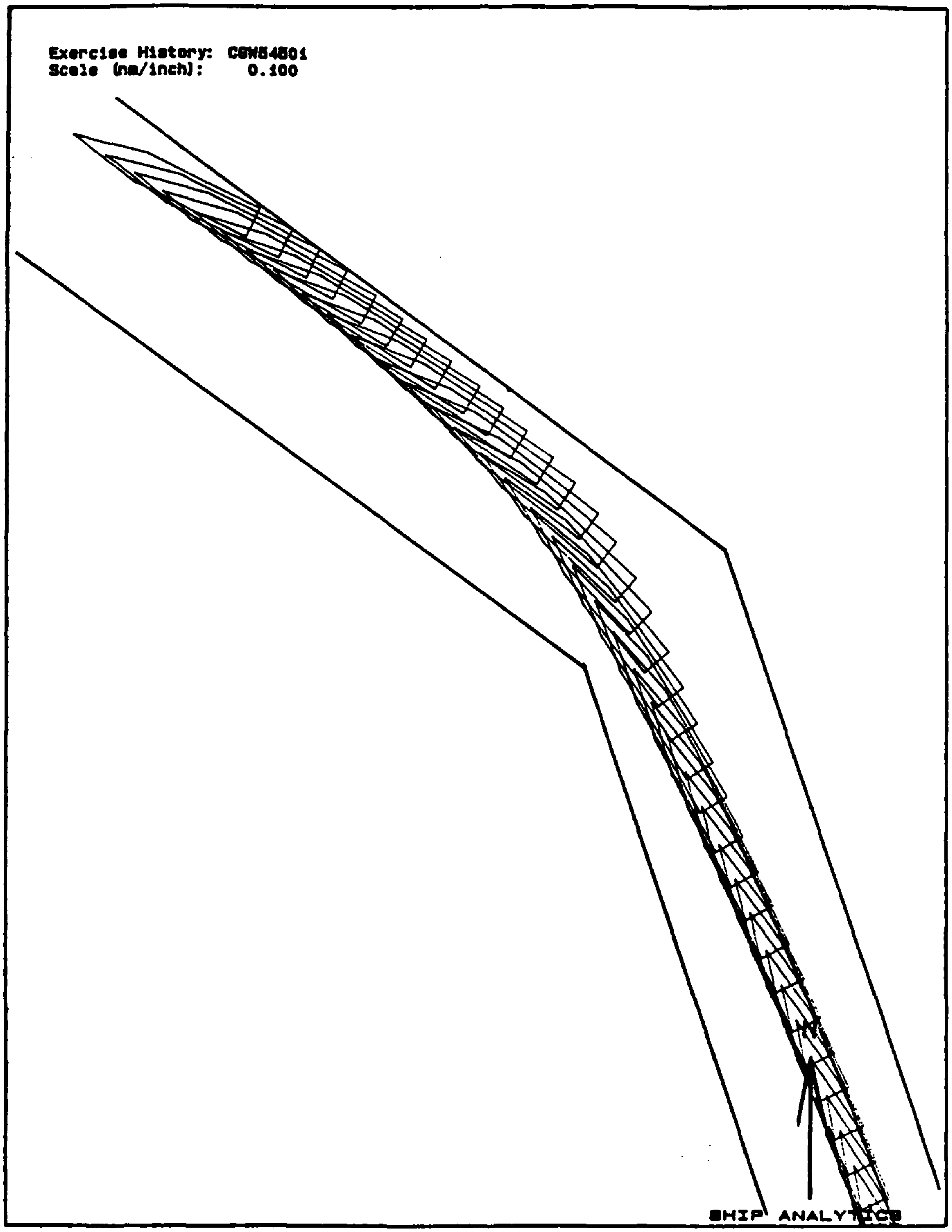

Figure 4-10: Successive outlines of the 150,000 dwt bulk carrier through the turn

4.3.2 Waterway Regions Based on Ship Maneuvers

Each individual run was examined for its constituent maneuvers; that is, identifiable patterns of ship's position, rudder angle, and heading as the transit proceeded by the requirements summarized in Figure 3-1. Based on characteristic relations among these measures and on associated RRF values, a number of maneuvering regions were identified. The seven possible regions are listed in Table 4-2 in an order that corresponds to their position in the transit illustrated in Figure 3-1. (Note that these regions are not exactly the same as those presently in the Design Manual, Smith et al., 1985. The consequences of the differences are discussed in the accompanying report, Mazurkiewicz and Smith, in preparation.)

TABLE 4-2. MANEUVERING REGIONS FOR THE EXPERIMENTAL TRANSIT

- Trackkeeping (not always present)
- Recovery 2 (not always present)
- Turn recovery
- Turn
- Turn entry
- Trackkeeping (not always present)
- Entry

The regions are described below in the order in which they were logically identified. The two trackkeeping regions are identified last because their definition depends on the way in which the neighboring regions are defined.

The entry region includes all actions necessary to establish the proper position and heading of the ship on, or very close to the centerline, from its initialization point at the right of the centerline (Figure 4-11). Rudder deflections of more than 5 degrees and an overshoot of the channel centerline are characteristic parameters for this region. Values selected to represent risk in this region are associated with the largest overshoot distance, D, of the ship outline from the waterway centerline. The start of this region is at the initialization point for the waterway. The end of the region occurs when the ship's center of gravity crosses the channel centerline after an initial overshoot. If the ship does not cross the centerline, the end of the region can be defined by the moment that the ship achieves a stable course parallel to the centerline.

The turn-entry region is associated with preparations for the turn (Figure 4-12). The position of the ship away from the channel centerline, ship headings of 0 to 5 degrees from the channel course, and momentary rudder deflections of up to 10 degrees are typical. Risk representation of this region is associated with the greatest distance, D_{te}, of the ship outline from the centerline. The beginning of this region is determined by

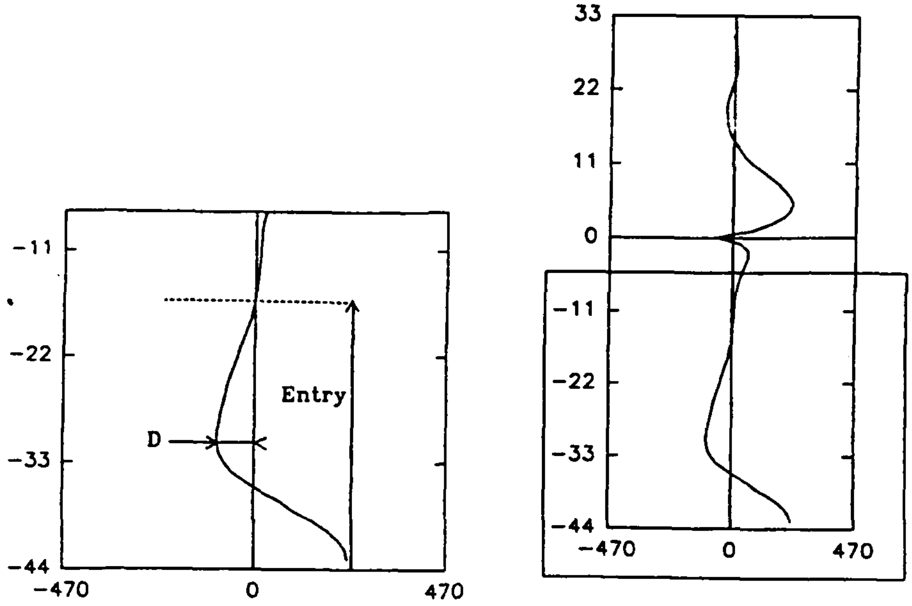

Figure 4-11: Track of the ship's center of gravity for a single run with an enlargement of the entry region

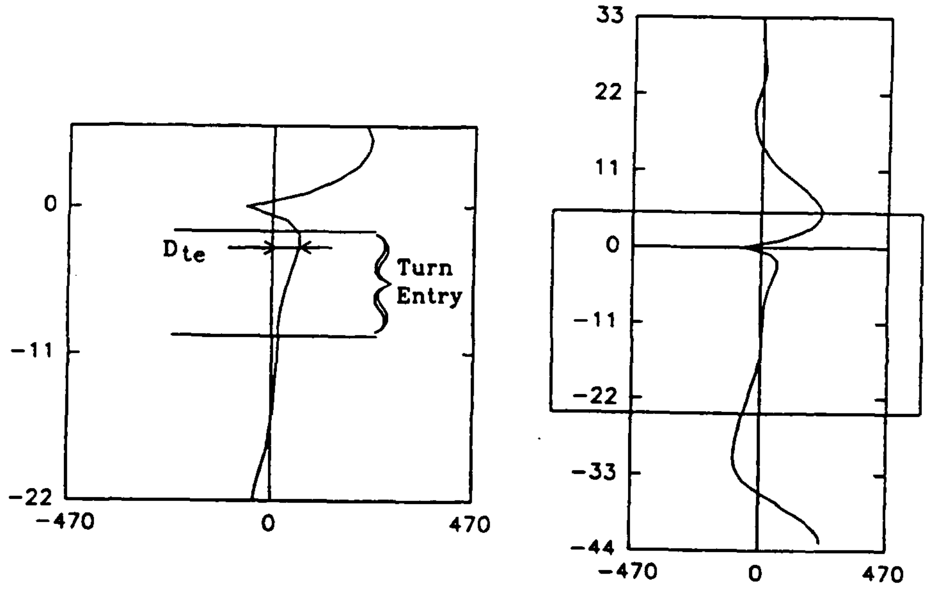

Figure 4-12: Track of the ship's center of gravity for a single run with an enlargement of the turn entry region

the end of the former one; the end of the region is marked by a continuous rudder deflection of 10 degrees or more in the turn direction, which is an indicator of the turn maneuver itself.

The turn region (Figure 4-13) comprises precisely the turn maneuver. Risk representation of this region is associated with large excursions of the ship outline from the centerline. (See also Figure 4-9.) Boundaries of this region are determined by the beginning and end of a continuous 10-degree or more deflection of the rudder in the turn direction.

The turn-recovery region is defined to include the first overshoot of the centerline by the center of gravity after the turn (Figure 4-14). Risk representation for the region is associated with the largest distance of the ship outline from the centerline. (See also Figure 4-10). This region begins when the rudder is reversed to a position counteracting the turn. The position of the second boundary depends on the next region. It can be the recovery-2 region or the trackkeeping region (or a new turn-entry region). The boundary can be established at a point where the ship's center of gravity crosses the waterway centerline. Alternatively, the boundary can be determined by the moment of stabilization of the ship's course.

The recovery-2 region includes a possible second overshoot of the ship, as shown in Figure 4-15. Risk representation is associated with the largest distance of the ship's outline from the waterway centerline. The region begins when the ship's center of gravity crosses the channel centerline. The end of the region is defined as was the end of turn-recovery region.

The trackkeeping region(s) included parts of the waterway where the ship maintains a stable course and rudder dynamics are minor (Figure 4-16). The level of risk for this region is the lowest. Values selected to represent risk for this region were associated with the average distance of the ship outline from the waterway centerline. The region is usually determined by the neighboring region. Any significant modification of the ship's course ends the trackkeeping region.

4.4 SUMMARY AND CONCLUSIONS

For a first step in the analysis, performance was examined using data grouped over all the runs made with each ship. The primary data were the distribution of crosstrack positions of the ships' center of gravity along the channel for each experimental scenario. (In the present experiment these distributions were composed of four runs by each of four pilots for each ship, or n=16.) An examination of the MNs and SDs of these distributions in the turn area (where the risk and the discrimination among ships were expected to be the greatest) showed that the crosstrack MNs were sensitive to differences in ship displacement but not to differences in ship controllability. The SDs did show some sensitivity to controllability, but not enough on which to base the analysis.

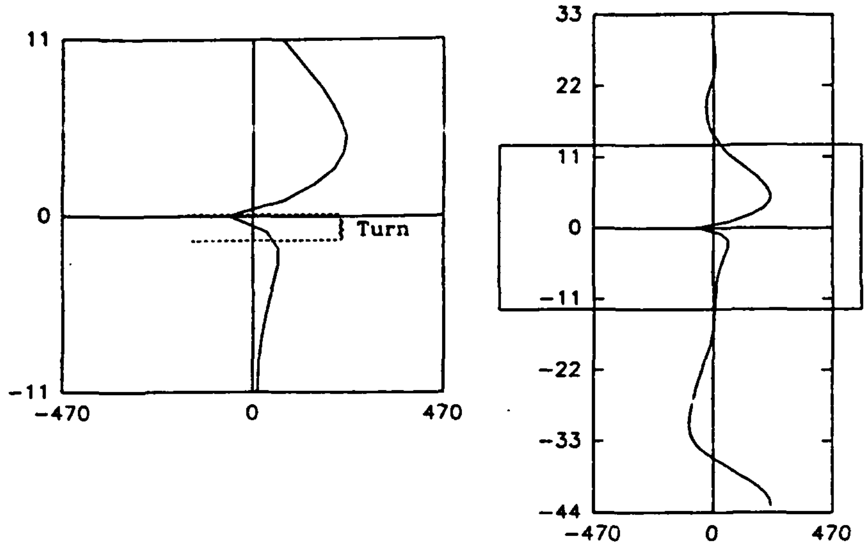

Figure 4-13: Track of the ship's center of gravity for a single run with an enlargement of the turn region

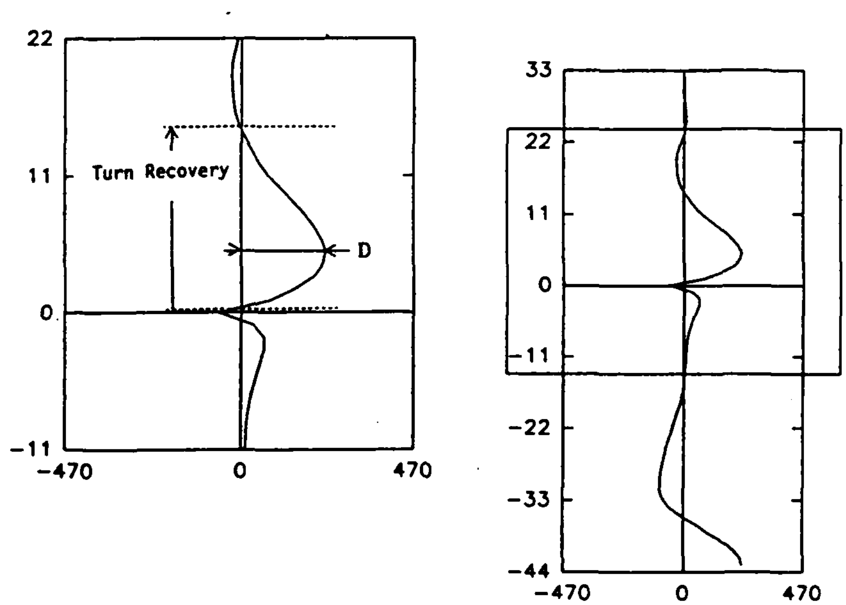

Figure 4-14: Track of the ship's center of gravity for a single run with an enlargement of the turn-recovery region

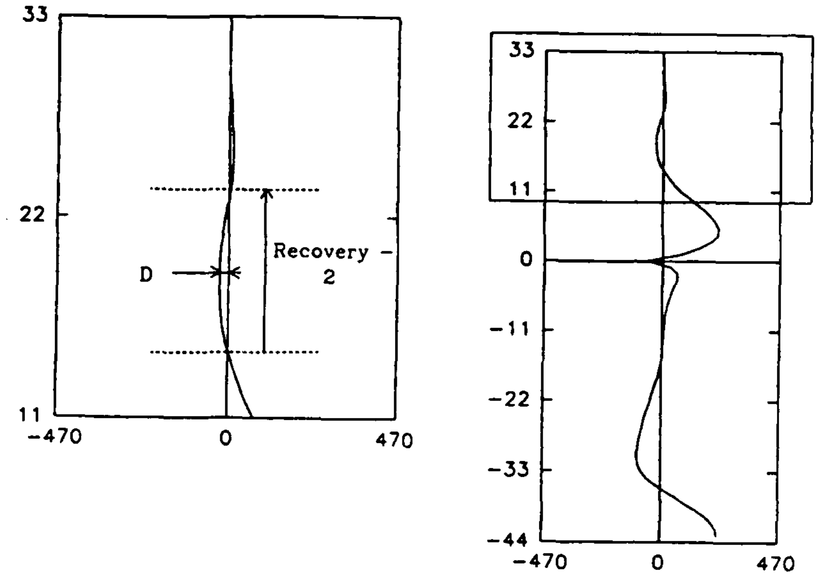

Figure 4-15: Track of the ship's center of gravity for a single run with an enlargement of the <u>recovery - 2 region</u>

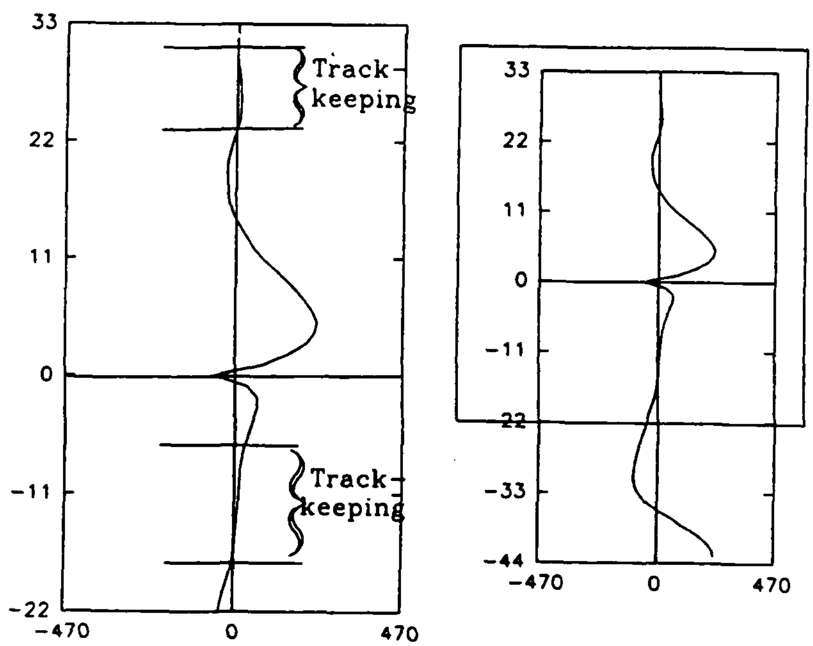

Figure 4-16: Track of the ship's center of gravity for a single run with an enlargement of the <u>trackkeeping regions</u>

In a search for more sensitive ways of examining the data, the ship tracks were grouped in smaller sets: the runs that each individual pilot had made with each ship (n=4). Examination of differences among pilots with the same ship showed that there were substantial differences, differences that might obscure differences between ships. Examination of differences among ships for one pilot showed that the SD, more than the MN, was related to ship controllability, reinforcing results with the overall group data.

Examination of individual runs showed that there were substantial qualitative similarities among runs with the different ships. Careful examination of these similarities identified seven distinctive maneuvers that made up the transit. These are described in some detail in the preceding section. On the assumption that performance grouped by maneuver would show the maximum sensitivity to ship parameters, these maneuvers formed the bases of further analyses.

For maximum sensitivity in the final analysis, representative performance data were selected from each individual run and each individual maneuver. The following general procedure was used: 1) in each run each maneuver that was present was identified, 2) for each maneuvering region, the specific data line, within the region where one extreme point of the ship was at the greatest distance from the centerline, was identified, and 3) the crosstrack position of the ship's center of gravity at that point was recorded. Because the preliminary analysis had shown that both the MN and the SD of crosstrack distributions had some sensitivity to ship characteristics, these statistics were calculated and used to represent the experimental scenarios in the final analysis (Mazurkiewicz and Smith, in preparation). In that analysis they showed sensitive and systematic relations to selected ship parameters.

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APPENDIX A

THE UNITED STATES COAST GUARD ACADEMY SIMULATOR

A.1 INTRODUCTION TO SCANTS

SCANTS, the Ship Control and Navigation Training System, was installed at the U.S. Coast Guard Academy in 1985 at a cost of approximately 3.4 million dollars. While it was originally intended as a training tool for USCG cadets, it now serves a variety of training and research functions. For cadet training, it is used, in concert with radar and navigation laboratory classes and on-the-water training, to teach rules-of-the-road and to prepare cadets to function as Officers of the Deck. The USCG also makes use of SCANTS in classes given to train prospective commanding officers and prospective executive officers (PCO/PXO). In recent years the simulator has been used for experiments in ship performance and in navigational displays done for the USCG Waterway Performance, Design and Evaluation Study. Ship Analytics built the simulator system, provides ongoing support and maintenance for its use in training, and conducts the Waterway experiments.

A.2 THE SCANTS FACILITY

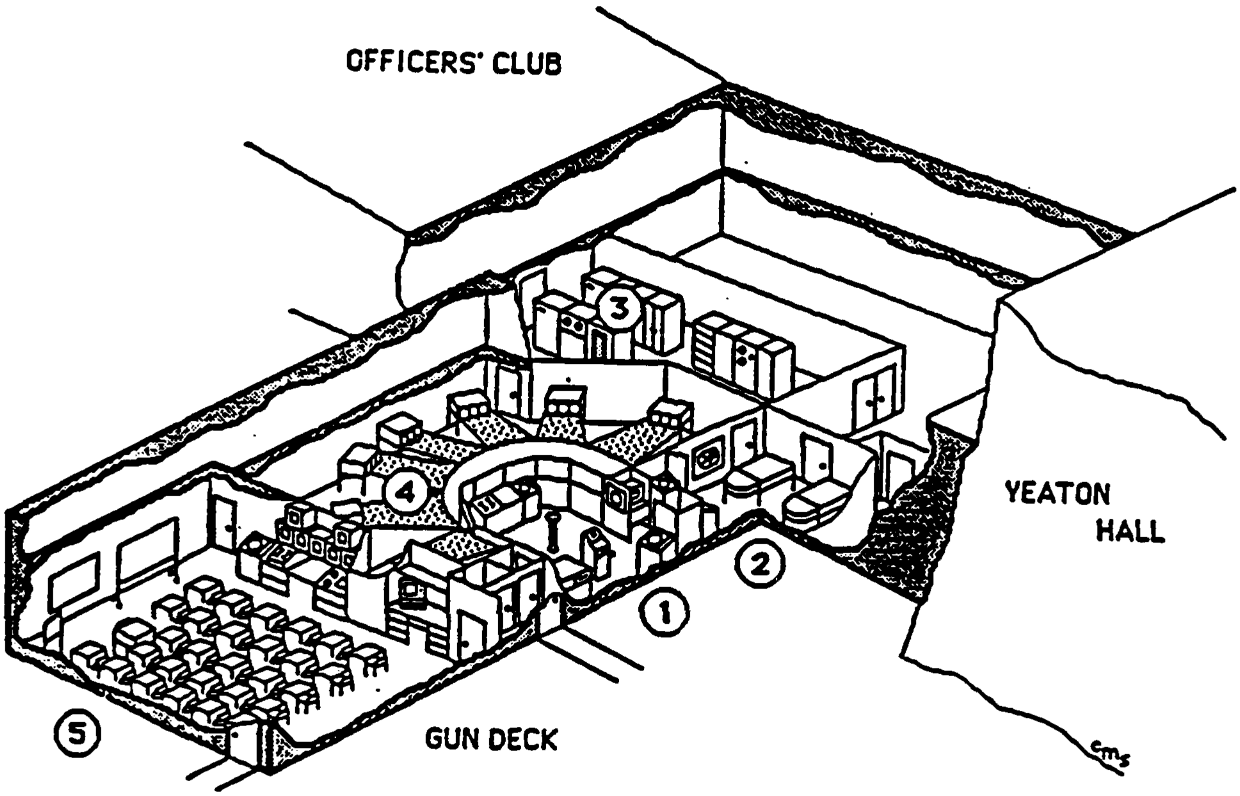
The SCANTS facility includes a full-size mock-up of a ship's bridge and combat information center (CIC), as illustrated in Figure A-1. The visual scene on the bridge consists of computer-generated color images rear-projected on seven screens, providing a 182-degree horizontal field of view and a resolution of 3 minutes of arc. Training at the Academy uses an ownship simulation of a 270- or a 378-foot Coast Guard cutter. However, other Ship Analytics ship models can be installed as ownships. Sophisticated ship hydrodynamic models provide realistic handling characteristics for the specific ship in use. This, along with a number of other capabilities, serves to make the simulation quite realistic. Environmental conditions such as wind, current, and height of tide, and bank or passing ship suction and cushion are simulated. Their effects on the ownship are apparent in the visual scene and in the bridge instrumentation (anemometer, fathometer, LORAN C, etc.) displays. Other bridge instrumentation includes working radios (generally used to simulate communication with traffic ships and other ship personnel), engine order telegraph (EOT), steering stand, pelorus, sound signal equipment, and two radar units.

Other components of the system are:

- Computer hardware including one Digital VAX 11/750, two VAX 11/780's, seven Adage image processing units, and an LSI 11/23 ADAC input/output processor located in a computer room adjacent to the CIC.

- Image projection instrumentation, consisting of seven RGB rear screen projectors capable of providing day or night color scenes, located in a projection room adjacent to the bridge. The original Barco-vision projectors were recently replaced with Sony projectors to improve the quality of the visual scene.

U.S. Coast Guard Academy
Ship Control and Navigation Training System
(SCANTS)



Conceptual view looking South from Hamilton Hall

1. Bridge: life-size, complete with steering stand, engine order telegraph, pelorus, communications and 2 radar indicators
2. Combat Information Center with full communications, 2 radar indicators, plotting and surface summary plot tables
3. Computer Room: 1 VAX 11/750, 2 VAX 11/780's, 7 Adage image processing units, ADAC input/output processor
4. Projector Room with 7 SONY rear screen projectors providing a 182° color day and night wrap-around visual display
5. 30 person briefing theater with graphic feedback display, remote monitoring station and instructor/operator station

- Briefing theater with graphic feedback display which allows viewing of ownship and traffic ship tracks after the simulation has ended.

- Remote monitoring station consisting of closed circuit television displays showing the bridge and CIC, and five CRT monitors duplicating the scene on the middle five screens on the bridge.

- Three instructor/operator stations which allow operation of the simulator from the remote monitoring station, the briefing theater, or a room between the bridge and CIC.

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APPENDIX B. U.S. Coast Guard Letter

U.S. Department of Transportation
United States Coast Guard

Commander
Fifth Coast Guard District

Federal Building
431 Crawford Street
Portsmouth, VA 23705-5004
Staff Symbol (oan)
Phone (804)398-6230

16500.SRA
17 MAR 1989

From: Commanding Officer, Fifth Coast Guard District
To: Commandant (G-NSR)

Subj: SHORT RANGE AIDS TO NAVIGATION DESIGN MANUAL (SRA DESIGN MANUAL)

1. We have designed an aid system for three critical waterways using the guidance in the Short Range Aids to Navigation Design Manual. These waterways are Cape Henry to Hampton Roads, Chesapeake Channel, from Cape Henry to Baltimore, and the Atlantic Ocean Channel. We believe there are some shortcomings in the manual and we request additional simulation studies for the design vessels used by the Army Corps of Engineers for these three waterways.

2. We employed the concepts of markings for turn, recovery and trackkeeping regions described in the design manual and also contained in Chapter 4 of the Aids to Navigation Manual - Administration, COMDTINST M16500.7. Buoy spacing and lighting characteristics used were those recommended in both publications. However, one of the best tools available to the channel designers in the (oan) branch was the ability to calculate relative risk factors for the various regions. The SRA Design MANUAL upper limit vessel is 100,000 DWT. The design vessels used by the Army Corps of Engineers (USACOE) were 150,000 DWT for the 50' Channel to Baltimore, the 55' Channel to Hampton Roads and the 60+ft Atlantic Ocean Channel. The Norfolk District, USACOE also considered a 225,000 DWT vessel in their design to plan for future use of the 55' Channels. Enclosure (1) is forwarded to indicate that Hampton Roads has already, with only a 50' Channel, loaded 151,000 DWT.

3. Baltimore and Hampton Roads port authorities estimate that three ships per day, per port would sail that would benefit from the newly dredged channel depths. Our assumption of using the 150,000 DWT ships as the largest waterway user is valid, as these type ships will regularly sail; vessels of 150,000 DWT or greater will not be uncommon.

(oan)
16500.SRA
17 MAR 1989

Subj: SHORT RANGE AIDS TO NAVIGATION DESIGN MANUAL (SRA DESIGN MANUAL)

4. We are enthusiastic supporters and users of the SRA design manual, however, its scope needs to be expanded to encompass the 150,000+ DWT vessels plying the district waterways. As other ports deepen their channels to accommodate the deeper draft colliers there will be an expanded need for the additional utility. My project officer is Mr. John Walters at FTS 827-9230.

C. S. PARK
By direction

Encl: (1) Article from VIRGINIAN PILOT of 22 FEB 89

Copy: R&D Center
ATTN: Dr. Mandler

BUSINESS NEWS

Collier sails with record load of coal

By Allen S. Roberts
Staff writer

NORFOLK — A Swedish collier sailed for South Korea with a record load of coal Tuesday night, affirming hopes that a deeper ship channel would bring more cargo through the Port of Hampton Roads.

The Nord Atlantic, which called at Pier 6 on Lamberts Point for more than 150,000 tons of coal, had loaded more than 139,000 tons by 7:30 p.m. Tuesday. The ship's master, Capt. Bo W. Axelson, planned to cast off with about 151,000 tons, drawing about 49 feet of water in the 50-foot outbound ship channel, to shatter the 137,000-ton record set by the Atara three years ago, when the channel was 45 feet.

Railroad and shipping executives, who lobbied for public funds to deepen the channel and invested corporate capital in their own rail and port facilities, hailed the sailing of the Nord Atlantic.

"We have spent billions of dollars over the years to maintain the finest transportation system — from mine to market — that exists in the world," said William B. Bales, vice president over coal and ore traffic at Norfolk Southern Corp. "We're seeing some opportunities that never existed before."

Since deepening the channel from 45 to 50 feet last year, Hampton Roads can lure the larger ships in increasingly dominating trade in coal and other bulk cargos.

As shippers use fewer ships to move more cargo, they will seek out deeper ports served by rate-cutting railroads and mines.

And that trend is likely to indefinitely stimulate coal exports through Hampton Roads, maritime industrialists said.

Norfolk Southern, which brought 28 million tons of coal last year for export through Pier 6, expects volume to reach 29 million to 31 million tons this year.

That would be money in the bank not only for Norfolk Southern, but also for maritime businesses throughout Hampton Roads, which take in an estimated $81 on each ton of coal through the ports.

The 50-feet channel has given Hampton Roads coal terminals a major advantage over 27 of the 28 other Atlantic ports.

The deeper channel effectively cuts 50 cents a ton from the ocean freight paid by shippers like Pohang Iron & Steel Ltd. of South Korea, which ordered the record load carried by the Nord Atlantic.

Pohang, choosing to buy more U.S. coal and less Australian coal, plans to steadily increase orders through Baltimore and Hampton Roads from nearly 2.4 million tons last year to as much as 3.5 million in 1992.

"It's hard for me to emphasize enough how important that 50 cents is," said Wilson J. Browning Jr., who served as Norfolk agent for Pohang's charter of the Nord Atlantic.

"Congress, by giving us this deeper channel, sent out the message that we're serious about remaining in the export coal business for the next 50 years."

And even as archrival Baltimore rushes to deepen its channel from 42 to 50 feet, Hampton Roads is already pressing to dredge its channel from 50 feet to 55 feet.

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Appendix C

PILOT BRIEFING (INCLUDING SHIP CHARACTERISTICS)

A package was prepared for each pilot, parts of which are presented here to describe the experimental situation, as it was presented to him, and his state of preparedness for it. The components of the package and their inclusion here are as follows:

- preliminary briefing notes and questionnaire (included here)

- a chartlet of the channel, a scale drawing of the ship in the channel, and a questionnaire for each scenario assigned to him (only sampled here)

- a set of "pilot cards" describing each ship assigned to him (All the pilot cards are presented, prefaced by a table summarizing the ship characteristics.)

SHIP PERFORMANCE EXPERIMENT, FALL 1989

INSTRUCTIONS TO THE PILOT FOR GROUP 1, SMALLER SHIPS

INTRODUCTION

The purpose of today's experiment is to evaluate the contribution of the ship's size and maneuverability to the transit of a narrow channel. You will be asked to make transits with different ships under similar conditions. There will be three ships: a 33,000 deadweight ton (dwt) bulker, a 1000-foot Great Lakes ore carrier, and a 76,000 dwt bulker. Information on each ship will be provided.

Because the ships vary so much in size, the width of the channel will be adjusted to the ship. To evaluate the contribution of channel width as a factor, one of the ships, the 76,000 dwt bulker, will be presented in three different channel widths.

The attached table summarizes the conditions for today's scenarios. One of these scenario will be run to familiarize you with the simulator and the general conditions. You may repeat that run or select an additional scenario for familiarization if you think it will be helpful. For the experiment proper you will be asked to do a total of eight transits in a pre-determined order. Each transit will take 30 to 40 minutes.

We have prepared a questionnaire to suggest topics for discussion, but we are interested in any comments you have on the day's activities.

TABLE C1: SCENARIO CONDITIONS: GROUP 1

Scenario	Ship	Displacement (Light tons)	LOA (Feet)	Beam (Feet)	Draft (Feet)	Rudder	Channel Width (Feet)
1	33,000 dwt bulk carrier	42,072	608	85	37	regular	489
2	1,000 - foot Great Lakes ore carrier	77,500	1000	105	28	regular	757
3	76,000 dwt bulk carrier	86,174	865	106	40	regular	685
8	76,000 dwt bulk carrier	86,174	865	106	40	regular	543
9	76,000 dwt bulk carrier	86,174	865	106	40	regular	400

SHIP PERFORMANCE EXPERIMENT, FALL 1989

INSTRUCTIONS TO THE PILOT FOR GROUP 2, LARGER SHIPS

INTRODUCTION

The purpose of today's experiment is to evaluate the contribution of the ship's size and maneuverability to the transit of a narrow channel. You will be asked to make transits with different ships under similar conditions. There will be three 150,000 deadweight ton (dwt) bulkers, sister ships differing in rudder design, and a 250,000 dwt tanker. Information on each ship will be provided.

Because the ships differ so much in size, the width of the channel will be adjusted to the ship. You will recive a chartlet for each channel.

The attached table summarizes the conditions for today's scenarios. One of these scenario will be run to familiarize you with the simulator and the general conditions. You may repeat that run or select an additional scenario for familiarization if you think it will be helpful. For the experiment proper you will be asked to do a total of eight transits in a predetermined order. Each transit will take 30 to 40 minutes.

We have prepared a questionnaire to suggest topics for discussion, but we are interested in any comments you have on the day's activities.

TABLE C-2: CONDITIONS: GROUP 2

Scenario	Ship	Displacement (Light tons)	LOA (Feet)	Beam (Feet)	Draft (Feet)	Rudder	Channel Width (Feet)
4	150,000 dwt bulker (R)	171,240	961	145	52	regular	798
5	150,000 dwt bulker (D)	171,240	961	145	52	degraded	798
6	150,000 dwt bulker (U)	171,240	961	145	52	up-graded	798
7	250,000 dwt tanker	282,924	1140	170	65	regular	943

THE CHANNEL CONDITIONS

Chartlets of the channel(s) are attached. There are two legs connected by a 35 degree turn to the left, from 341 degrees to 306 degrees. The width of this channel is adjusted for each scenario as indicated on each chartlet. There are no bank or bottom effects. The channel exists only as the buoy coordinates. The intention is that the buoys, and not the banks, provide the position information needed for the transit.

There is a current to 341 degrees that will be following at 1.5 knots at the start of the transit, below buoys "1" and "2." It decreases gradually to 1.0 knots at the turn and to zero after buoys "13" and "14." As you take the ship around the turn it will be broad on the port quarter.

There is a wind from 161 degrees, with some slight varations in direction. It gusts to 30 knots.

The channel is marked by gated buoys, spaced in the straightaways at 1.25 nautical miles (nm), with half that distance to the first gate at each side of the turn. The turn is marked by three buoys. The buoys will always be at their exact charted positions.

All runs will be made in daylight and with unlimited visibility. Radar will not be available. There will be no traffic.

MANEUVERING INSTRUCTIONS

The transit will start approximately 3 nm below the turn, below buoys "1" and "2," and 25% of the channel width to the right of centerline. The heading will be 341 degrees, the course of the channel. The Engine Order Telegraph (EOT) will be set at half a head which is 9 knots through the water for all ships.

Please take the ship to the centerline of the channel as quickly as you think prudent and proceed, keeping the center point of the ship as close to the centerline, again, as you think prudent. A track as close to the centerline as is practical is important to the experiment. The objective is to determine how precisely each ship can maneuver and can maintain a designated track. A wide "centerline " for all the ships will not reveal differences among them.

As you approach the turn, take whatever track you think is appropriate. You may change the speed in the turn, as you think appropriate. Please change the EOT yourself and announce your change. (For the 1000-foot Great Lakes ore carrier, please use the two engines together. Do not use them to maneuver.)

After the turn, please return to the centerline and maintain that track, again as quickly and precisely as you think prudent. If you changed the speed, please return it to half a head and announce your change.

There will be a helmsman to receive and execute your helm orders. You may give either course or rudder orders, as you think appropriate.

INFORMATION ON TODAY'S SHIPS

You will receive a booklet containing PILOT CARDS for each of today's ships. For each ship there is a picture, a list of ship particulars, and
a table of maneuvering speeds. The Cards also show maneuvering data for the ships. These data will be different for each ship.

The most commonly used test of maneuvering performance for a ship is the TURNING CIRCLE. To perform this test, the rudder is moved from midships to 35 degrees and held until the ship's heading has changed 360 degrees. Distances are recorded from this maneuver:
ADVANCE is the distance forward the ship will move in the time it takes the heading to change 90 degrees.
TRANSFER is the distance perpendicular to the original line of travel the ship will move in the time it take the heading to change 90 degrees.
TACTICAL DIAMETER is the distance perpendicular to the original line of travel the ship will move in the time it takes the heading to change 180 degrees.
These measures are presented here in both ownship lengths and feet.

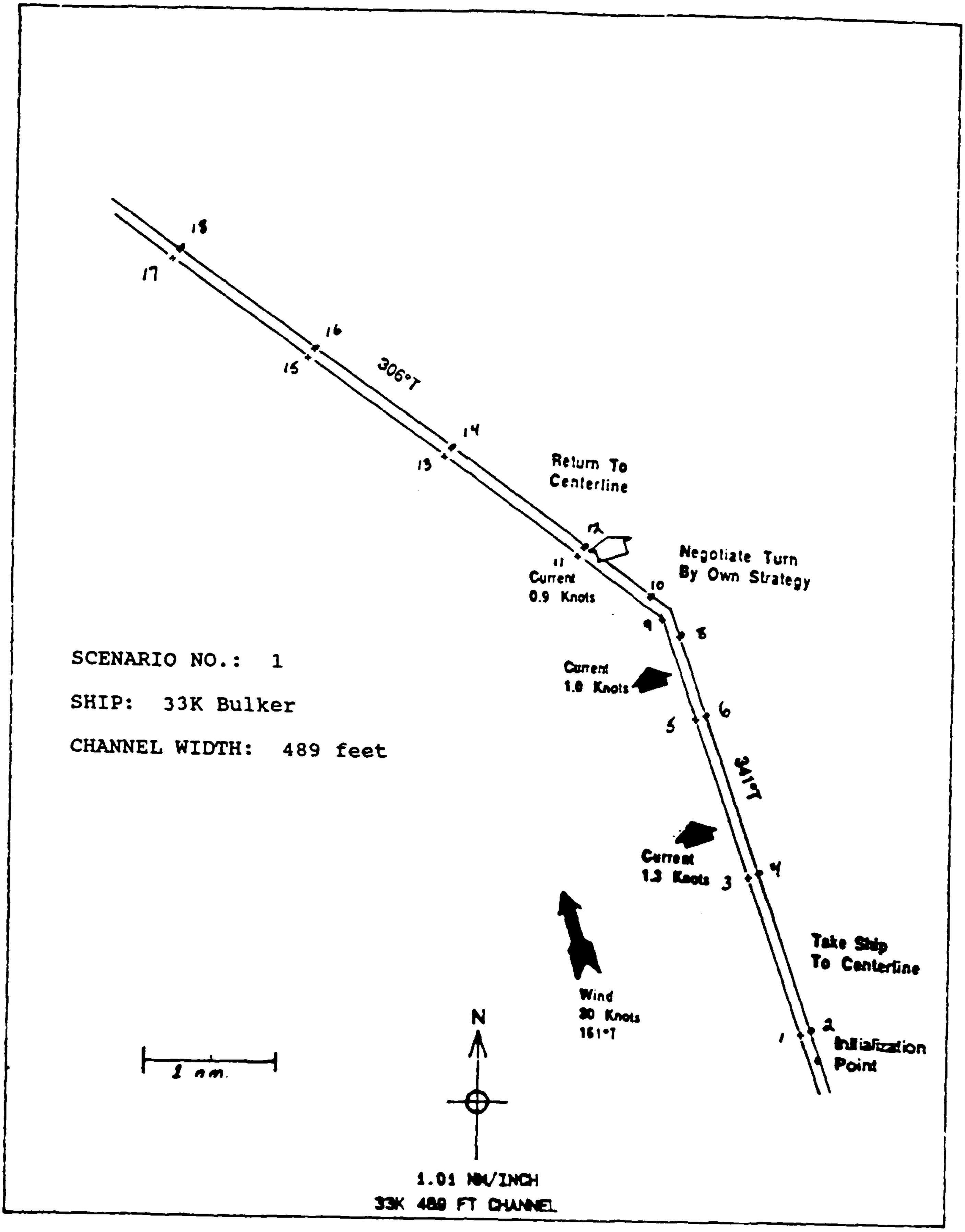
The ZIG-ZAG maneuver is less common. To perform this maneuver the rudder is changed from midships to starboard some selected amount. Our plots show 15 degrees. The rudder is held there until the ship's heading has also changed 15 degrees. A time measure is presented: TIME TO REACH EXECUTED HEADING CHANGE. At this point the rudder is changed 15 degrees to port. The ship's head continues to starboard for some number of degrees: FIRST OVERSHOOT ANGLE. The ship's head returns to the original direction in a time measure: REACH. Finally, the ship's heading provides a: SECOND OVERSHOOT ANGLE. A plot and values read from that plot are presented for each ship.

GENERAL QUESTIONS

1. Have you ever before "piloted" a simulator?
Which simulator?
What kind of exercise was it?
What did you think of the experience?

2. In your routine work, what is a "big" ship?
How frequently do you pilot a ship this big?
What are the dimensions of the waterway through which you take this ship: width, depth, turns, length of reaches?
What are the aids like?
What type and volume of traffic do you encounter?
What use do you make of radar?
What track do you follow: centerline, right of center?
What speed do you use, and under what circumstances do you vary the speed?
What role do the banks and bottom of the waterway play in the transit? What special provisions do you make for the ship's size?

3. What dimensions do you use to describe the size and the maneuverablity of a ship?
What do you like to know about a new ship before you take control?



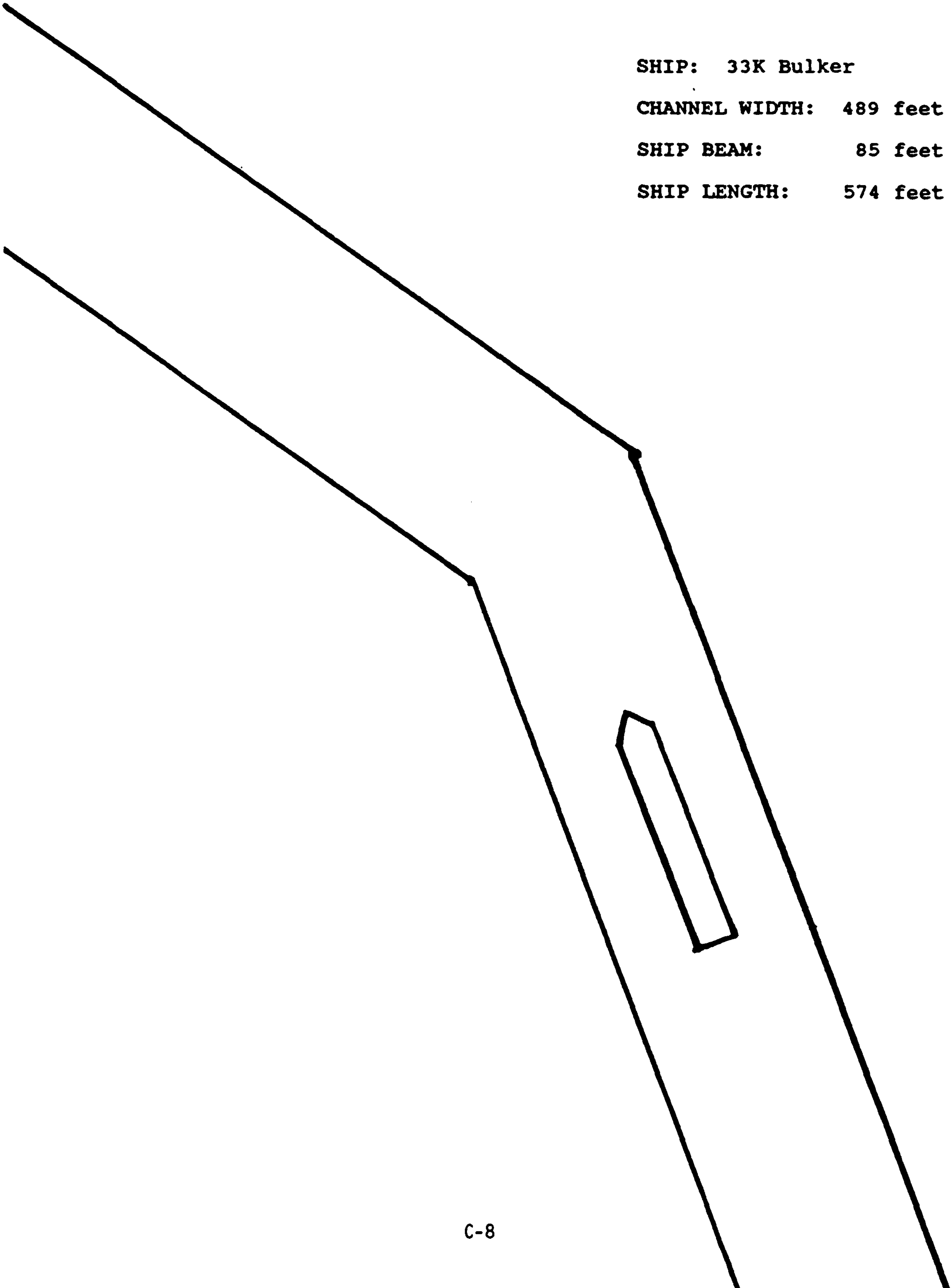
18
17
16
15
306°T
14
13
Return To
Centerline
12
11
Current
0.9 Knots
10
Negotiate Turn
By Own Strategy
9
8
Current
1.0 Knots
SCENARIO NO.: 1
SHIP: 33K Bulker
CHANNEL WIDTH: 489 feet
5
6
341°T
Current
1.3 Knots
3
4
Take Ship
To Centerline
Wind
30 Knots
161°T
N
1
2
Initialization
Point
1 nm.
1.01 NM/INCH
33K 489 FT CHANNEL

SHIP: 33K Bulker

CHANNEL WIDTH: 489 feet

SHIP BEAM: 85 feet

SHIP LENGTH: 574 feet



QUESTIONS FOR SCENARIOS

1. In your opinion, is each ship realistic?
What did you like, or not like, about each?

2. Where the wind and current realistic as described?
How much did they add to the difficulty of the transit?

3. Where the aids sufficient for the task?

4. Where the maneuvering instructions realistic:
the speed instructions,
the centerline instructions?
What would you have done differently at sea?

5. Was the width of the channel appropriate for each ship?
Was it tight, generous?
Did the lack of banks or bottom effects play a part in the transit? If so, please describe?

6. Generally, how difficult and how safe was the transit?

7. In your opinion, was the transit a fair measure of what the ship can do? If not, why not?

8. What is your opinion of arrangements or sequence of the experimental scenarios?

9. What is your opinion of the information presented in the PILOT CARDS?

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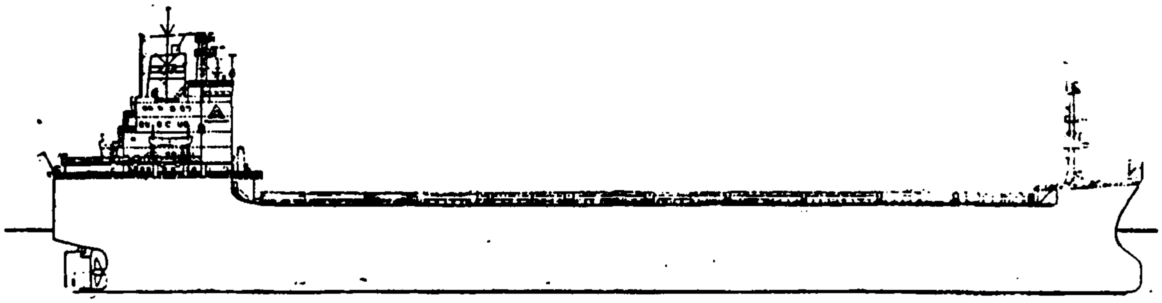
SHIP ANALYTICS LINES   P I L O T   C A R D

M/S ' 33 K BULK CARRIER '
****



VESSEL PARTICULARS

Length between perpediculars... 574.15 ft
Beam............................ 85.30 ft
Draft, loaded................... 37.35 ft
Block Coefficient............... 0.800 --
Displacement, loaded.........42,072. LT
Max. speed...................... 15.6 knots

No. of engines .... 1 --
Engine type.................. Diesel --

Rudder turn rate .... 2.7 deg/s

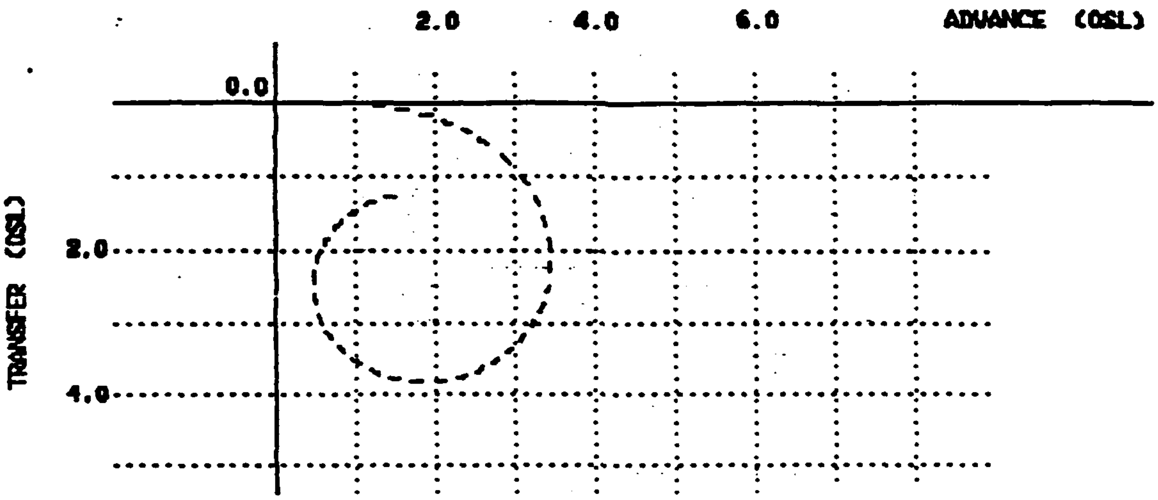
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	-105.		
2. AS - HALF	- 50.		
3. AS - SLOW	- 25.		
4. AS - DSLOW	- 12.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	38.	5.0	8.45
7. AH - SLOW	50.	6.6	11.15
8. AH - HALF	68.	9.0	15.20
9. AH - FULL	95.	12.5	21.11
10. AH - SEA	120.	15.6	26.33

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG)....	3.41 osl	..... 1,955 ft
Transfer (90 deg)....	1.68 osl	..... 962 ft
Tactical Diameter	3.75 osl	..... 2,155 ft



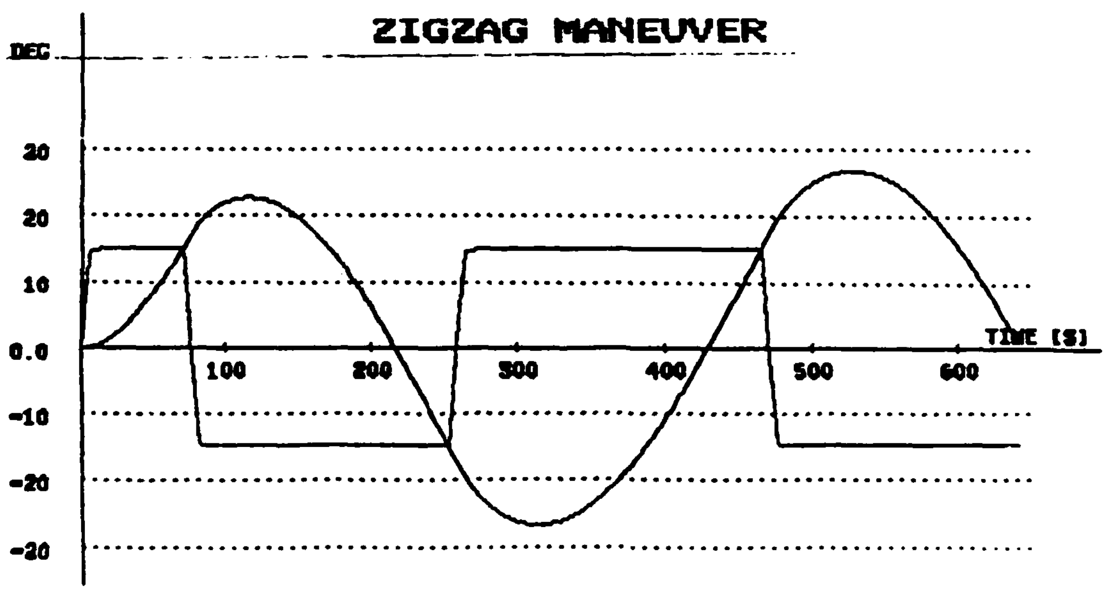
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ...... 7.5 deg

Time to Reach Execute
Heading Change............ 71. sec

Reach.....................216. sec

Second Overshoot Angle.....11.9 deg

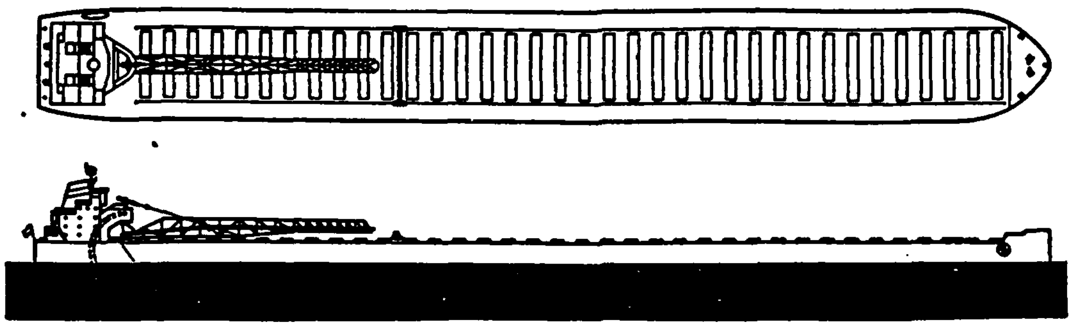


3. ship marginally unstable (spiral maneuver)

SHIP ANALYTICS LINES   P I L O T   C A R D

M/S ' 1000 FT G.L. CARRIER '

****



VESSEL PARTICULARS

Length between perpediculars...	990.00	ft
Beam...........................	105.00	ft
Draft, loaded..................	27.50	ft
Block Coefficient..............	0.947	--
Displacement, loaded...........	77,500.	LT
Max. speed.....................	12.8	knots
No. of engines	2+2	--
Engine type....................	Diesel	--
Rudder turn rate	4.3	deg/s

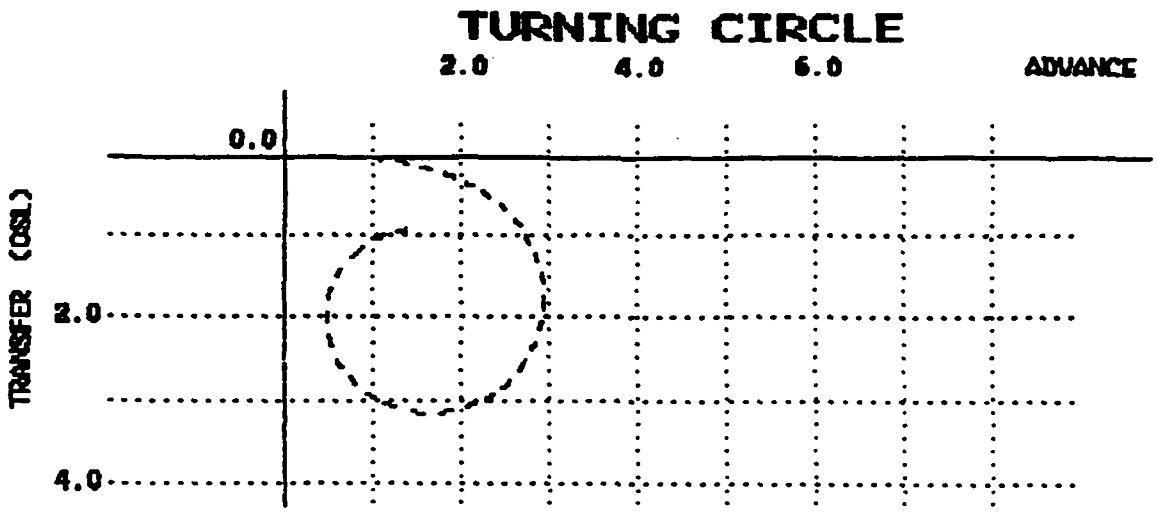
MANEUVERING SPEEDS:

CPP/EOT Settings	PITCH	RPM	Speed	
	ft	rev/min	knots	ft/s
1. AS - FULL	-9.0	120.		
2. AS - HALF	-9.0	90.		
3. AS - SLOW	-6.0	70.		
4. AS - DSLOW	-3.0	50.		
5. STOP	0.0	45.	0.0	0.0
6. AH - DSLOW	8.0	57.	5.0	8.41
7. AH - SLOW	13.0	68.	6.6	11.21
8. AH - HALF	15.0	90.	9.0	15.24
9. AH - FULL	17.5	120.	12.5	21.14
10. AH - SEA	19.0	120.	12.8	21.57

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG).... 2.92 osl ..... 2,890 ft
Transfer (90 deg).... 1.52 osl ..... 1,513 ft
Tactical Diameter ..... 3.14 osl ..... 3,141 ft



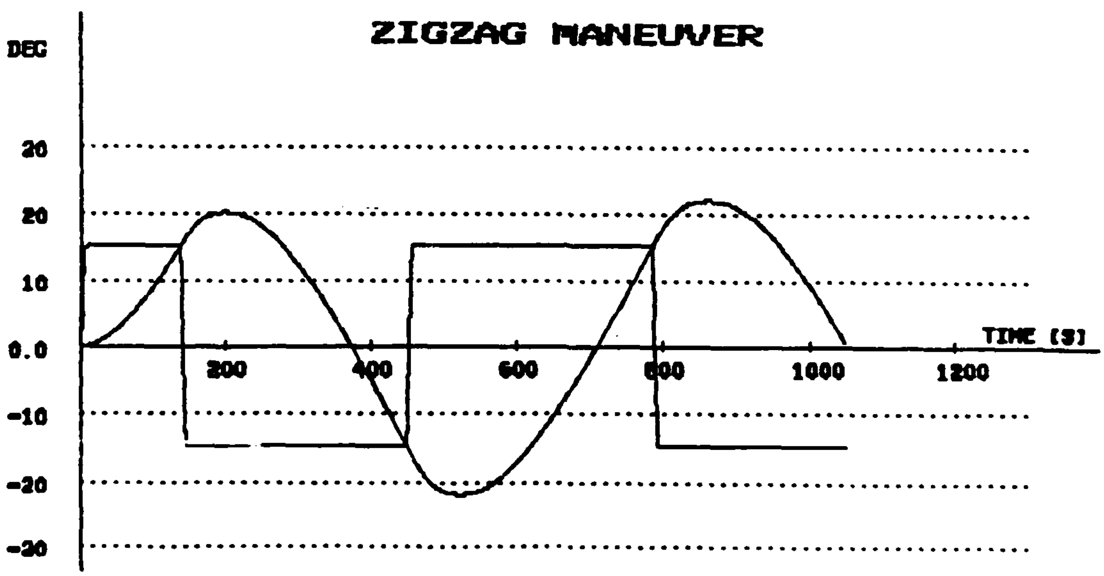
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ...... 5.1 deg

Time to Reach Execute
Heading Change............138. sec

Reach.....................372. sec

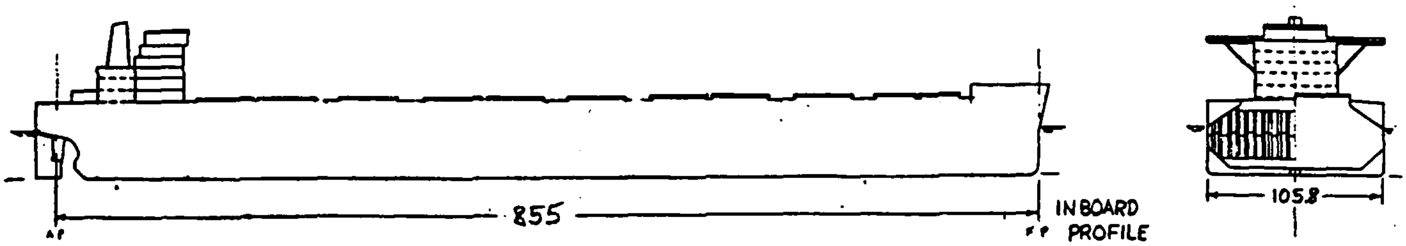
Second Overshoot Angle..... 6.9 deg

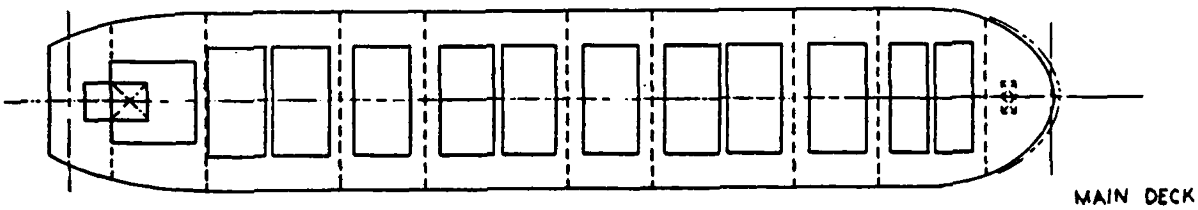


3. ship stable (spiral maneuver)

SHIP ANALYTICS LINES P I L O T C A R D

M/S ' 76 K BULK CARRIER '
****





VESSEL PARTICULARS

Length between perpediculars...	855.00	ft
Beam............................	105.82	ft
Draft, loaded...................	40.00	ft
Block Coefficient...............	0.850	--
Displacement, loaded............	86,174.	LT
Max. speed......................	16.5	knots
No. of engines	1	--
Engine type.....................	Diesel	--
Rudder turn rate	2.5	deg/s

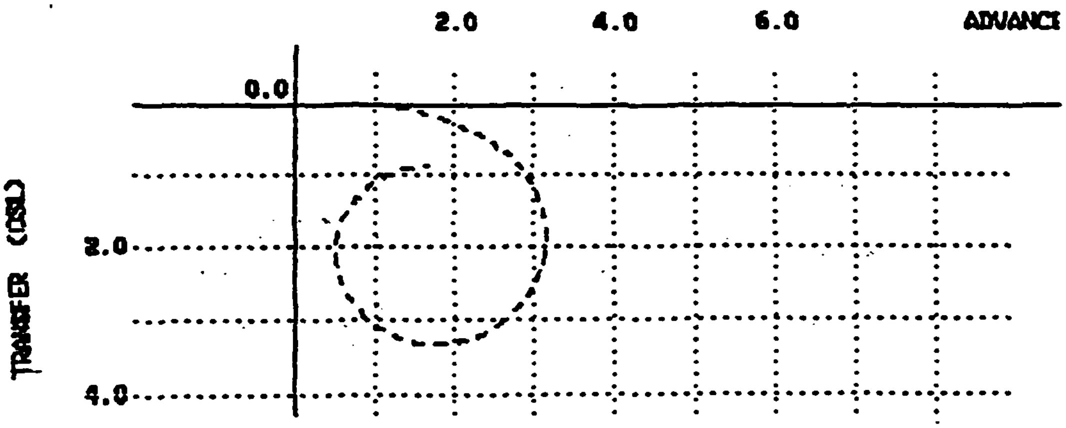
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	- 80.		
2. AS - HALF	- 40.		
3. AS - SLOW	- 20.		
4. AS - DSLOW	- 10.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	25.	5.0	8.45
7. AH - SLOW	33.	6.6	11.15
8. AH - HALF	45.	9.0	15.20
9. AH - FULL	63.	12.5	21.11
10. AH - SEA	83.	16.5	27.92

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG)....	3.11 osl	..... 2,660 ft
Transfer (90 deg)....	1.45 osl	..... 1,238 ft
Tactical Diameter	3.28 osl	..... 2,803 ft



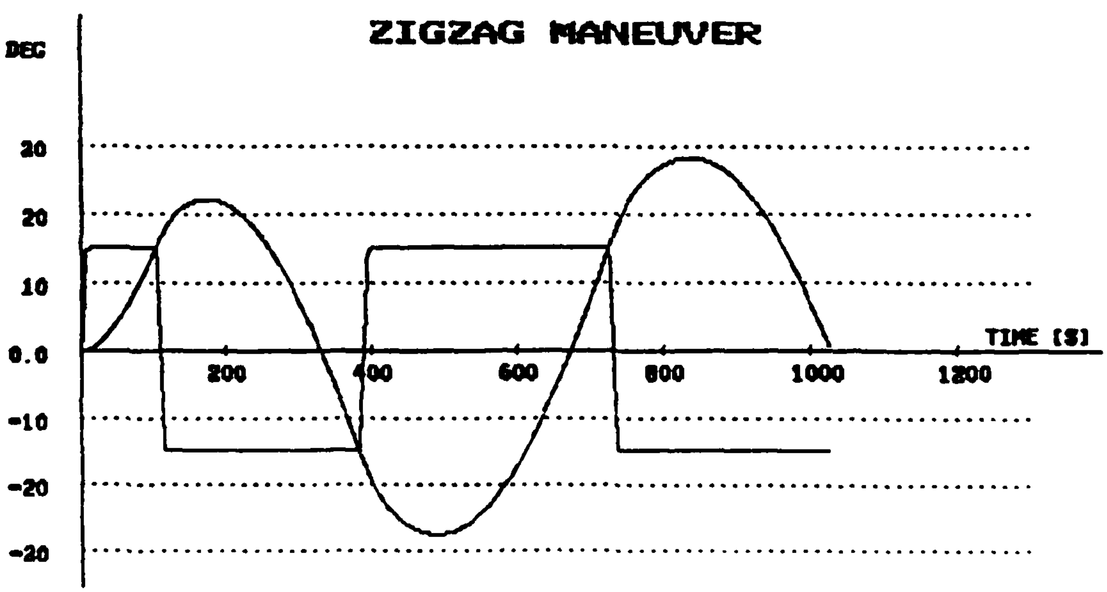
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ...... 7.0 deg

Time to Reach Execute
Heading Change............104. sec

Reach.....................329. sec

Second Overshoot Angle.....12.6 deg

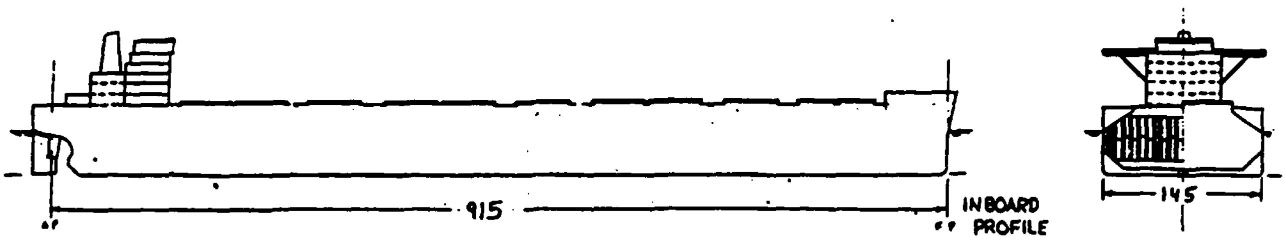


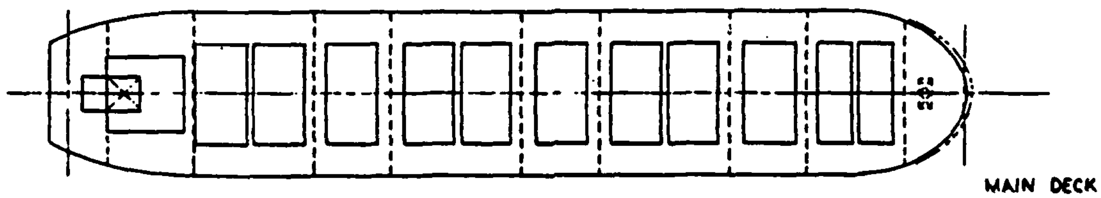
3. ship unstable (spiral maneuver)

SHIP ANALYTICS LINES PILOT CARD

M/S ' 150 K BULK CARRIER / COLLIER'

****





VESSEL PARTICULARS

Length between perpediculars... 915.00 ft
Beam.......................... 145.00 ft
Draft, loaded................. 52.00 ft
Block Coefficient............. 0.850 --
Displacement, loaded........171,240. LT
Max. speed.................... 15.1 knots

No. of engines .... 1 --
Engine type.................. Steam Turbine

Rudder turn rate .... 2.4 deg/s

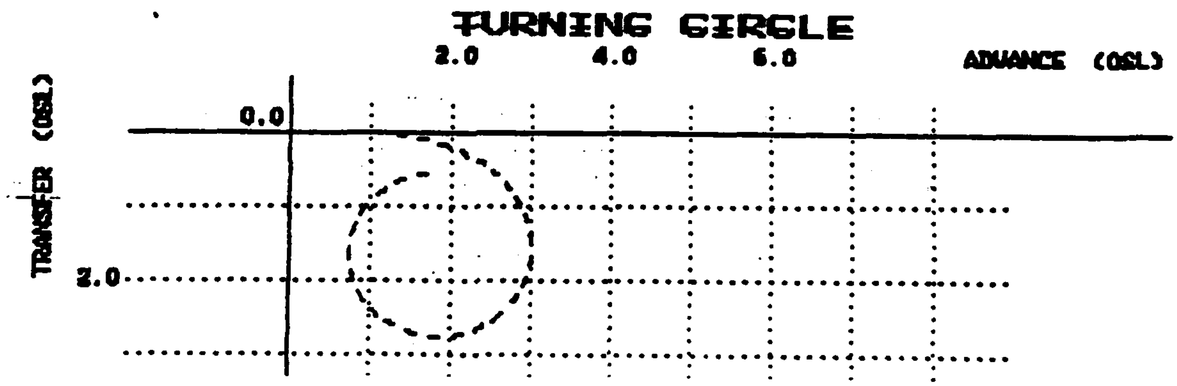
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	- 60.		
2. AS - HALF	- 40.		
3. AS - SLOW	- 20.		
4. AS - DSLOW	- 10.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	29.	5.0	8.45
7. AH - SLOW	38.	6.6	11.15
8. AH - HALF	52.	9.0	15.20
9. AH - FULL	72.	12.5	21.11
10. AH - SEA	86.5	15.1	25.50

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG)).... 2.93 osl ..... 2,678 ft
Transfer (90 deg).... 1.14 osl ..... 1,041 ft
Tactical Diameter ..... 2.71 osl ..... 2,476 ft



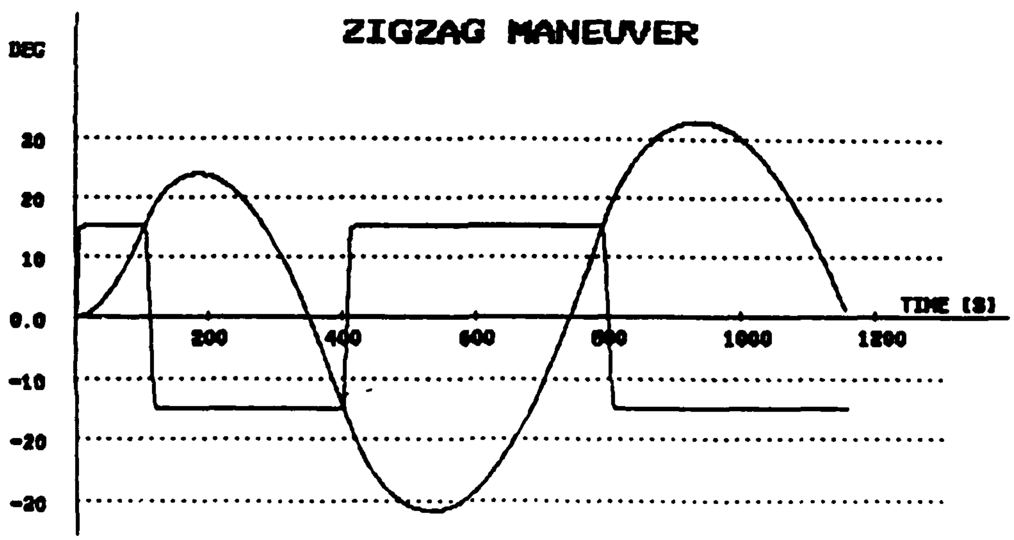
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ...... 8.8 deg

Time to Reach Execute
Heading Change............106. sec

Reach.....................350. sec

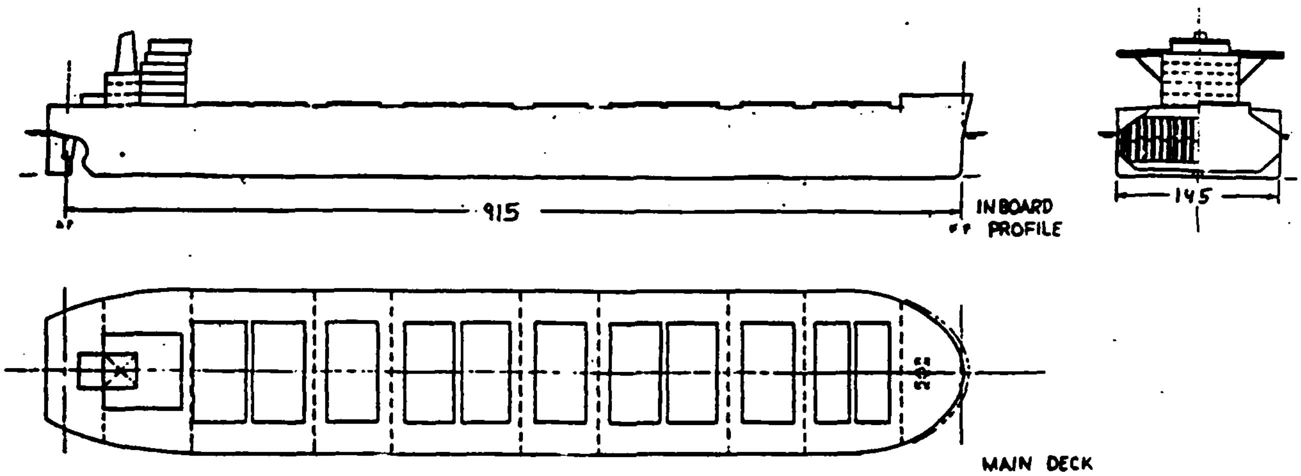
Second Overshoot Angle.....16.7 deg



3. ship unstable (spiral maneuver)

SHIP ANALYTICS LINES PILOT CARD

M/S ' 150 K BULK CARRIER / degraded rudder'



VESSEL PARTICULARS

Length between perpediculars...	915.00	ft
Beam...........................	145.00	ft
Draft, loaded..................	52.00	ft
Block Coefficient..............	0.850	--
Displacement, loaded........	171,240.	LT
Max. speed.....................	15.1	knots
No. of engines	1	--
Engine type....................	Steam Turbine	
Rudder turn rate	2.4	deg/s

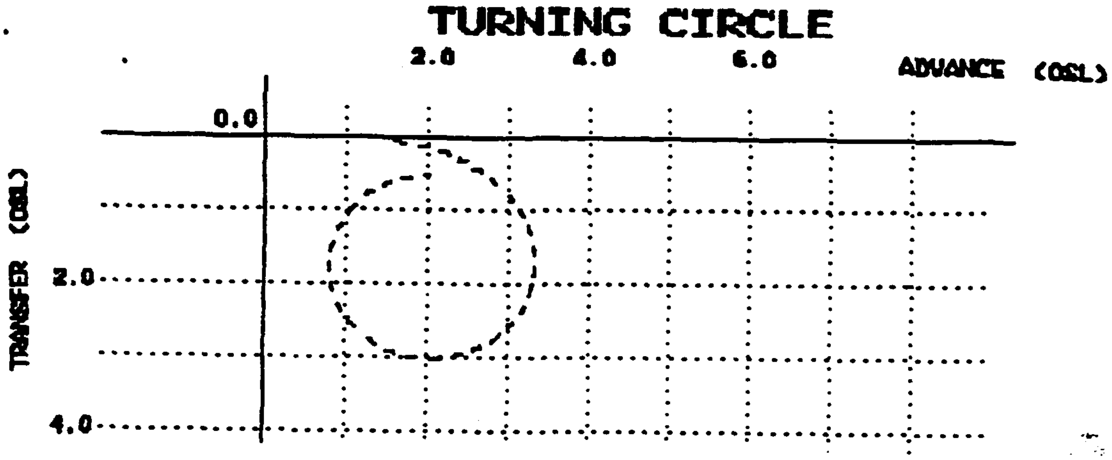
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	- 60.		
2. AS - HALF	- 40.		
3. AS - SLOW	- 20.		
4. AS - DSLOW	- 10.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	29.	5.0	8.45
7. AH - SLOW	38.	6.6	11.15
8. AH - HALF	52.	9.0	15.20
9. AH - FULL	72.	12.5	21.11
10. AH - SEA	86.5	15.1	25.50

DEEP WATER MANEUVERING CHRACTERISTICS
----

1. TURNING CIRCLE -35 DEG, 9 KNOTS

```
Advance  ( 90 DEG )....  3.25 osl  ..... 2,970 ft
Transfer ( 90 deg )....  1.27 osl  ..... 1,159 ft
Tactical Diameter .....  2.97 osl  ..... 2,717 ft
```



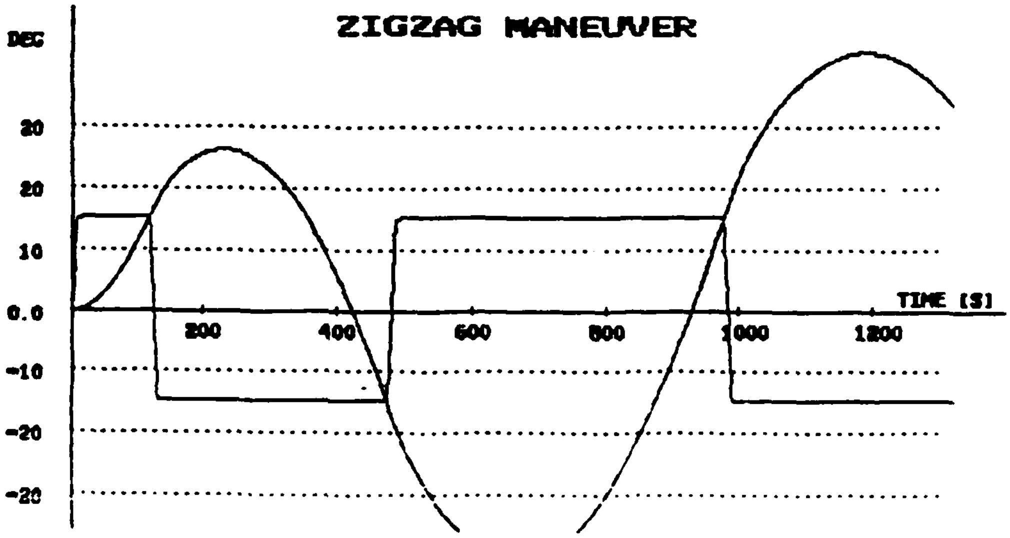
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ......11.2 deg

Time to Reach Execute
Heading Change............120. sec

Reach.....................422. sec

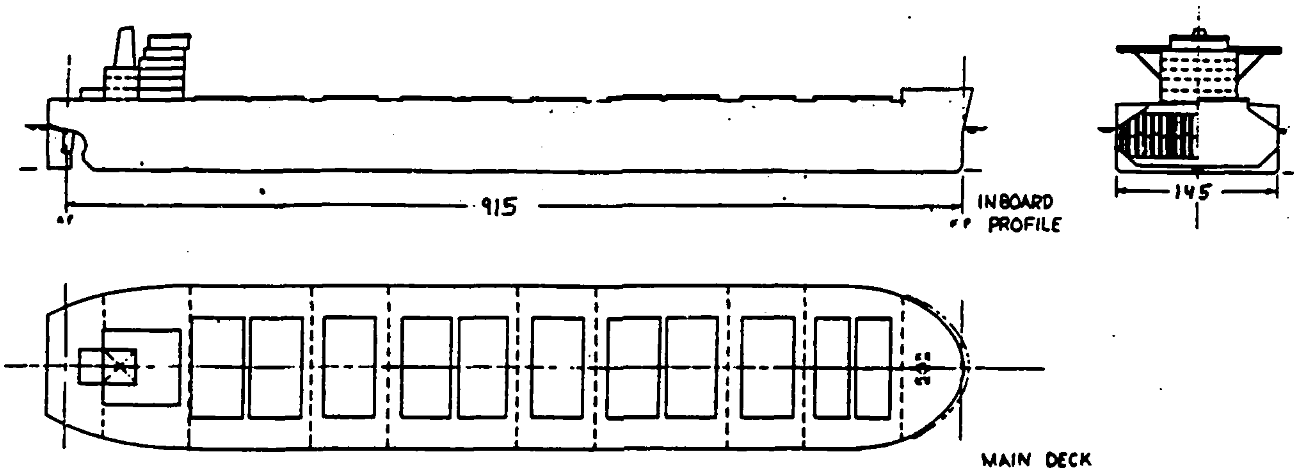
Second Overshoot Angle.....25.4 deg



3. ship unstable (spiral maneuver)

SHIP ANALYTICS LINES   P I L O T   C A R D

M/S ' 150 K BULK CARRIER / upgraded rudder'



VESSEL PARTICULARS

Length between perpediculars...	915.00	ft
Beam.........................	145.00	ft
Draft, loaded................	52.00	ft
Block Coefficient............	0.850	--
Displacement, loaded........	171,240.	LT
Max. speed...................	15.1	knots
No. of engines	1	--
Engine type..................	Steam Turbine	
Rudder turn rate	2.4	deg/s

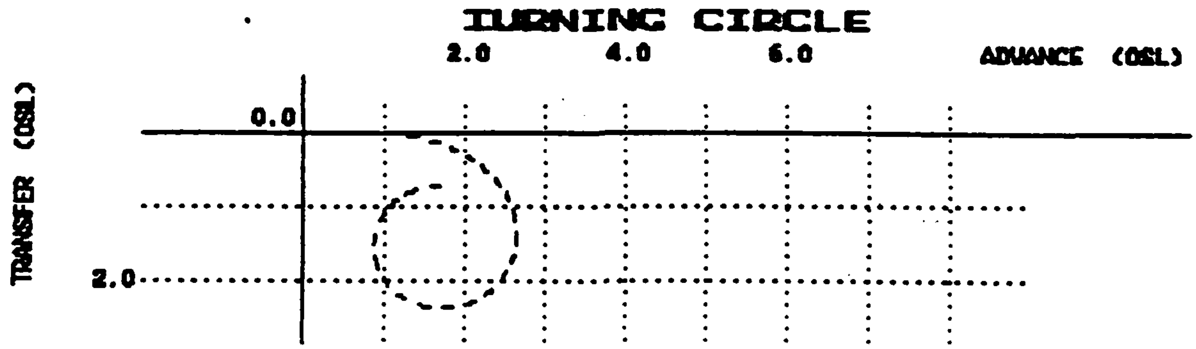
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	- 60.		
2. AS - HALF	- 40.		
3. AS - SLOW	- 20.		
4. AS - DSLOW	- 10.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	29.	5.0	8.45
7. AH - SLOW	38.	6.6	11.15
8. AH - HALF	52.	9.0	15.20
9. AH - FULL	72.	12.5	21.11
10. AH - SEA	86.5	15.1	25.50

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG)....	2.57 osl	.....	2,354 ft
Transfer (90 deg)....	0.99 osl	.....	903 ft
Tactical Diameter	2.33 osl	.....	2,133 ft



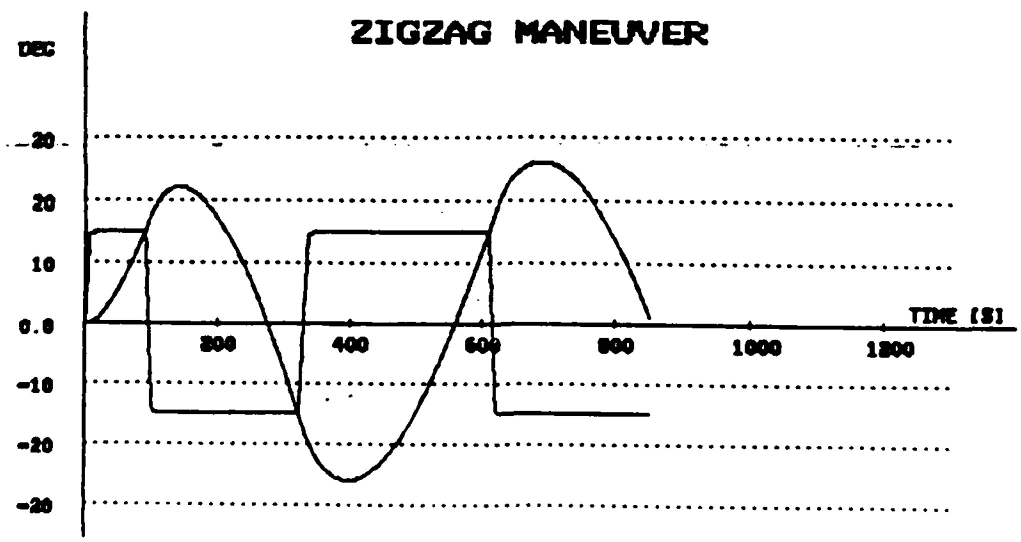
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ....6.9 deg

Time to Reach Execute
Heading Change.............90. sec

Reach.....................274. sec

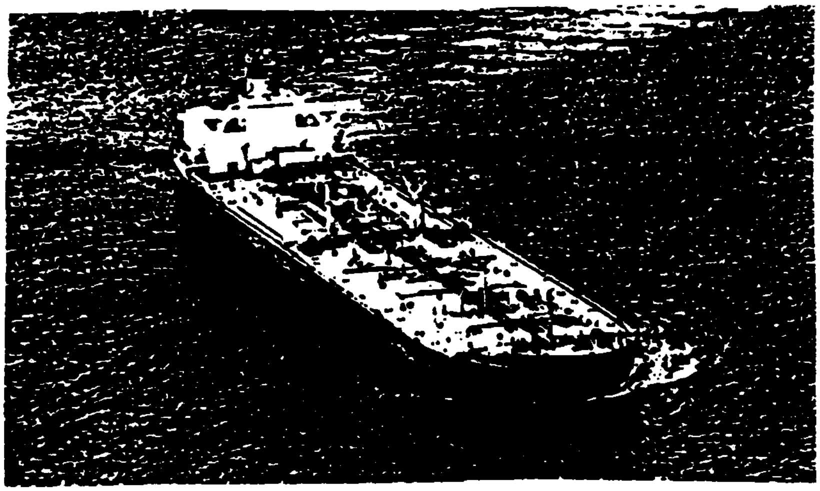
Second Overshoot Angle.....11.1 deg



3. ship marginally unstable (spiral maneuver)

SHIP ANALYTICS LINES P I L O T C A R D

M/S ' 250 K TANKER'



VESSEL PARTICULARS

Length between perpediculars...	1085.00	ft
Beam..........................	170.00	ft
Draft, loaded..................	61.00	ft
Block Coefficient..............	0.850	--
Displacement, loaded........	282,924.	LT
Max. speed.....................	15.2	knots
No. of engines	1	--
Engine type....................	Diesel	--
Rudder turn rate	2.33	deg/s

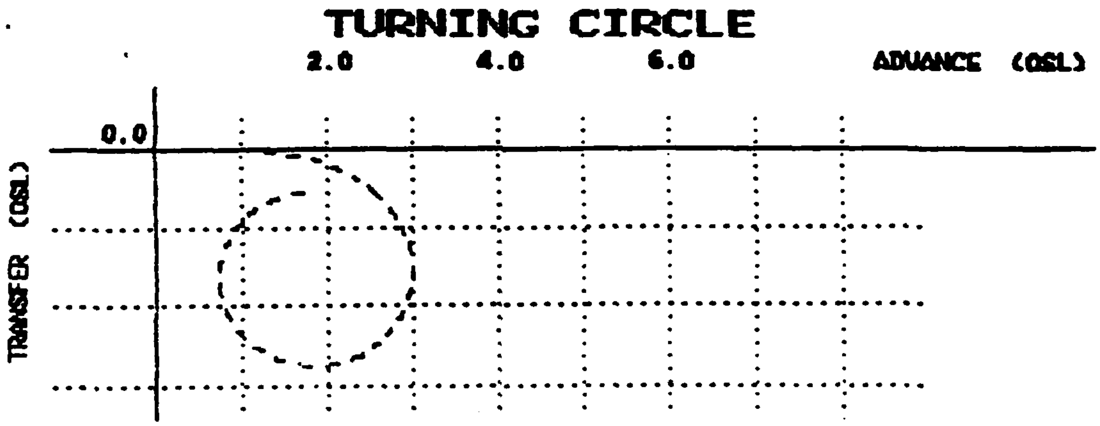
MANEUVERING SPEEDS:

EOT Settings	RPM	Speed	
	rev/min	knots	ft/s
1. AS - FULL	- 75.		
2. AS - HALF	- 40.		
3. AS - SLOW	- 20.		
4. AS - DSLOW	- 10.		
5. STOP	0.	0.0	0.0
6. AH - DSLOW	26.	5.0	8.45
7. AH - SLOW	35.	6.6	11.15
8. AH - HALF	47.	9.0	15.20
9. AH - FULL	66.	12.5	21.11
10. AH - SEA	80.	15.2	25.72

DEEP WATER MANEUVERING CHRACTERISTICS

1. TURNING CIRCLE -35 DEG, 9 KNOTS

Advance (90 DEG)....	2.92 osl	..... 3,163 ft
Transfer (90 deg)....	1.12 osl	..... 1,219 ft
Tactical Diameter	2.70 osl	..... 2,925 ft



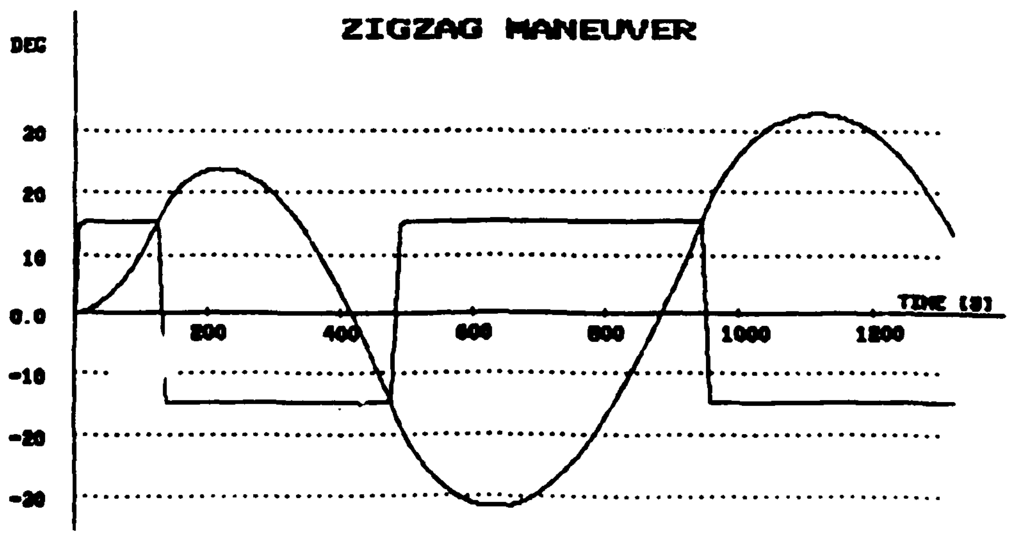
2. -15 / 15 ZIGZAG 9 KNOTS

First Overshoot Angl ...... 8.7 deg

Time to Reach Execute
Heading Change............126. sec

Reach.....................416. sec

Second Overshoot Angle.....16.9 deg



3. ship unstable (spiral maneuver)

Appendix D

PERFORMANCE DATA BY GROUP (TABLES)

The listings that follow present group performance data prepared according to the procedures described in Section 4 in the text. The tracks made by ownship's center of gravity for 16 transits (four for each of four pilots) through the waterway were sampled at "data lines" every 475 feet. The crosstrack distances were used in off-line calculations. In the accompanying tables, the first column identifies the data lines, from the start of the transit at Data line -43, to the turn center at Data line 0, and past the turn with positively-numbered data lines. The means and standard deviations (SD) are presented at each data line. Also presented are components of the calculation of the relative risk factor, RRF, by the formula presented in Table 4-1. B' is the crosstrack distance between the port and starboard "extreme points" of the ship. For each data line the mean of B' divided by two is presented. The next two columns are NS and NP, the number of SDs that fall between the extreme point and the channel edge to starboard and to port, respectively. The RRF values are in the final column.

The conditions for each of the nine scenarios are summarized in the accompanying table, taken from Section 3.

TABLE D-1: CONDITIONS FOR EXPERIMENTAL SCENARIOS

Scenario	Ship	Displacement (Light tons)	Length (Feet)	Beam (Feet)	Draft (Feet)	Rudder	Channel Width (Feet)
1	33,000 dwt bulk carrier	42,072	574	85	37	regular	489
2	1,000 - foot Great Lakes ore carrier	77,500	990	105	28	regular	757
3	76,000 dwt bulk carrier	86,174	855	106	40	regular	685
4	150,000 dwt bulker (R)	171,240	915	145	52	regular	798
5	150,000 dwt bulker (D)	171,240	915	145	52	degraded	798
6	150,000 dwt bulker (U)	171,240	915	145	52	up-graded	798
7	250,000 dwt tanker	282,924	1085	170	65	regular	943
8	76,000 dwt bulk carrier	86,174	855	106	40	regular	543
9	76,000 dwt bulk carrier	86,174	855	106	40	regular	400

33k all runs
ship length = 574. beam = 85.
channel width: 489.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	101.	9.	67.28	8.49	30.90	0.0000
-42	90.	13.	67.28	6.65	20.35	0.0000
-41	60.	21.	64.83	5.60	11.28	0.0000
-40	29.	28.	57.40	5.64	7.72	0.0000
-39	11.	28.	52.43	6.49	7.29	0.0000
-38	-5.	23.	48.73	8.70	8.31	0.0000
-37	-10.	19.	48.73	10.86	9.78	0.0000
-36	-13.	18.	46.23	12.05	10.54	0.0000
-35	-14.	19.	45.00	11.15	9.69	0.0000
-34	-14.	24.	45.00	8.90	7.76	0.0000
-33	-13.	28.	45.00	7.48	6.55	0.0000
-32	-13.	34.	43.75	6.26	5.49	0.0000
-31	-13.	39.	42.50	5.50	4.82	0.0000
-30	-13.	41.	42.50	5.25	4.63	0.0000
-29	-12.	42.	42.50	5.07	4.52	0.0000
-28	-10.	42.	42.50	5.00	4.52	0.0000
-27	-9.	41.	43.75	5.05	4.62	0.0000
-26	-7.	40.	43.75	5.25	4.89	0.0000
-25	-5.	38.	45.00	5.32	5.06	0.0000
-24	-2.	36.	43.75	5.63	5.53	0.0000
-23	1.	33.	43.75	6.02	6.06	0.0000
-22	3.	33.	45.00	6.01	6.17	0.0000
-21	6.	30.	43.75	6.41	6.78	0.0000
-20	8.	28.	43.75	6.85	7.39	0.0000
-19	9.	27.	43.75	7.11	7.79	0.0000
-18	11.	26.	43.75	7.42	8.24	0.0000
-17	12.	26.	43.75	7.12	8.03	0.0000
-16	14.	27.	43.75	6.88	7.91	0.0000
-15	16.	28.	43.75	6.65	7.78	0.0000
-14	17.	30.	43.75	6.18	7.35	0.0000
-13	20.	31.	43.75	5.81	7.10	0.0000
-12	23.	32.	43.75	5.59	7.04	0.0000
-11	26.	33.	44.98	5.24	6.82	0.0000
-10	31.	34.	47.45	4.90	6.71	0.0000
-9	38.	35.	47.48	4.55	6.69	0.0000
-8	45.	37.	47.48	4.09	6.52	0.0000
-7	53.	40.	47.48	3.58	6.24	0.0002
-6	61.	42.	47.48	3.20	6.09	0.0007
-5	69.	45.	47.48	2.83	5.89	0.0023
-4	77.	49.	46.23	2.49	5.66	0.0064
-3	82.	48.	52.43	2.27	5.67	0.0116
-2	67.	44.	83.15	2.17	5.24	0.0150
-1	10.	47.	123.35	2.37	2.80	0.0115
0	-115.	39.	90.32	6.84	0.99	0.1611
1	-22.	46.	47.48	4.76	3.80	0.0001
2	17.	48.	53.68	3.63	4.34	0.0001
3	32.	43.	59.88	3.53	5.01	0.0002
4	33.	48.	62.38	3.12	4.51	0.0009
5	30.	52.	58.63	3.03	4.19	0.0012
6	27.	55.	58.63	2.89	3.88	0.0020
7	26.	59.	57.40	2.76	3.63	0.0030
8	24.	63.	54.90	2.62	3.36	0.0048
9	23.	64.	54.90	2.59	3.30	0.0053
10	24.	62.	52.43	2.70	3.48	0.0038
11	26.	57.	53.68	2.88	3.79	0.0021
12	28.	54.	52.43	3.04	4.07	0.0012
13	30.	49.	51.18	3.33	4.54	0.0004
14	32.	45.	51.18	3.56	4.97	0.0002
15	33.	43.	52.43	3.69	5.23	0.0001
16	33.	42.	52.40	3.78	5.32	0.0001
17	31.	41.	52.43	3.92	5.40	0.0000
18	27.	39.	51.18	4.23	5.59	0.0000
19	25.	38.	49.95	4.43	5.71	0.0000
20	24.	37.	49.95	4.65	5.97	0.0000
21	24.	35.	52.43	4.86	6.22	0.0000
22	20.	31.	49.95	5.68	7.02	0.0000
23	18.	28.	49.95	6.31	7.59	0.0000
24	14.	24.	49.95	7.42	8.58	0.0000
25	8.	23.	110.45	5.42	6.12	0.0000
26	3.	23.	107.93	5.89	6.14	0.0000
27	-1.	22.	107.93	6.22	6.12	0.0000
28	-4.	21.	106.68	6.75	6.41	0.0000
29	-6.	21.	105.30	6.92	6.40	0.0000
30	-6.	22.	105.30	6.61	6.06	0.0000

1000 ft all runs
ship length = 990. beam = 105.
channel width: 757.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	181.	3.	71.88	47.26	*****	0.0000
-42	178.	5.	78.33	26.05	*****	0.0000
-41	161.	10.	89.02	12.60	44.27	0.0000
-40	134.	18.	93.29	8.45	23.46	0.0000
-39	105.	29.	91.16	6.38	13.67	0.0000
-38	71.	32.	86.89	6.86	11.27	0.0000
-37	41.	36.	78.33	7.25	9.56	0.0000
-36	19.	38.	74.03	7.43	8.42	0.0000
-35	2.	37.	67.58	8.27	8.40	0.0000
-34	-12.	37.	58.97	9.09	8.41	0.0000
-33	-20.	36.	61.13	9.25	8.17	0.0000
-32	-23.	33.	56.82	10.49	9.10	0.0000
-31	-24.	30.	56.82	11.56	9.96	0.0000
-30	-24.	28.	56.82	12.21	10.52	0.0000
-29	-25.	27.	56.82	12.97	11.11	0.0000
-28	-25.	26.	54.66	13.61	11.63	0.0000
-27	-26.	26.	54.66	13.38	11.41	0.0000
-26	-23.	25.	56.82	13.63	11.79	0.0000
-25	-20.	25.	56.82	13.70	12.10	0.0000
-24	-16.	25.	56.82	13.59	12.30	0.0000
-23	-11.	24.	56.82	14.01	13.09	0.0000
-22	-6.	22.	56.82	14.59	14.06	0.0000
-21	-2.	22.	54.66	14.84	14.69	0.0000
-20	3.	22.	54.66	14.56	14.78	0.0000
-19	6.	22.	54.66	14.53	15.05	0.0000
-18	8.	22.	54.66	14.37	15.14	0.0000
-17	11.	23.	56.82	13.41	14.36	0.0000
-16	14.	24.	56.82	12.59	13.73	0.0000
-15	18.	25.	56.82	12.20	13.61	0.0000
-14	23.	25.	58.97	11.85	13.66	0.0000
-13	29.	26.	58.97	11.18	13.37	0.0000
-12	35.	28.	61.13	10.01	12.49	0.0000
-11	42.	32.	61.13	8.64	11.30	0.0000
-10	49.	35.	61.13	7.62	10.41	0.0000
-9	57.	39.	61.13	6.60	9.47	0.0000
-8	65.	44.	63.28	5.62	8.54	0.0000
-7	74.	50.	63.28	4.84	7.84	0.0000
-6	86.	57.	63.28	4.03	7.05	0.0000
-5	95.	62.	63.28	3.53	6.58	0.0002
-4	105.	68.	58.97	3.16	6.25	0.0008
-3	106.	71.	86.89	2.61	5.57	0.0045
-2	81.	72.	135.53	2.25	4.51	0.0122
-1	12.	72.	204.78	2.24	2.57	0.0146
0	-110.	71.	135.40	4.97	1.87	0.0307
1	-12.	80.	61.13	4.11	3.8C	0.0001
2	26.	85.	80.47	3.19	3.80	0.0008
3	44.	84.	80.47	3.02	4.07	0.0013
4	54.	78.	84.75	3.06	4.43	0.0011
5	58.	76.	86.89	3.07	4.59	0.0011
6	57.	75.	84.75	3.15	4.68	0.0008
7	54.	73.	84.76	3.31	4.80	0.0005
8	50.	68.	82.62	3.61	5.07	0.0002
9	47.	65.	76.18	3.95	5.39	0.0000
10	45.	62.	78.33	4.14	5.59	0.0000
11	44.	58.	76.18	4.46	5.97	0.0000
12	41.	56.	76.18	4.65	6.12	0.0000
13	38.	55.	76.18	4.83	6.23	0.0000
'4	35.	54.	76.18	4.98	6.30	0.0000
15	33.	53.	76.18	5.12	6.36	0.0000
16	31.	52.	74.04	5.27	6.44	0.0000
17	28.	52.	74.04	5.38	6.45	0.0000
18	26.	50.	74.04	5.62	6.66	0.0000
19	25.	46.	69.74	6.18	7.28	0.0000
20	25.	42.	67.59	6.79	7.96	0.0000
21	25.	40.	67.59	7.20	8.46	0.0000
22	26.	39.	67.58	7.39	8.73	0.0000
23	26.	38.	67.58	7.58	8.98	0.0000
24	25.	39.	67.58	7.36	8.66	0.0000
25	24.	41.	65.43	6.97	8.13	0.0000
26	23.	43.	65.43	6.71	7.78	0.0000
27	22.	43.	63.28	6.86	7.90	0.0000
28	22.	41.	63.28	7.08	8.11	0.0000
29	22.	40.	63.28	7.33	8.45	0.0000
30	21.	38.	63.28	7.69	8.79	0.0000

76k2 - 658 ft chan, all runs (16)
ship length = 855. beam = 106.
channel width: 685.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	157.	5.	84.52	20.02	82.57	0.0000
-42	150.	8.	88.19	13.01	50.17	0.0000
-41	120.	15.	90.03	8.80	24.75	0.0000
-40	89.	26.	86.36	6.53	13.47	0.0000
-39	60.	33.	84.53	6.08	9.78	0.0000
-38	27.	38.	77.14	6.27	7.70	0.0000
-37	7.	41.	64.17	6.66	7.00	0.0000
-36	-9.	36.	60.45	7.98	7.49	0.0000
-35	-20.	30.	60.45	9.90	8.62	0.0000
-34	-24.	25.	58.58	12.12	10.23	0.0000
-33	-28.	19.	60.45	15.96	13.04	0.0000
-32	-31.	16.	58.59	19.58	15.74	0.0000
-31	-31.	16.	58.59	20.22	16.25	0.0000
-30	-31.	17.	54.86	18.42	14.83	0.0000
-29	-30.	18.	56.73	17.21	13.96	0.0000
-28	-28.	19.	54.86	16.88	13.89	0.0000
-27	-26.	19.	56.73	16.61	13.87	0.0000
-26	-24.	19.	54.86	16.45	13.95	0.0000
-25	-21.	19.	54.86	16.33	14.11	0.0000
-24	-18.	19.	54.86	15.83	13.94	0.0000
-23	-16.	19.	54.86	15.80	14.16	0.0000
-22	-13.	20.	54.86	15.29	13.97	0.0000
-21	-10.	22.	54.86	13.73	12.85	0.0000
-20	-7.	23.	56.73	12.65	12.05	0.0000
-19	-3.	25.	56.73	11.79	11.52	0.0000
-18	0.	26.	54.86	11.11	11.12	0.0000
-17	3.	28.	54.86	10.17	10.39	0.0000
-16	6.	30.	58.58	9.10	9.52	0.0000
-15	11.	33.	58.58	8.18	8.83	0.0000
-14	16.	37.	56.72	7.40	8.26	0.0000
-13	21.	41.	56.72	6.44	7.46	0.0000
-12	25.	44.	56.72	5.90	7.02	0.0000
-11	30.	49.	60.45	5.13	6.34	0.0000
-10	37.	54.	62.31	4.55	5.91	0.0000
-9	44.	56.	60.45	4.23	5.78	0.0000
-8	53.	62.	62.31	3.67	5.41	0.0001
-7	64.	66.	62.31	3.27	5.20	0.0005
-6	74.	70.	62.31	2.97	5.09	0.0015
-5	85.	75.	62.31	2.59	4.85	0.0048
-4	95.	80.	60.45	2.33	4.71	0.0099
-3	100.	82.	77.11	2.02	4.43	0.0217
-2	80.	76.	126.27	1.80	3.89	0.0359
-1	18.	75.	185.65	1.85	2.32	0.0424
0	-102.	60.	131.61	5.22	1.83	0.0336
1	-2.	61.	66.03	4.61	4.53	0.0000
2	52.	61.	79.00	3.48	5.17	0.0003
3	74.	55.	86.36	3.29	5.98	0.0005
4	80.	51.	86.36	3.47	6.63	0.0003
5	76.	46.	88.19	3.84	7.14	0.0001
6	70.	44.	82.67	4.33	7.53	0.0000
7	64.	42.	80.82	4.71	7.72	0.0000
8	59.	45.	78.97	4.53	7.12	0.0000
9	53.	51.	75.29	4.21	6.29	0.0000
10	50.	58.	69.74	3.86	5.61	0.0001
11	50.	62.	69.74	3.61	5.24	0.0002
12	50.	65.	71.60	3.42	4.96	0.0003
13	48.	65.	73.45	3.41	4.88	0.0003
14	45.	65.	73.45	3.47	4.85	0.0003
15	42.	63.	71.60	3.64	4.98	0.0001
16	39.	60.	71.60	3.88	5.17	0.0001
17	35.	57.	69.74	4.15	5.37	0.0000
18	31.	54.	67.88	4.53	5.70	0.0000
19	28.	50.	69.74	4.89	6.00	0.0000
20	23.	47.	69.74	5.28	6.28	0.0000
21	19.	44.	67.88	5.76	6.60	0.0000
22	13.	43.	67.88	6.09	6.70	0.0000
23	7.	41.	66.03	6.56	6.90	0.0000
24	2.	39.	64.17	7.04	7.15	0.0000
25	-1.	37.	62.31	7.66	7.59	0.0000
26	-4.	34.	62.31	8.39	8.16	0.0000
27	-7.	31.	60.45	9.31	8.89	0.0000
28	-9.	29.	58.59	10.20	9.56	0.0000
29	-12.	28.	58.59	10.73	9.89	0.0000
30	-13.	27.	56.73	11.19	10.20	0.0000

150k Orig. all runs
ship length = 915. beam = 145.
channel width: 798.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	191.	2.	102.24	57.07	*****	0.0000
-42	185.	4.	108.12	29.45	*****	0.0000
-41	160.	13.	113.98	9.40	33.39	0.0000
-40	128.	31.	112.04	5.12	13.39	0.0000
-39	100.	42.	108.14	4.53	9.30	0.0000
-38	66.	55.	102.25	4.17	6.54	0.0000
-37	39.	67.	90.39	4.03	5.19	0.0000
-36	18.	72.	86.43	4.09	4.58	0.0000
-35	0.	76.	82.45	4.19	4.18	0.0000
-34	-11.	77.	78.47	4.31	4.03	0.0000
-33	-19.	75.	80.47	4.50	4.00	0.0000
-32	-24.	72.	76.49	4.81	4.15	0.0000
-31	-26.	69.	74.49	5.09	4.33	0.0000
-30	-28.	65.	74.49	5.44	4.57	0.0000
-29	-28.	62.	76.49	5.70	4.79	0.0000
-28	-26.	58.	76.49	6.00	5.10	0.0000
-27	-24.	55.	74.49	6.36	5.48	0.0000
-26	-21.	52.	74.49	6.63	5.82	0.0000
-25	-19.	50.	74.49	6.92	6.14	0.0000
-24	-17.	47.	74.49	7.34	6.60	0.0000
-23	-14.	45.	74.49	7.55	6.91	0.0000
-22	-13.	44.	74.49	7.74	7.14	0.0000
-21	-12.	43.	72.50	7.90	7.36	0.0000
-20	-10.	43.	72.50	7.75	7.31	0.0000
-19	-8.	44.	72.50	7.59	7.22	0.0000
-18	-7.	44.	74.49	7.59	7.27	0.0000
-17	-5.	44.	74.49	7.43	7.20	0.0000
-16	-3.	45.	72.50	7.25	7.11	0.0000
-15	-1.	46.	72.50	7.18	7.14	0.0000
-14	1.	45.	72.50	7.27	7.31	0.0000
-13	3.	44.	74.49	7.32	7.44	0.0000
-12	4.	42.	78.47	7.53	7.74	0.0000
-11	8.	39.	80.47	8.06	8.45	0.0000
-10	11.	36.	78.47	8.72	9.33	0.0000
-9	16.	34.	78.47	8.93	9.87	0.0000
-8	22.	34.	78.47	8.79	10.06	0.0000
-7	28.	36.	78.47	8.23	9.80	0.0000
-6	33.	37.	80.47	7.71	9.52	0.0000
-5	39.	40.	78.48	6.94	8.89	0.0000
-4	43.	43.	82.44	6.38	8.40	0.0000
-3	41.	45.	104.23	5.59	7.40	0.0000
-2	25.	50.	141.21	4.68	5.67	0.0000
-1	-23.	53.	200.97	4.17	3.32	0.0005
0	-113.	51.	148.63	7.18	2.71	0.0034
1	16.	56.	88.41	5.25	5.81	0.0000
2	80.	59.	116.01	3.44	6.18	0.0003
3	105.	64.	121.87	2.67	5.95	0.0038
4	112.	72.	119.91	2.31	5.42	0.0104
5	106.	79.	119.91	2.19	4.90	0.0143
6	93.	81.	117.95	2.32	4.63	0.0102
7	79.	80.	110.12	2.62	4.59	0.0044
8	66.	80.	102.25	2.89	4.55	0.0019
9	57.	79.	100.28	3.06	4.49	0.0011
10	49.	76.	94.35	3.37	4.67	0.0004
11	46.	73.	94.35	3.55	4.82	0.0002
12	44.	71.	92.37	3.71	4.96	0.0001
13	42.	70.	94.35	3.76	4.95	0.0001
14	39.	70.	90.38	3.86	4.98	0.0001
15	37.	69.	90.39	3.94	4.99	0.0000
16	35.	68.	88.41	4.04	5.05	0.0000
17	34.	68.	84.44	4.13	5.12	0.0000
18	35.	68.	82.45	4.15	5.17	0.0000
19	37.	70.	84.44	3.95	5.00	0.0000
20	38.	71.	84.44	3.90	4.99	0.0000
21	38.	70.	84.44	3.97	5.07	0.0000
22	38.	67.	84.44	4.15	5.29	0.0000
23	36.	63.	84.44	4.45	5.61	0.0000
24	35.	58.	80.47	4.91	6.13	0.0000
25	34.	52.	80.47	5.52	6.83	0.0000
26	34.	45.	80.47	6.36	7.87	0.0000
27	33.	40.	78.48	7.26	8.94	0.0000
28	33.	36.	78.48	8.07	9.90	0.0000
29	31.	33.	80.47	8.75	10.66	0.0000
30	28.	31.	80.47	9.30	11.11	0.0000

150k Degr., all runs
ship length = 915. beam = 145.
channel width: 798.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	191.	3.	96.32	42.20	*****	0.0000
-42	187.	5.	102.23	23.30	*****	0.0000
-41	165.	14.	112.05	8.71	32.28	0.0000
-40	138.	26.	112.05	5.83	16.62	0.0000
-39	109.	34.	110.09	5.23	11.58	0.0000
-38	73.	49.	110.09	4.39	7.35	0.0000
-37	41.	62.	104.21	4.11	5.44	0.0000
-36	12.	70.	96.33	4.15	4.50	0.0000
-35	-14.	78.	82.45	4.22	3.85	0.0001
-34	-29.	80.	78.47	4.38	3.66	0.0001
-33	-37.	77.	80.47	4.62	3.65	0.0001
-32	-42.	72.	80.47	5.01	3.85	0.0001
-31	-44.	67.	82.46	5.40	4.09	0.0000
-30	-45.	61.	80.47	5.92	4.47	0.0000
-29	-42.	56.	78.48	6.48	4.96	0.0000
-28	-39.	52.	78.48	6.87	5.37	0.0000
-27	-36.	51.	78.48	6.97	5.57	0.0000
-26	-31.	49.	78.48	7.13	5.87	0.0000
-25	-27.	49.	78.48	7.03	5.95	0.0000
-24	-22.	50.	78.48	6.84	5.97	0.0000
-23	-17.	50.	78.48	6.81	6.13	0.0000
-22	-13.	49.	76.49	6.79	6.28	0.0000
-21	-9.	48.	72.50	6.97	6.58	0.0000
-20	-8.	47.	74.49	7.10	6.77	0.0000
-19	-7.	44.	74.49	7.53	7.21	0.0000
-18	-8.	42.	72.50	7.91	7.54	0.0000
-17	-9.	40.	72.50	8.30	7.86	0.0000
-16	-10.	39.	72.50	8.72	8.22	0.0000
-15	-10.	37.	72.50	9.05	8.51	0.0000
-14	-9.	36.	72.50	9.20	8.69	0.0000
-13	-9.	36.	72.50	9.33	8.84	0.0000
-12	-7.	35.	76.49	9.38	8.96	0.0000
-11	-4.	34.	78.47	9.58	9.35	0.0000
-10	0.	33.	78.47	9.63	9.65	0.0000
-9	7.	33.	80.45	9.36	9.79	0.0000
-8	15.	34.	80.45	8.90	9.75	0.0000
-7	22.	36.	80.45	8.25	9.47	0.0000
-6	31.	40.	80.45	7.18	8.71	0.0000
-5	39.	46.	80.47	6.03	7.73	0.0000
-4	45.	52.	78.47	5.34	7.10	0.0000
-3	48.	60.	102.25	4.16	5.75	0.0000
-2	35.	65.	137.29	3.49	4.56	0.0002
-1	-11.	65.	202.54	3.18	2.84	0.0030
0	-99.	55.	133.04	6.63	3.04	0.0012
1	39.	60.	94.33	4.43	5.73	0.0000
2	114.	76.	108.13	2.33	5.35	0.0099
3	146.	87.	129.58	1.42	4.77	0.0778
4	145.	95.	135.33	1.25	4.32	0.1056
5	128.	103.	133.39	1.33	3.81	0.0919
6	105.	112.	129.59	1.46	3.33	0.0725
7	77.	121.	121.85	1.65	2.93	0.0512
8	50.	126.	117.97	1.83	2.62	0.0380
9	27.	126.	112.09	2.07	2.50	0.0254
10	7.	119.	104.19	2.42	2.54	0.0133
11	-5.	107.	94.28	2.89	2.80	0.0045
12	-12.	90.	92.29	3.53	3.27	0.0007
13	-16.	71.	92.31	4.57	4.12	0.0000
14	-16.	56.	88.37	5.84	5.27	0.0000
15	-16.	49.	84.42	6.78	6.14	0.0000
16	-12.	51.	82.44	6.47	6.01	0.0000
17	-6.	56.	80.47	5.74	5.54	0.0000
18	1.	63.	78.48	5.06	5.10	0.0000
19	8.	66.	80.47	4.68	4.92	0.0000
20	14.	67.	78.48	4.60	5.00	0.0000
21	18.	65.	78.48	4.64	5.20	0.0000
22	23.	63.	78.48	4.71	5.43	0.0000
23	26.	60.	80.47	4.84	5.72	0.0000
24	29.	57.	80.47	5.05	6.06	0.0000
25	30.	54.	80.47	5.39	6.49	0.0000
26	30.	50.	78.48	5.83	7.03	0.0000
27	30.	46.	78.48	6.36	7.66	0.0000
28	29.	43.	78.48	6.77	8.12	0.0000
29	28.	41.	76.49	7.15	8.50	0.0000
30	27.	40.	78.48	7.37	8.71	0.0000

150k Upgr., all runs
ship length = 915. beam = 145.
channel width: 798.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	189.	3.	106.15	33.18	*****	0.0000
-42	183.	6.	110.07	16.52	73.22	0.0000
-41	155.	20.	108.12	6.70	21.94	0.0000
-40	126.	33.	108.12	4.91	12.47	0.0000
-39	101.	45.	106.17	4.28	8.80	0.0000
-38	68.	59.	100.28	3.88	6.17	0.0001
-37	43.	69.	94.35	3.79	5.03	0.0001
-36	23.	72.	86.43	4.02	4.67	0.0000
-35	4.	74.	82.45	4.24	4.36	0.0000
-34	-7.	73.	78.48	4.46	4.27	0.0000
-33	-15.	71.	78.48	4.76	4.33	0.0000
-32	-20.	66.	74.49	5.21	4.61	0.0000
-31	-21.	63.	74.49	5.47	4.82	0.0000
-30	-20.	60.	74.49	5.73	5.07	0.0000
-29	-18.	58.	74.49	5.96	5.32	0.0000
-28	-16.	56.	74.49	6.09	5.51	0.0000
-27	-15.	55.	74.49	6.18	5.65	0.0000
-26	-13.	55.	72.50	6.15	5.67	0.0000
-25	-13.	55.	74.49	6.11	5.65	0.0000
-24	-11.	55.	74.49	6.08	5.70	0.0000
-23	-8.	54.	74.49	6.12	5.81	0.0000
-22	-7.	53.	72.50	6.25	5.98	0.0000
-21	-6.	52.	72.50	6.34	6.11	0.0000
-20	-5.	51.	72.50	6.48	6.30	0.0000
-19	-4.	50.	72.50	6.57	6.42	0.0000
-18	-3.	49.	72.50	6.69	6.58	0.0000
-17	-2.	48.	72.50	6.82	6.72	0.0000
-16	-2.	47.	72.50	6.96	6.89	0.0000
-15	-1.	46.	72.50	7.12	7.09	0.0000
-14	-1.	45.	74.49	7.30	7.28	0.0000
-13	0.	42.	74.49	7.66	7.68	0.0000
-12	2.	40.	76.49	8.06	8.17	0.0000
-11	4.	38.	74.49	8.52	8.74	0.0000
-10	7.	35.	74.49	9.05	9.43	0.0000
-9	9.	34.	74.49	9.40	9.96	0.0000
-8	12.	33.	78.47	9.32	10.04	0.0000
-7	16.	32.	76.48	9.55	10.54	0.0000
-6	21.	31.	76.48	9.63	10.94	0.0000
-5	25.	31.	76.48	9.72	11.37	0.0000
-4	29.	31.	80.47	9.29	11.19	0.0000
-3	29.	34.	106.20	7.73	9.45	0.0000
-2	12.	35.	148.88	6.76	7.42	0.0000
-1	-38.	35.	204.60	6.66	4.51	0.0000
0	-130.	37.	152.21	10.30	3.20	0.0007
1	-6.	62.	94.33	5.02	4.84	0.0000
2	59.	80.	96.25	3.06	4.55	0.0011
3	93.	92.	96.29	2.29	4.32	0.0110
4	117.	104.	106.18	1.68	3.93	0.0465
5	126.	108.	108.15	1.53	3.87	0.0631
6	126.	108.	108.17	1.52	3.86	0.0644
7	123.	106.	106.20	1.59	3.92	0.0559
8	118.	104.	104.23	1.70	3.99	0.0446
9	112.	98.	102.25	1.87	4.15	0.0307
10	107.	92.	102.25	2.07	4.39	0.0192
11	100.	84.	98.29	2.37	4.75	0.0089
12	94.	78.	102.22	2.61	5.03	0.0045
13	86.	72.	102.22	2.92	5.31	0.0018
14	76.	69.	98.29	3.23	5.44	0.0006
15	70.	70.	98.27	3.32	5.31	0.0005
16	61.	72.	98.27	3.33	5.02	0.0004
17	52.	77.	92.37	3.32	4.69	0.0005
18	45.	81.	90.40	3.23	4.34	0.0006
19	41.	84.	86.43	3.25	4.23	0.0006
20	39.	84.	84.44	3.30	4.23	0.0005
21	38.	83.	82.46	3.36	4.27	0.0004
22	37.	80.	84.44	3.48	4.42	0.0003
23	37.	76.	82.45	3.69	4.65	0.0001
24	36.	69.	82.45	4.04	5.08	0.0000
25	36.	62.	82.45	4.53	5.68	0.0000
26	34.	55.	84.43	5.11	6.34	0.0000
27	30.	48.	82.45	5.95	7.18	0.0000
28	26.	43.	80.47	6.88	8.09	0.0000
29	22.	39.	80.47	7.55	8.65	0.0000
30	17.	36.	78.48	8.41	9.38	0.0000

250k ** all runs
ship length = 1085. beam = 170.
channel width: 943.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	228.	1.	108.57	*****	*****	0.0000
-42	225.	2.	115.61	54.17	*****	0.0000
-41	211.	6.	124.94	22.23	91.57	0.0000
-40	187.	14.	129.58	11.01	37.71	0.0000
-39	159.	24.	129.58	7.62	20.81	0.0000
-38	127.	38.	131.89	5.64	12.41	0.0000
-37	101.	48.	127.25	5.08	9.31	0.0000
-36	68.	60.	115.61	4.78	7.05	0.0000
-35	40.	71.	103.87	4.63	5.75	0.0000
-34	21.	75.	94.44	4.74	5.28	0.0000
-33	9.	77.	94.45	4.79	5.02	0.0000
-32	0.	73.	92.08	5.18	5.18	0.0000
-31	-6.	69.	89.72	5.63	5.46	0.0000
-30	-10.	65.	87.36	6.08	5.77	0.0000
-29	-13.	62.	89.73	6.41	6.00	0.0000
-28	-15.	57.	89.73	6.93	6.42	0.0000
-27	-16.	53.	89.73	7.57	6.96	0.0000
-26	-17.	49.	89.73	8.07	7.39	0.0000
-25	-17.	47.	87.36	8.62	7.88	0.0000
-24	-17.	44.	87.36	9.11	8.32	0.0000
-23	-17.	42.	87.36	9.49	8.71	0.0000
-22	-15.	42.	87.36	9.58	8.85	0.0000
-21	-14.	42.	87.36	9.58	8.90	0.0000
-20	-13.	41.	87.36	9.58	8.98	0.0000
-19	-11.	41.	87.36	9.57	9.03	0.0000
-18	-10.	41.	87.36	9.70	9.22	0.0000
-17	-9.	40.	87.36	9.91	9.47	0.0000
-16	-7.	40.	87.36	9.77	9.40	0.0000
-15	-6.	41.	89.73	9.46	9.17	0.0000
-14	-3.	42.	92.09	9.07	8 91	0.0000
-13	-1.	42.	92.09	8.95	8.92	0.0000
-12	4.	43.	94.45	8.67	8.84	0.0000
-11	10.	43.	94.43	8.48	8.92	0.0000
-10	15.	43.	94.43	8.40	9.10	0.0000
-9	22.	44.	94.43	8.00	8.99	0.0000
-8	30.	47.	94.43	7.31	8.57	0.0000
-7	38.	52.	94.43	6.57	8.07	0.0000
-6	47.	56.	94.43	5.85	7.53	0.0000
-5	53.	59.	94.45	5.45	7.24	0.0000
-4	52.	63.	115.62	4.79	6.44	0.0000
-3	42.	68.	141.22	4.27	5.51	0.0000
-2	14.	75.	189.11	3.58	3.96	0.0002
-1	-40.	75.	250.13	3.49	2.42	0.0080
0	-136.	65.	156.96	6.91	2.73	0.0032
1	4.	66.	113.19	5.36	5.49	0.0000
2	97.	68.	106.18	3.98	6.84	0.0000
3	148.	75.	124.89	2.63	6.57	0.0043
4	172.	82.	136.54	1.97	6.15	0.0244
5	182.	90.	138.88	1.67	5.72	0.0475
6	180.	96.	141.22	1.56	5.30	0.0594
7	169.	103.	141.23	1.57	4.87	0.0582
8	153.	106.	138.91	1.69	4.56	0.0455
9	136.	107.	134.27	1.87	4.41	0.0307
10	119.	104.	134.27	2.10	4.37	0.0179
11	101.	99.	129.61	2.44	4.49	0.0073
12	83.	90.	129.61	2.89	4.73	0.0019
13	65.	80.	124.95	3.50	5.12	0.0002
14	50.	74.	117.94	4.08	5.43	0.0000
15	37.	67.	113.23	4.81	5.91	0.0000
16	25.	61.	110.90	5.53	6.36	0.0000
17	18.	58.	106.21	6.03	6.66	0.0000
18	12.	57.	103.86	6.28	6.71	0.0000
19	10.	56.	96.79	6.52	6.87	0.0000
20	10.	56.	94.44	6.57	6.92	0.0000
21	11.	56.	92.09	6.61	7.01	0.0000
22	14.	55.	94.45	6.64	7.13	0.0000
23	17.	53.	92.09	6.84	7.48	0.0000
24	20.	51.	94.45	7.03	7.82	0.0000
25	23.	48.	92.09	7.45	8.41	0.0000
26	25.	45.	92.09	7.89	9.02	0.0000
27	27.	43.	92.09	8.16	9.41	0.0000
28	28.	42.	92.09	8.44	9.81	0.0000
29	29.	41.	89.72	8.65	10.07	0.0000
30	28.	40.	92.09	8.85	10.28	0.0000

76k3 - 543 ft chan, all runs (8)
ship length = 855. beam = 106.
channel width: 543.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	123.	6.	82.68	10.99	51.72	0.0000
-42	115.	8.	90.05	7.81	34.92	0.0000
-41	88.	15.	90.05	6.41	18.36	0.0000
-40	57.	24.	86.38	5.34	10.14	0.0000
-39	29.	24.	82.69	6.56	8.90	0.0000
-38	1.	27.	71.60	7.36	7.44	0.0000
-37	-17.	26.	60.44	8.84	7.56	0.0000
-36	-30.	20.	60.45	12.08	9.10	0.0000
-35	-36.	16.	60.45	15.92	11.29	0.0000
-34	-36.	14.	56.73	17.39	12.35	0.0000
-33	-36.	16.	56.73	16.14	11.55	0.0000
-32	-33.	19.	56.73	13.20	9.66	0.0000
-31	-29.	22.	56.73	10.86	8.31	0.0000
-30	-25.	25.	56.73	9.42	7.44	0.0000
-29	-22.	29.	56.73	8.02	6.56	0.0000
-28	-17.	32.	53.00	7.29	6.22	0.0000
-27	-14.	34.	53.00	6.86	6.01	0.0000
-26	-12.	35.	53.00	6.53	5.85	0.0000
-25	-10.	35.	53.00	6.47	5.93	0.0000
-24	-8.	35.	53.00	6.51	6.04	0.0000
-23	-7.	34.	53.00	6.68	6.28	0.0000
-22	-5.	33.	53.00	6.67	6.39	0.0000
-21	-3.	33.	53.00	6.62	6.47	0.0000
-20	0.	33.	53.00	6.70	6.58	0.0000
-19	2.	33.	53.00	6.63	6.73	0.0000
-18	4.	34.	53.00	6.37	6.61	0.0000
-17	6.	34.	53.00	6.21	6.56	0.0000
-16	8.	35.	53.00	6.09	6.53	0.0000
-15	9.	35.	53.00	6.00	6.54	0.0000
-14	11.	34.	53.00	6.10	6.76	0.0000
-13	12.	34.	56.73	6.00	6.73	0.0000
-12	14.	35.	56.73	5.74	6.53	0.0000
-11	16.	38.	56.73	5.24	6.06	0.0000
-10	18.	41.	60.44	4.72	5.59	0.0000
-9	24.	44.	60.44	4.26	5.34	0.0000
-8	33.	47.	64.17	3.69	5.06	0.0001
-7	39.	50.	64.17	3.33	4.89	0.0004
-6	50.	53.	64.17	2.95	4.83	0.0016
-5	61.	56.	64.17	2.59	4.75	0.0048
-4	70.	59.	60.45	2.37	4.73	0.0089
-3	80.	60.	56.73	2.27	4.95	0.0116
-2	78.	56.	90.06	1.84	4.60	0.0329
-1	48.	50.	154.85	1.39	3.30	0.0828
0	-38.	52.	111.98	3.80	2.34	0.0097
1	89.	58.	67.88	1.96	5.01	0.0250
2	137.	61.	97.38	0.61	5.09	0.2709
3	146.	63.	104.69	0.32	4.97	0.3745
4	139.	67.	104.69	0.41	4.57	0.3409
5	119.	70.	101.05	0.74	4.16	0.2296
6	95.	74.	97.40	1.07	3.63	0.1424
7	73.	78.	90.06	1.40	3.28	0.0813
8	54.	76.	90.05	1.68	3.11	0.0474
9	38.	69.	82.65	2.18	3.29	0.0151
10	28.	58.	75.25	2.91	3.89	0.0018
11	21.	45.	75.25	3.93	4.86	0.0000
12	15.	32.	71.57	5.74	6.67	0.0000
13	13.	25.	67.88	7.62	8.66	0.0000
14	13.	20.	67.88	9.37	10.61	0.0000
15	13.	20.	67.89	9.44	10.70	0.0000
16	13.	22.	67.89	8.64	9.82	0.0000
17	14.	24.	67.89	7.85	9.02	0.0000
18	16.	27.	67.89	6.98	8.13	0.0000
19	16.	29.	64.17	6.62	7.74	0.0000
20	18.	30.	64.17	6.26	7.44	0.0000
21	19.	33.	64.17	5.64	6.75	0.0000
22	18.	35.	64.17	5.44	6.46	0.0000
23	16.	35.	64.17	5.45	6.33	0.0000
24	13.	37.	60.45	5.37	6.08	0.0000
25	11.	37.	60.45	5.42	6.02	0.0000
26	10.	34.	60.45	5.90	6.51	0.0000
27	7.	31.	64.17	6.51	6.97	0.0000
28	2.	29.	60.45	7.27	7.39	0.0000
29	-5.	27.	60.45	8.07	7.74	0.0000
30	-11.	26.	60.45	8.49	7.67	0.0000

76k1 - 400 ft chan, all runs (8)
ship length = 855. beam = 106.
channel width: 400.

DL	Mean	SD	Mean B"/2	NS	NP	RRF
-43	89.	5.	79.00	6.76	43.94	0.0000
-42	82.	6.	82.68	5.57	31.17	0.0000
-41	58.	12.	82.69	4.87	14.46	0.0000
-40	32.	21.	75.30	4.33	7.33	0.0000
-39	13.	23.	71.60	4.96	6.05	0.0000
-38	-7.	28.	64.17	5.03	4.52	0.0000
-37	-20.	31.	60.44	5.22	3.91	0.0000
-36	-29.	28.	60.45	5.96	3.94	0.0000
-35	-32.	26.	60.45	6.61	4.13	0.0000
-34	-31.	24.	56.73	7.17	4.62	0.0000
-33	-31.	26.	56.73	6.75	4.36	0.0000
-32	-27.	28.	56.73	6.08	4.16	0.0000
-31	-24.	33.	56.73	5.09	3.61	0.0000
-30	-21.	38.	56.73	4.27	3.20	0.0002
-29	-16.	42.	56.73	3.81	3.03	0.0007
-28	-13.	44.	53.00	3.65	3.04	0.0013
-27	-10.	45.	53.00	3.49	3.05	0.0013
-26	-7.	45.	56.73	3.34	3.02	0.0013
-25	-4.	44.	56.73	3.36	3.17	0.0017
-24	-1.	43.	56.73	3.39	3.33	0.0012
-23	1.	41.	56.73	3.45	3.51	0.0007
-22	6.	39.	56.73	3.51	3.80	0.0005
-21	9.	39.	53.00	3.57	4.03	0.0003
-20	11.	36.	53.00	3.74	4.32	0.0002
-19	12.	34.	53.00	3.92	4.64	0.0001
-18	13.	32.	53.00	4.15	4.92	0.0000
-17	14.	30.	53.00	4.43	5.33	0.0000
-16	15.	29.	56.73	4.43	5.47	0.0000
-15	16.	27.	60.45	4.58	5.74	0.0000
-14	16.	27.	56.73	4.78	6.01	0.0000
-13	17.	28.	56.73	4.54	5.79	0.0000
-12	18.	27.	56.73	4.55	5.87	0.0000
-11	21.	28.	60.44	4.24	5.77	0.0000
-10	25.	28.	60.44	4.15	5.99	0.0000
-9	31.	29.	60.44	3.79	5.98	0.0000
-8	38.	33.	64.17	2.99	5.34	0.0001
-7	46.	35.	60.44	2.67	5.30	0.0014
-6	54.	39.	64.17	2.11	4.90	0.0038
-5	62.	44.	64.17	1.67	4.49	0.0174
-4	71.	48.	60.45	1.42	4.40	0.0475
-3	79.	51.	60.45	1.20	4.30	0.0778
-2	70.	46.	104.69	0.54	3.57	0.1151
-1	35.	44.	161.82	0.08	1.66	0.2948
0	-64.	46.	111.92	3.28	0.53	0.5166
1	62.	65.	71.57	1.02	2.91	0.2986
2	102.	76.	97.34	0.01	2.68	0.1557
3	110.	73.	97.40	-0.10	2.93	0.4997
4	106.	62.	97.40	-0.05	3.39	0.5415
5	91.	47.	101.05	0.16	4.01	0.5202
6	74.	31.	97.40	0.91	5.64	0.4364
7	50.	26.	93.73	2.17	6.08	0.1814
8	32.	31.	86.38	2.61	4.64	0.0150
9	15.	41.	79.00	2.58	3.30	0.0045
10	5.	46.	71.60	2.67	2.90	0.0054
11	2.	43.	64.17	3.09	3.20	0.0057
12	4.	35.	67.89	3.62	3.84	0.0017
13	7.	26.	64.17	4.97	5.50	0.0002
14	11.	17.	64.17	7.53	8.89	0.0000
15	16.	8.	64.17	15.56	19.79	0.0000
16	20.	8.	67.89	14.48	19.68	0.0000
17	23.	13.	67.89	8.32	11.73	0.0000
18	23.	19.	67.89	5.65	8.00	0.0000
19	21.	24.	67.89	4.55	6.31	0.0000
20	19.	28.	67.89	4.08	5.46	0.0000
21	16.	31.	67.89	3.73	4.74	0.0001
22	12.	35.	67.89	3.42	4.08	0.0003
23	8.	40.	60.45	3.31	3.69	0.0006
24	6.	43.	60.45	3.10	3.36	0.0014
25	5.	44.	56.73	3.16	3.38	0.0012
26	5.	42.	60.44	3.21	3.45	0.0010
27	4.	38.	60.44	3.55	3.77	0.0003
28	2.	33.	60.45	4.12	4.24	0.0000
29	-1.	31.	64.17	4.37	4.32	0.0000
30	-7.	31.	60.45	4.71	4.27	0.0000

Appendix E

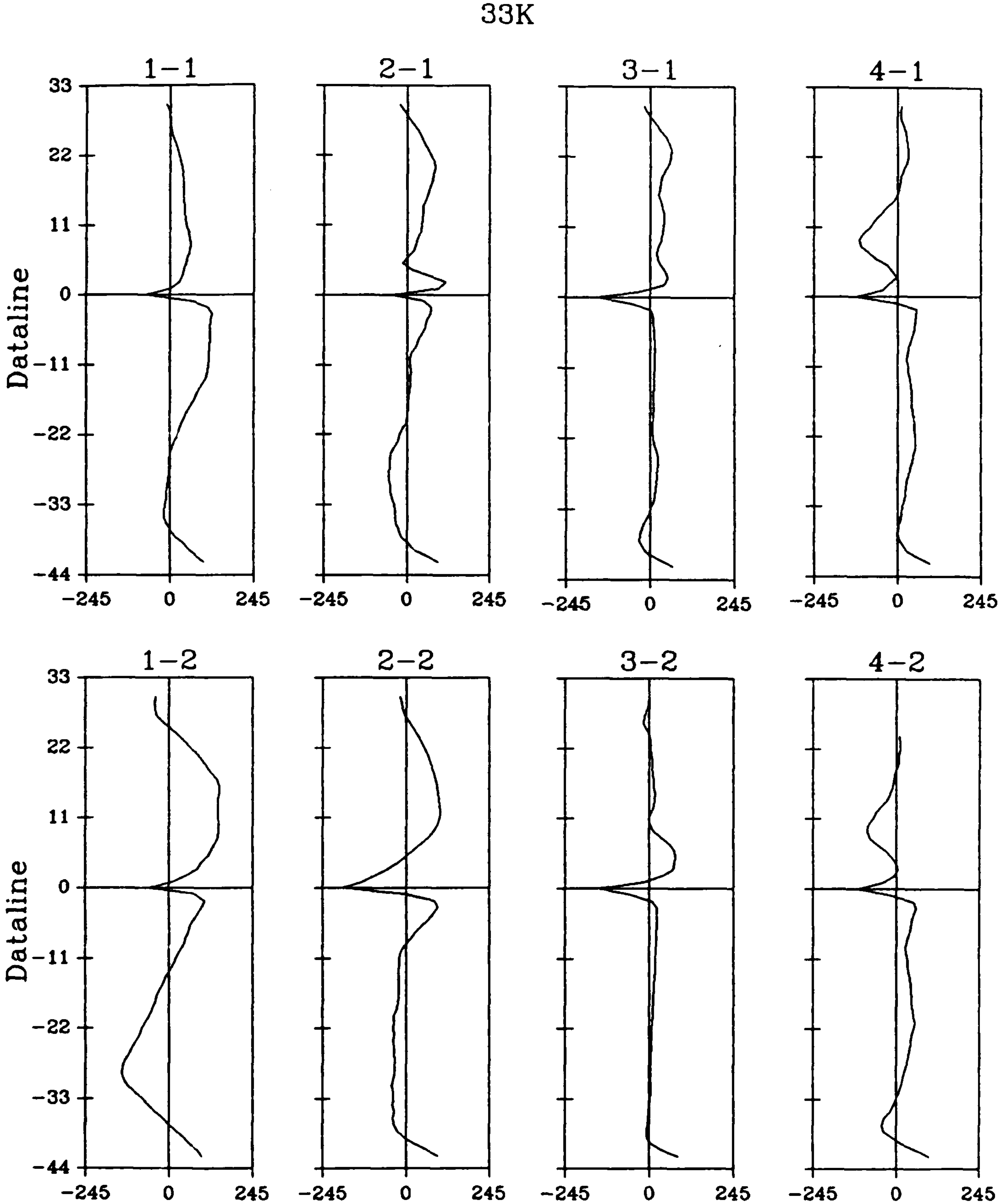
PERFORMANCE DATA BY INDIVIDUAL RUN (PLOTS)

The plots that follow present performance for individual runs prepared according to the procedures described in Section 4 in the text. The track made by ownship's center of gravity for each transit was sampled at "data lines" every 475 feet. The 16 runs are presented for each ship; eight runs are presented for each of the scenarios with the 76,000 deadweight ton bulker in an additional channel. In each plot the x-axis is the channel width with zero at the centerline. The y-axis is the length of the channel with zero at the turn center. Each run is identified by two digits: the pilot's number and the repetition of that ship for that pilot.

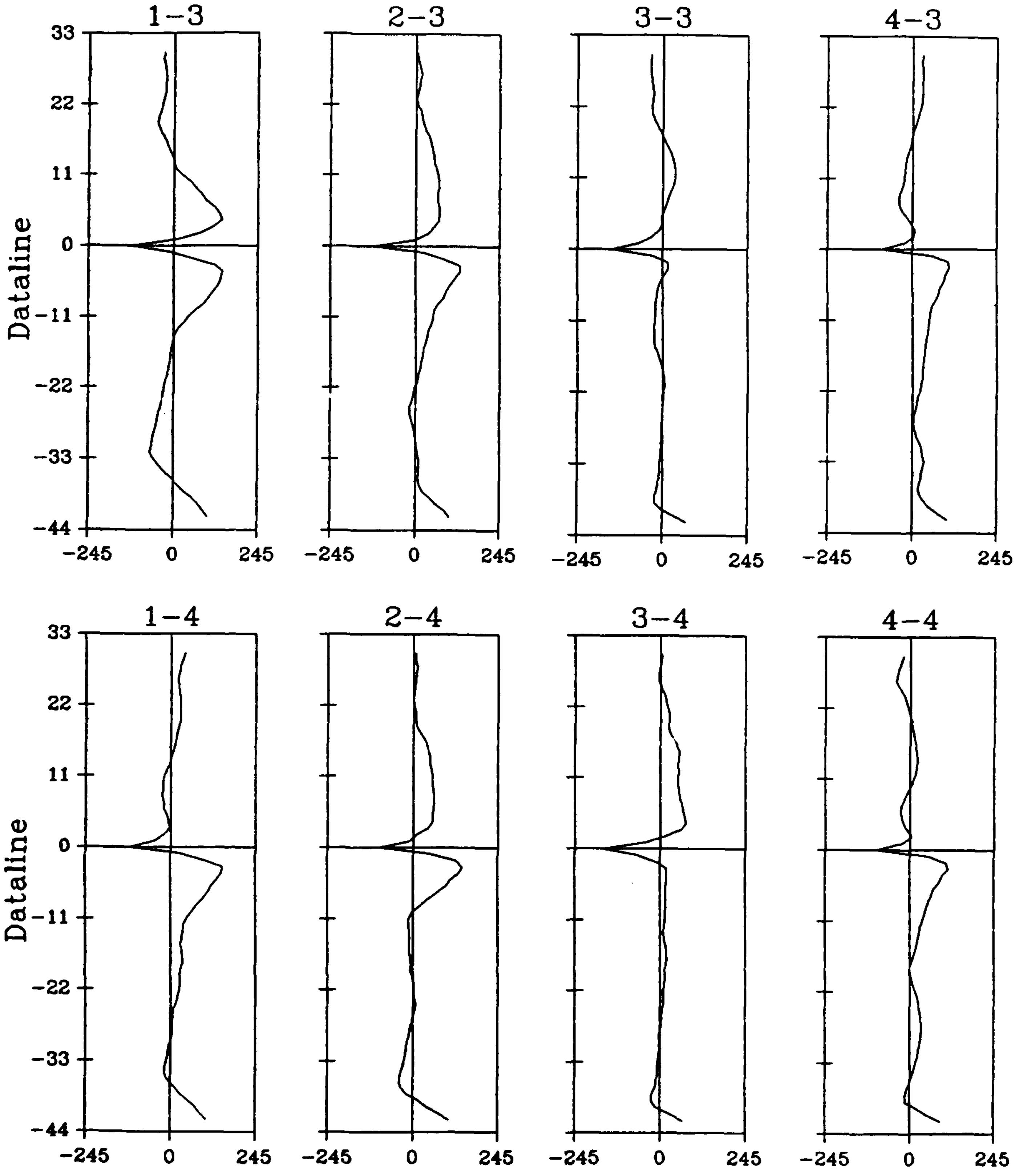
The conditions for each of the nine scenarios are summarized in the accompanying table, taken from Section 3.

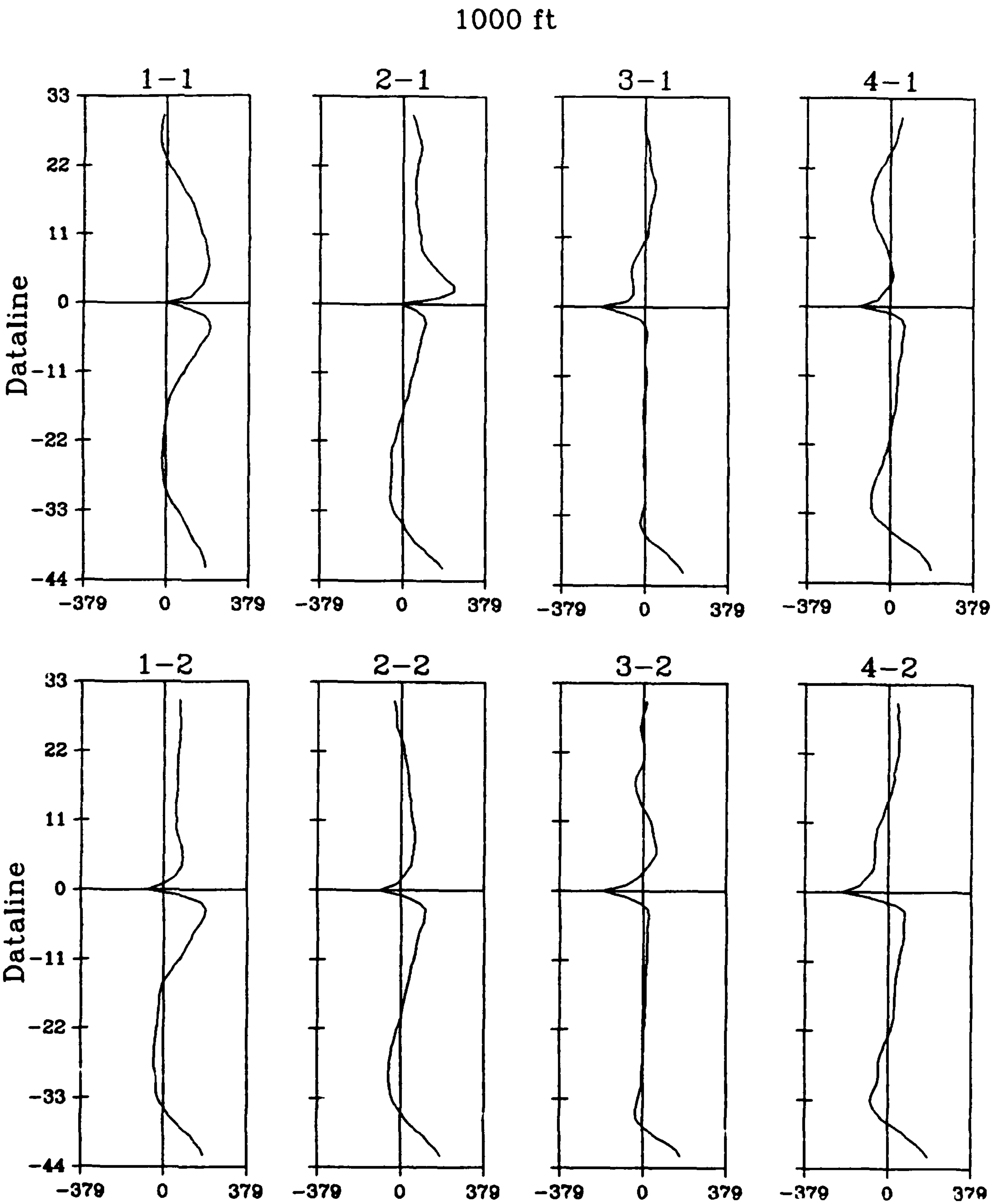
TABLE E-1: CONDITIONS FOR EXPERIMENTAL SCENARIOS

Scenario	Ship	Displacement (Light tons)	Length (Feet)	Beam (Feet)	Draft (Feet)	Rudder	Channel Width (Feet)
1	33,000 dwt bulk carrier	42,072	574	85	37	regular	489
2	1,000 - foot Great Lakes ore carrier	77,500	990	105	28	regular	757
3	76,000 dwt bulk carrier	86,174	855	106	40	regular	685
4	150,000 dwt bulker (R)	171,240	915	145	52	regular	798
5	150,000 dwt bulker (D)	171,240	915	145	52	degraded	798
6	150,000 dwt bulker (U)	171,240	915	145	52	up-graded	798
7	250,000 dwt tanker	282,924	1085	170	65	regular	943
8	76,000 dwt bulk carrier	86,174	855	106	40	regular	543
9	76,000 dwt bulk carrier	86,174	855	106	40	regular	400


33K
1-1
2-1
3-1
4-1
1-2
2-2
3-2
4-2
Dataline
33
22
11
0
-11
-22
-33
-44
-245
0
245

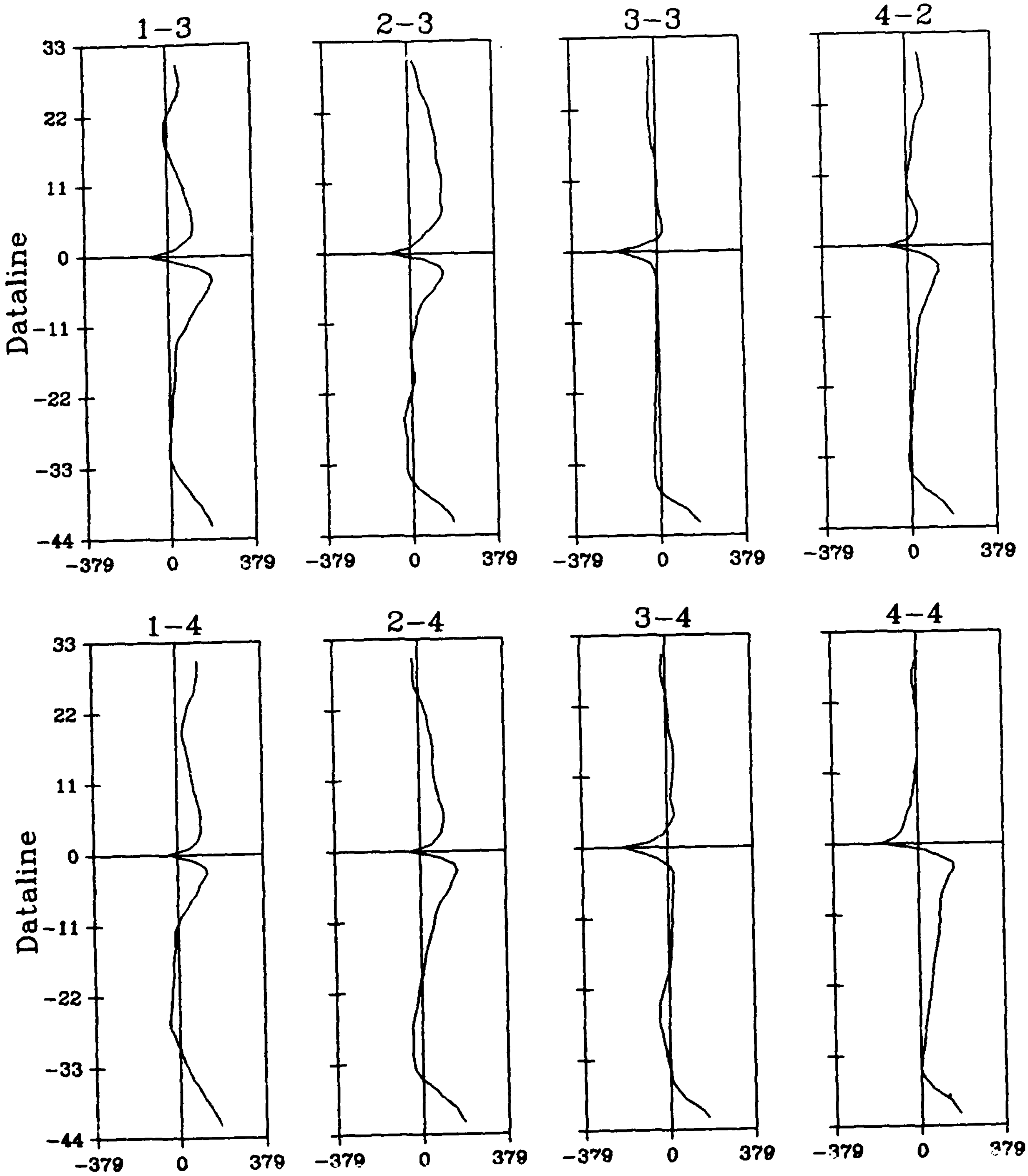
33k (con't)


1-3
2-3
3-3
4-3
1-4
2-4
3-4
4-4
Dataline
Dataline
33
22
11
0
-11
-22
-33
-44
-245
0
245

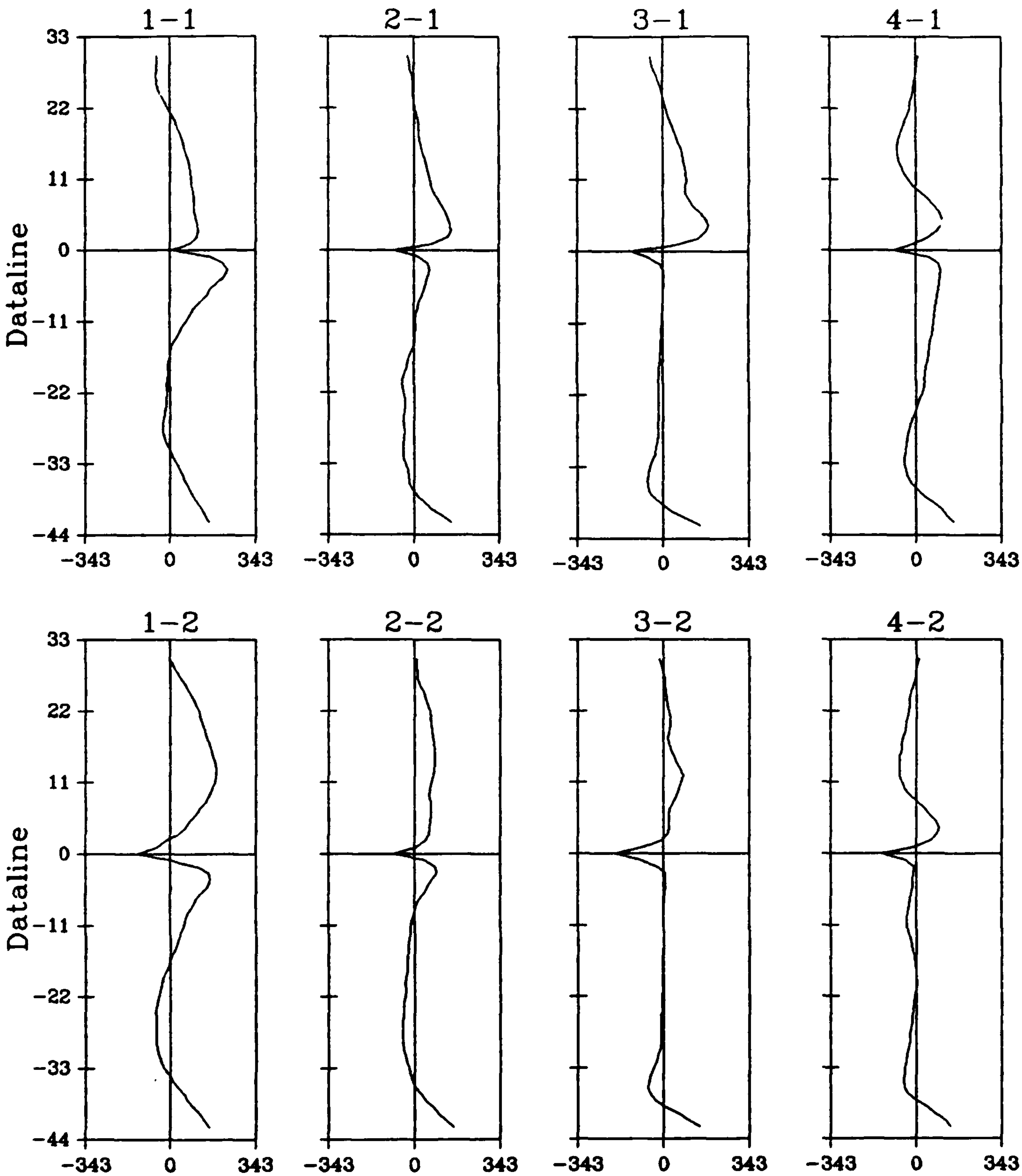


1000 ft
1-1
2-1
3-1
4-1
1-2
2-2
3-2
4-2
Dataline
33
22
11
0
-11
-22
-33
-44
-379
0
379

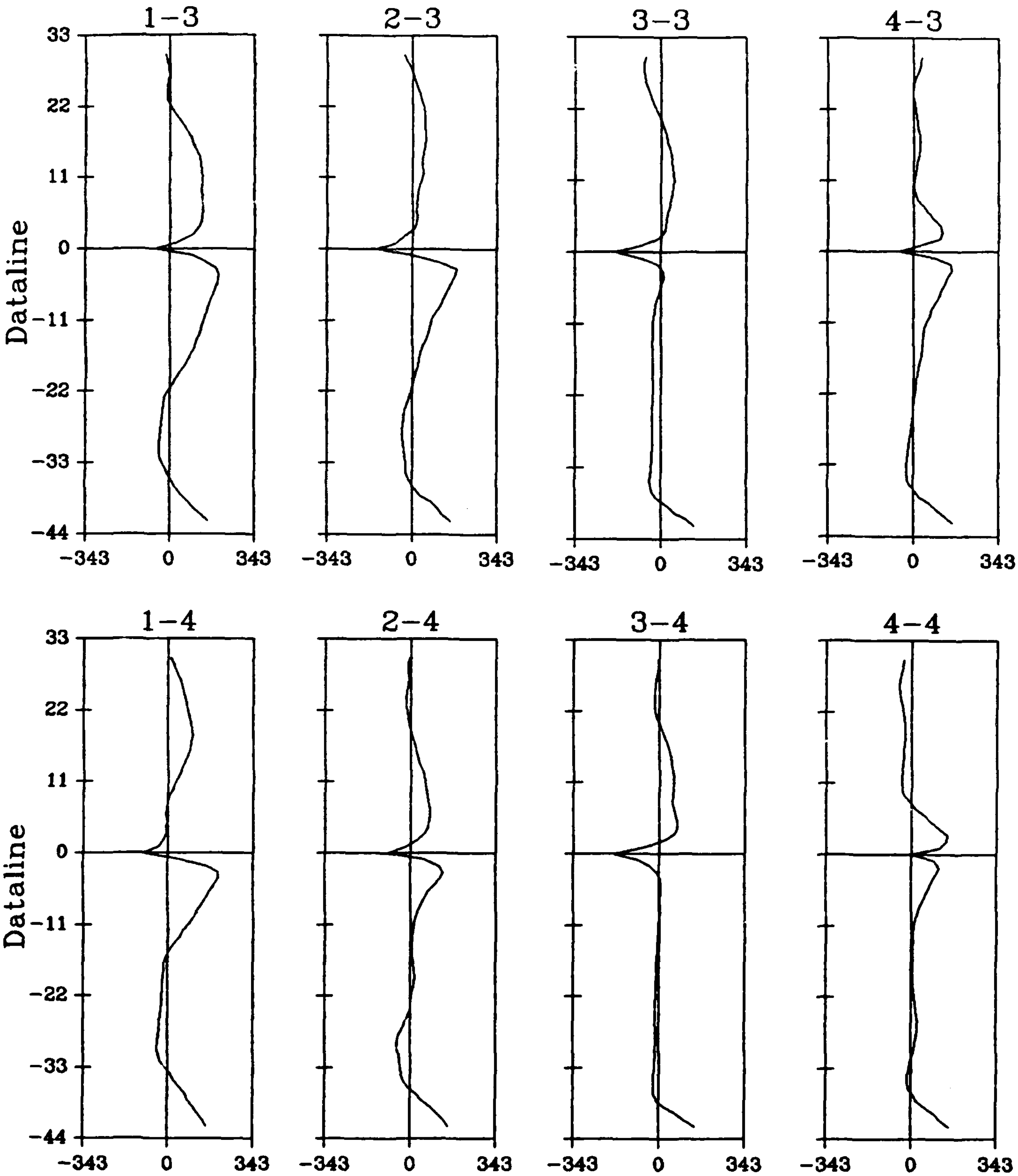
1000 ft (con't)

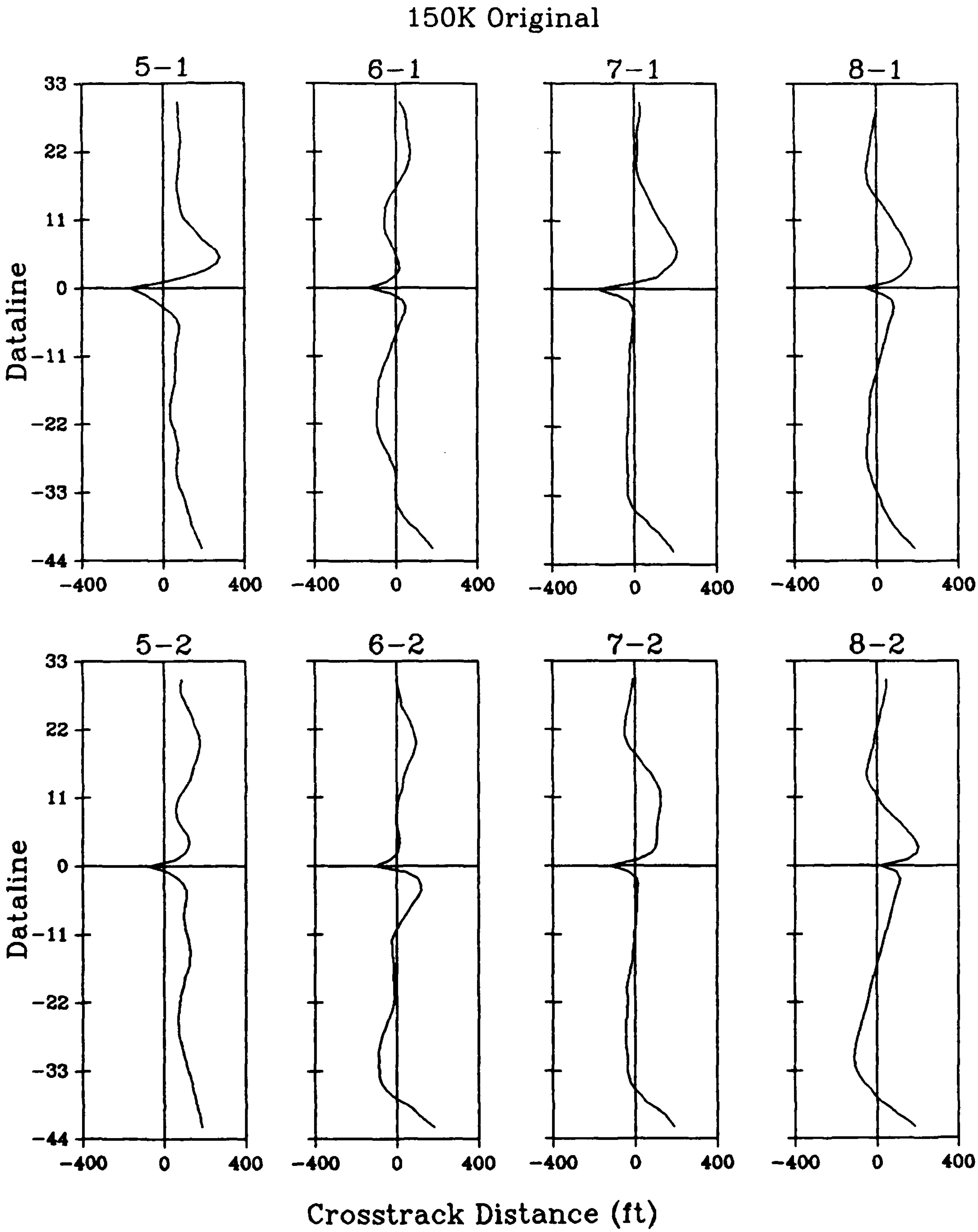


76k – 685 ft chan.

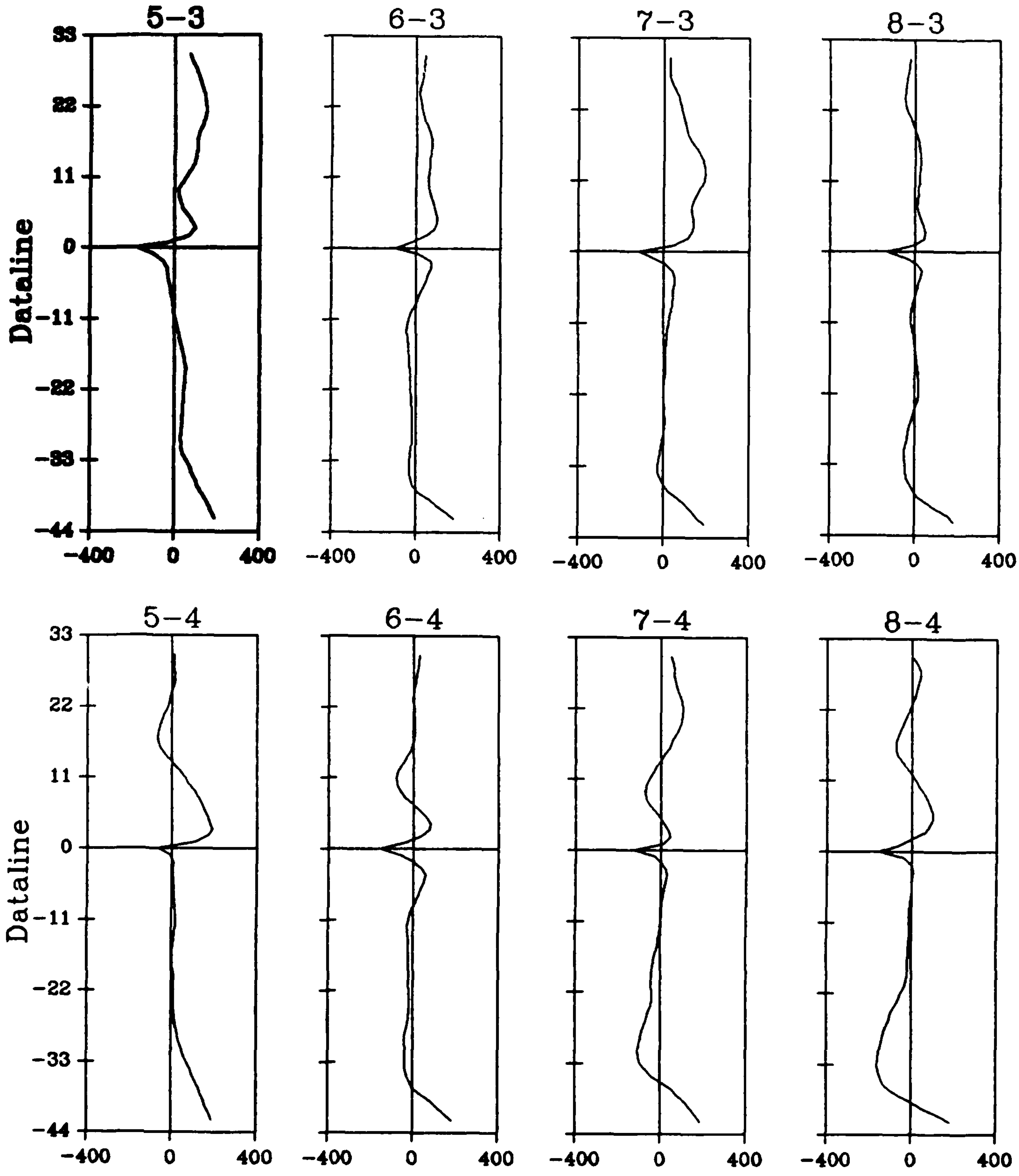


76k – 685 ft chan. (con't)

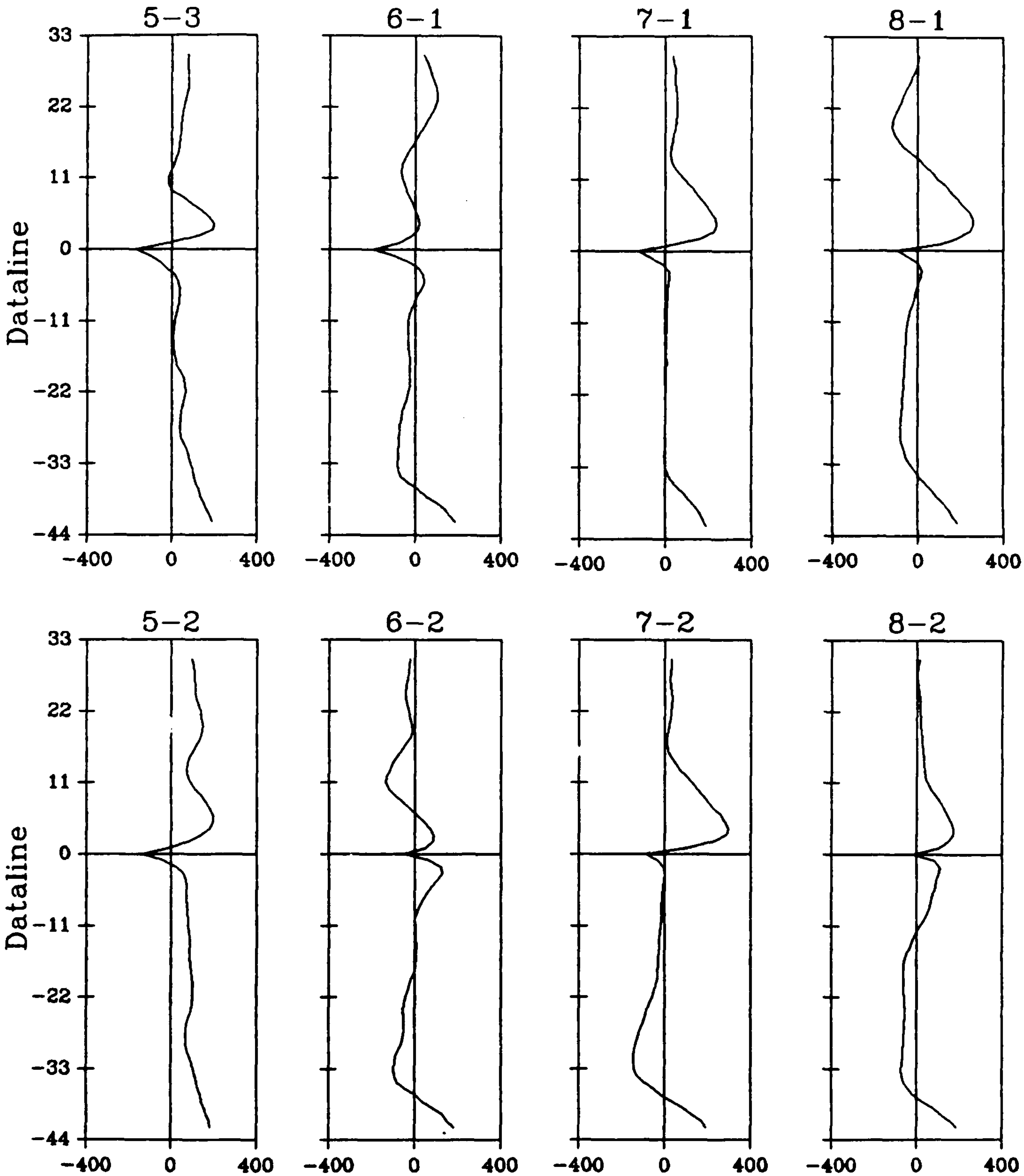



150K Original
5-1
6-1
7-1
8-1
5-2
6-2
7-2
8-2
Dataline
33
22
11
0
-11
-22
-33
-44
-400
0
400
Crosstrack Distance (ft)

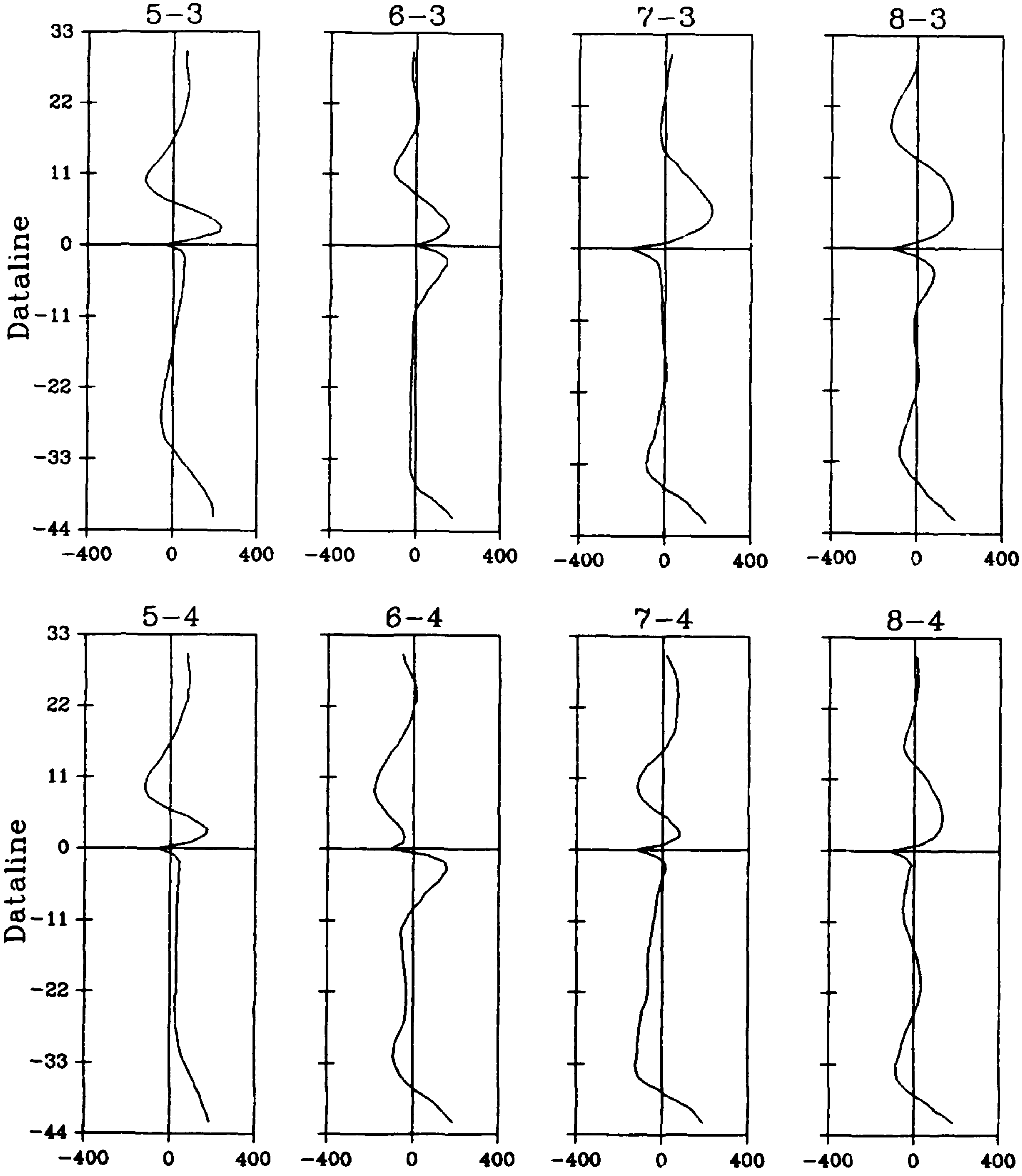
150k Original (con't)

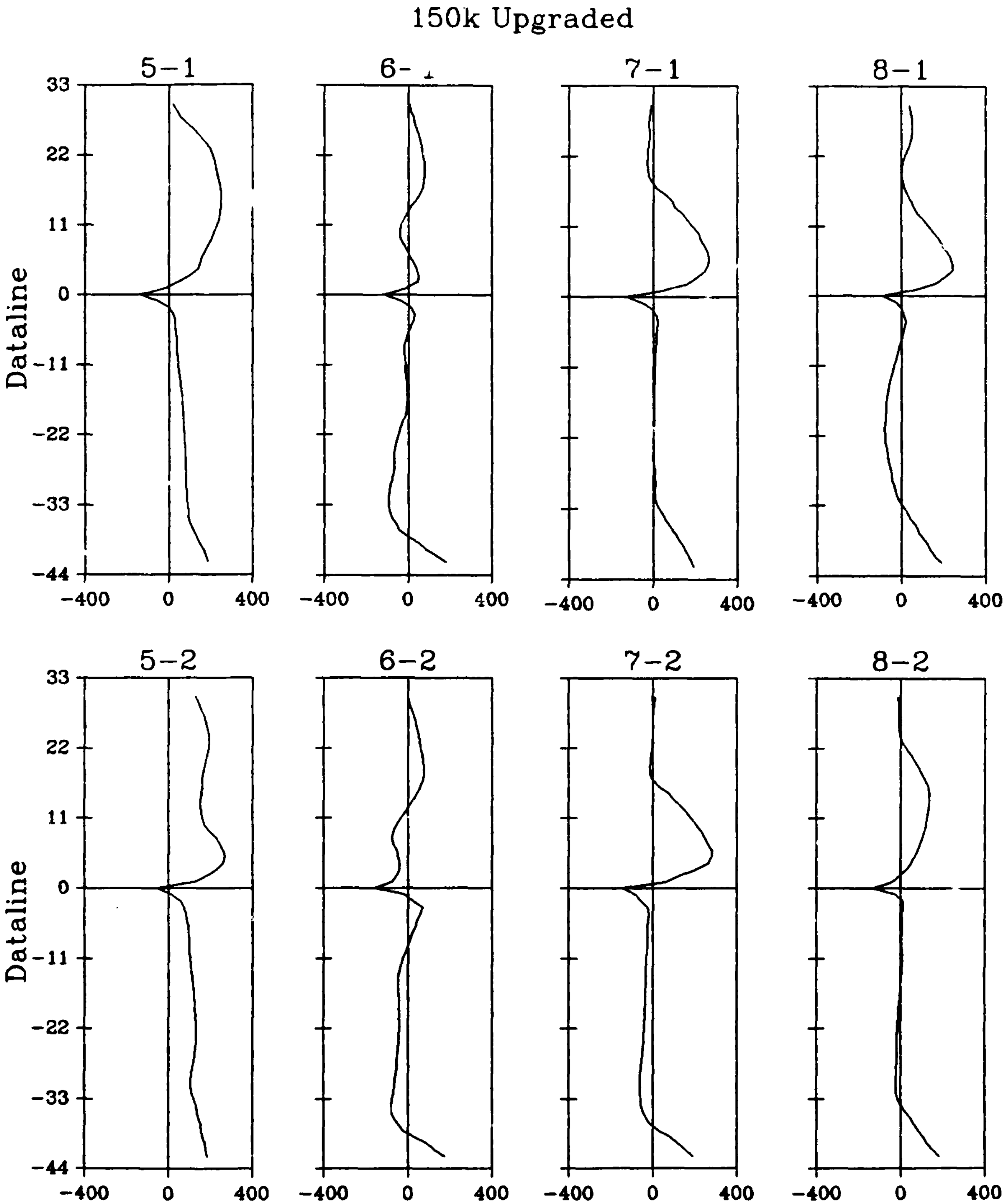


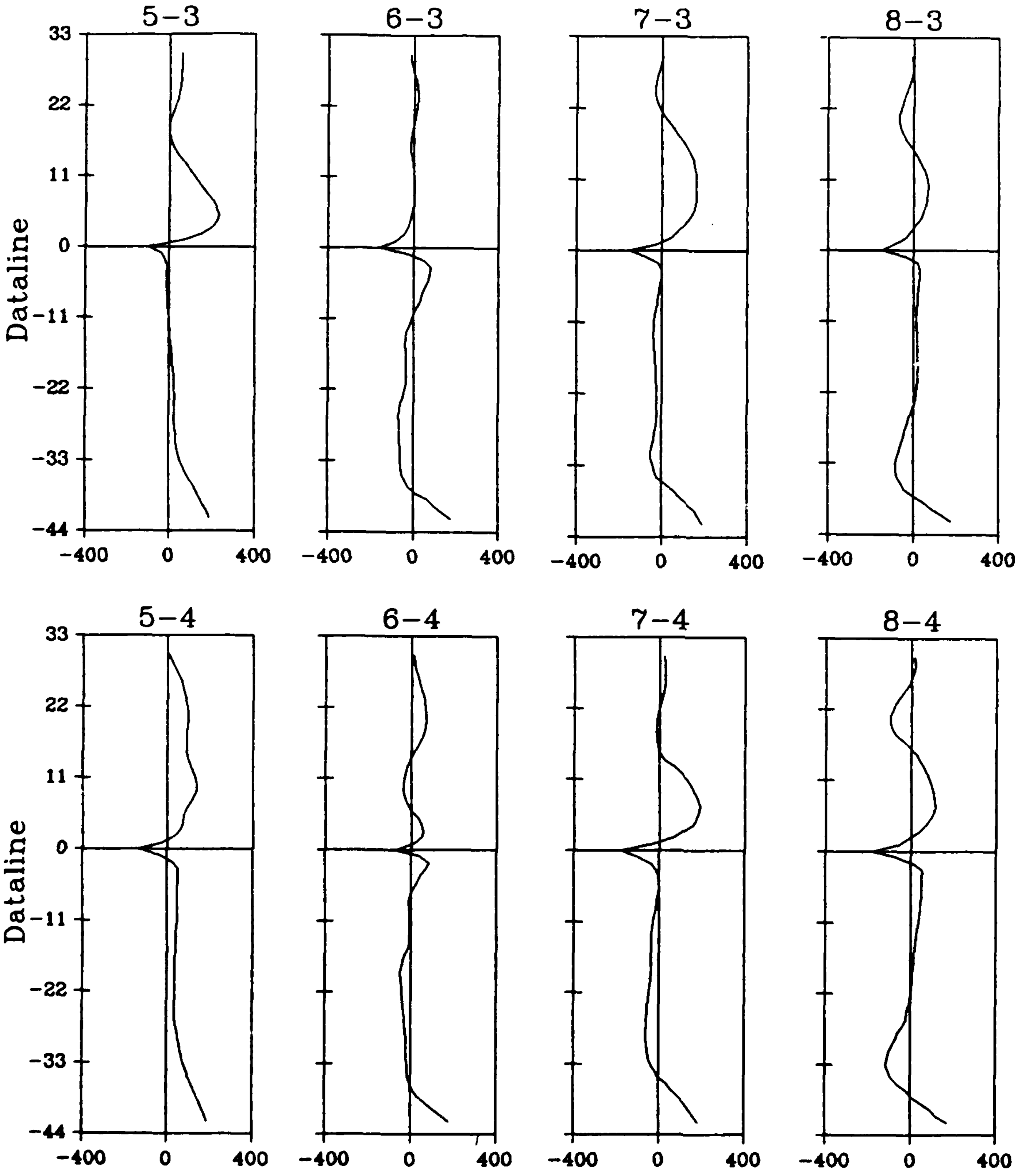
150k Degraded

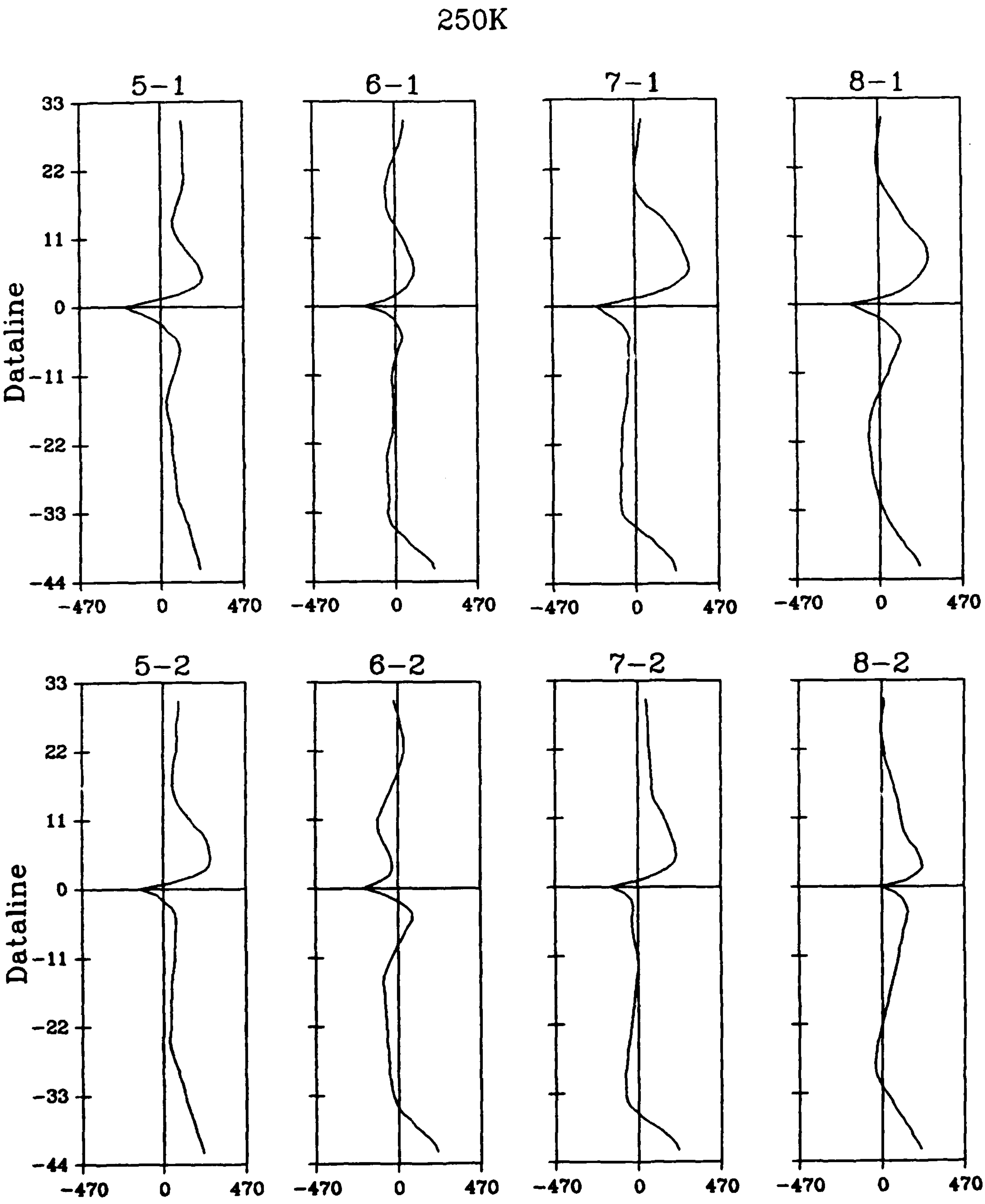


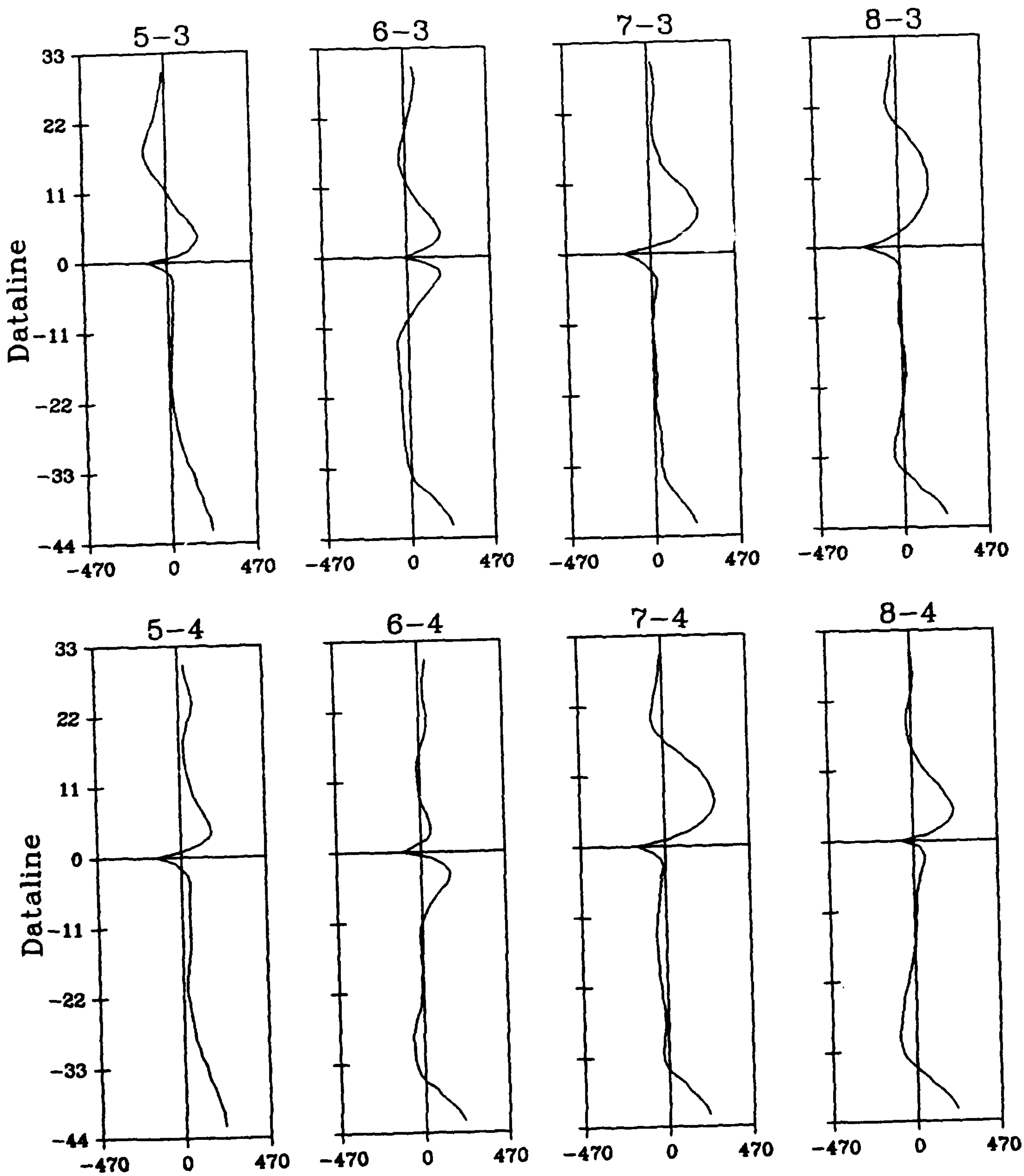
150k Degraded (con't)



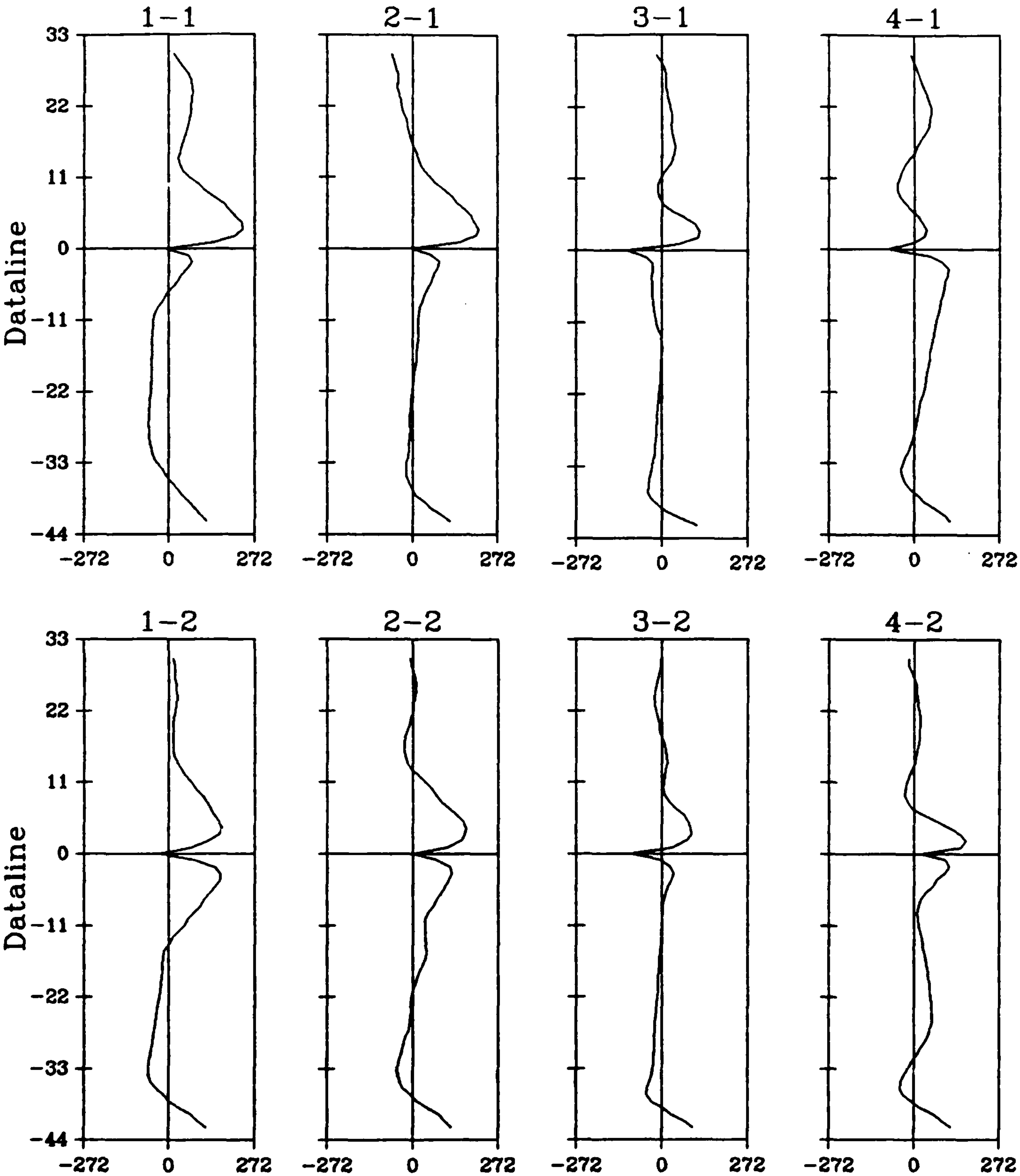

150k Upgraded
5−1
6−1
7−1
8−1
5−2
6−2
7−2
8−2
Dataline
33
22
11
0
−11
−22
−33
−44
−400
0
400


5-3
6-3
7-3
8-3
5-4
6-4
7-4
8-4
Dataline
33
22
11
0
-11
-22
-33
-44
-400
0
400

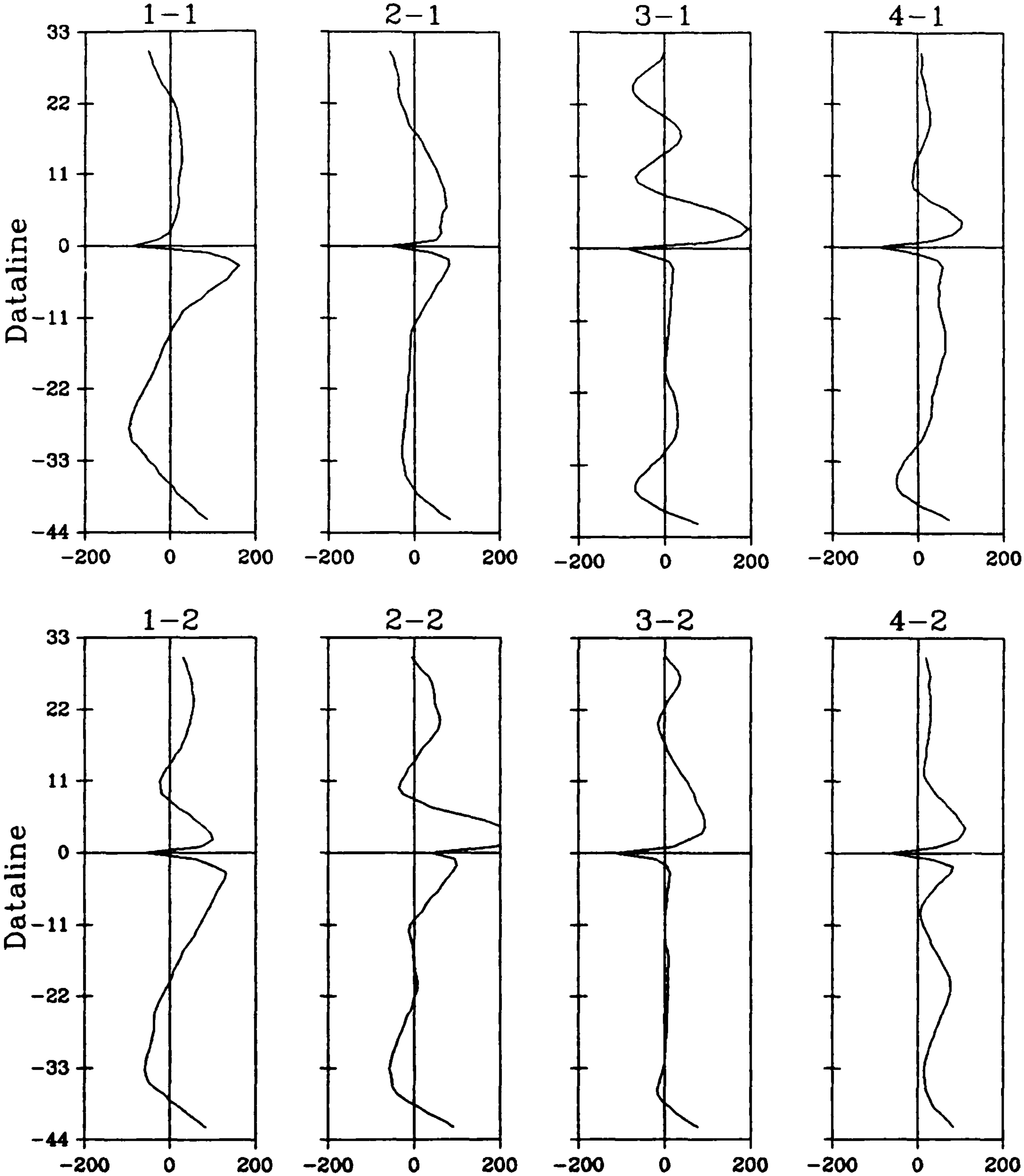

250K
5-1
6-1
7-1
8-1
5-2
6-2
7-2
8-2
Dataline
33
22
11
0
-11
-22
-33
-44
-470
0
470


5-3
6-3
7-3
8-3
5-4
6-4
7-4
8-4
Dataline
33
22
11
0
-11
-22
-33
-44
-470
0
470

76k – 543 ft chan.



76k – 400 ft chan.



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