RELATIONSHIP OF SHIP SIZE TO TRANSIT PERFORMANCE IN A CHANNEL SECTION CONTAINING CROSS CURRENT

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ABSTRACT

Special environmental conditions occur in many restricted waterways which provide a challenge to transiting .navigators. One condition found in some harbors is a waterway section where a significant current enters from the side at an angle to the transit path and gradually realigns its direction to coincide with the transit path. A recent study conducted at CAORF provides an insight into the difficulties of maneuvering through this current condition and the effect of ship size an the degree of difficulty Results and observations from the study are presented. The process followed in conducting the study described in the paper suggests the general methodology for studying special environmental conditions in specific waterways.

INTRODUCTION

Decisions regarding the feasibility of navigating restricted waterways with a given size ship may be enhanced by assessment of the trackkeeping performance of specific vessels within specific ports. Such an assessment may be absolute (determination of operating envelope), or comparative, in which inferential statistics are employed to determine whether or not there is any significant difference between the performance of various ship types operating or proposed within the restricted waterways.

Although such assessment may possibly be determined on the basis of data gained through experimentation with the transit of actual ships through the port, logistic considerations, cost constraints, and safety requirements suggest the utility of simulation as an alternative research approach. Considering the perceptual, control (human), and dynamic (engineering) elements of this simulation problem, a real time "man-in-the-loop" simulation was employed.

This experiment was designed to determine whether ship size is a factor in navigation within a channel when cross current is encountered. It provides both descriptive and inferential statistical information relating to the performance of two ships (65,000 and 89,000 dwt tankers) in a single restricted waterway. The experiment was carried out on the Computer Aided Operations Research Facility (CAORF) operated by the National Maritime Research Center at Kings Point, New York.

EXPERIMENTAL DESIGN

Variables

The problem is principally defined as identification of the variance in performance accounted for by each of two levels of a single variable (65,000 and 89,000 dwt tankers – ship size) under constant environmental and control (pilot) conditions. Performance variability between ship sizes is calculated at several (10) points during the transit based upon channel or current characteristics. Banks are present along the channel, and bank effects are included in the environmental forces; however, bank effects were not a predominant factor leading to performance differences within the channel for each ship size. The result is a presentation of both descriptive and inferential statistical data relating to variation in performance due to ship size at frequent points along the channel.

Subjects

To obtain this data numerous experimental runs were made on the simulator by subjects who alternately piloted both the 65,000 and 89,000 dwt tankers down the channel. Parameters of ship's position, velocity, and orientation were recorded at 100 foot intervals; pilot's ship control behaviors (helm, course, and engine orders) were recorded manually as they occurred. Each of 3 subjects piloted the 65,000 and the 89,000 dwt tanker 4 times each for a total of 8 runs per subject or 24 for the group. The order of runs was designed to alternate between ships for each individual and between individuals for the order of runs so that both ships received an equal number of runs under similar conditions of subject learning and fatigue.

Subjects were selected for the experiment on the basis of their familiarity with similar piloting conditions. Those conditions were the presence of relatively high and steep channel banks and the presence of a strong quartering current for a segment of the run. United States Gulf coast pilots are very familiar with bank effects due to the configurations of many gulf waterways, and some are also experienced in dealing with quartering currents of significant magnitude (greater than 6 knots). The services of three pilots from the Gulf area were acquired for the purpose of conducting experimental runs. Each had in excess of 20 years of pilotage experience.

Familiarization

Efforts to select subjects familiar with the experimental conditions notwithstanding, substantial precautions were taken to give the pilots sufficient familiarization with the ships, and especially the characteristics of the channel, so that the learning curve would be appreciably flattened before experimental runs commenced. In this experimental design (repeated measures) subjects experience all levels of each variable in equal measure (all pilots conducted four runs each on the 65,000 and 89,000 dwt tankers), familiarization could therefore be accomplished without separation of experimental scenario conditions, i.e., familiarization with the two ships was conducted simultaneously with waterway familiarization. The familiarization scenarios were identical to those in the experiment. Following each familiarization run, the subject would be shown a video tape of the situation display (plan view of the ship's transit of the channel) to facilitate the learning process. Familiarization was continued to criterion rather than a specific number of runs, that criterion being successful transit of the channel in the 65,000 dwt class vessel. These same familiarization runs permitted the researchers to establish a realistic degree of difficulty for the scenario based upon the criterion of successful 65,000 dwt transits.

Visual Data Base

The visual data base consists of a modeling of the general characteristics of visible structures and landforms in the area, the configuration of the channel and adjacent river and all aids to navigation (buoys, beacons, and ranges). The configuration of the scenario area provided is shown in Figure 1. Transits start at the bottom of the figure and traverse the channel in a northerly direction to the point between the lighted beacons – a distance of about 2-1/2 nautical miles.

The requirement for a range was determined during the presimulation and familiarization runs. The physical (large ship/narrow channel) and dynamic (current/banks) elements of this shiphandling problem were compounded by perceptual difficulties of pilots in establishing crosstrack deviations during and immediately following entry into the quartering current.

Lacking a range, pilots could rely solely upon the perspective afforded by the final set of staggered buoys and the beacon lights, and distance-off estimations from the closer staggered buoys at the point of maximum current set. Angular comparisons of channel heading to midchannel bearing from ownship, generally based upon jackstaff bifurcation of aids to navigation ahead, were made very difficult by the extreme crab angle carried in this segment of the channel. Perspective and distance-off techniques, though available, were not effective as the buoys were not only staggered, but more significantly, did not mark the channel edges and were not equidistant in their displacement from the channel edge. Without the range, pilots had difficulty in perceiving a crosstrack displacement. The range corrected for this difficulty and reshaped the scenario to one principally of a physical and dynamic problem.

Current Model

The environmental parameters for the scenario consisted of daylight, full visibility, and no wind. Current velocity and direction were modeled on the basis of assumed flow lines. These flow lines were developed from the channel configuration. A diagram of the current vectors is provided in Figure 2. The velocities of the current

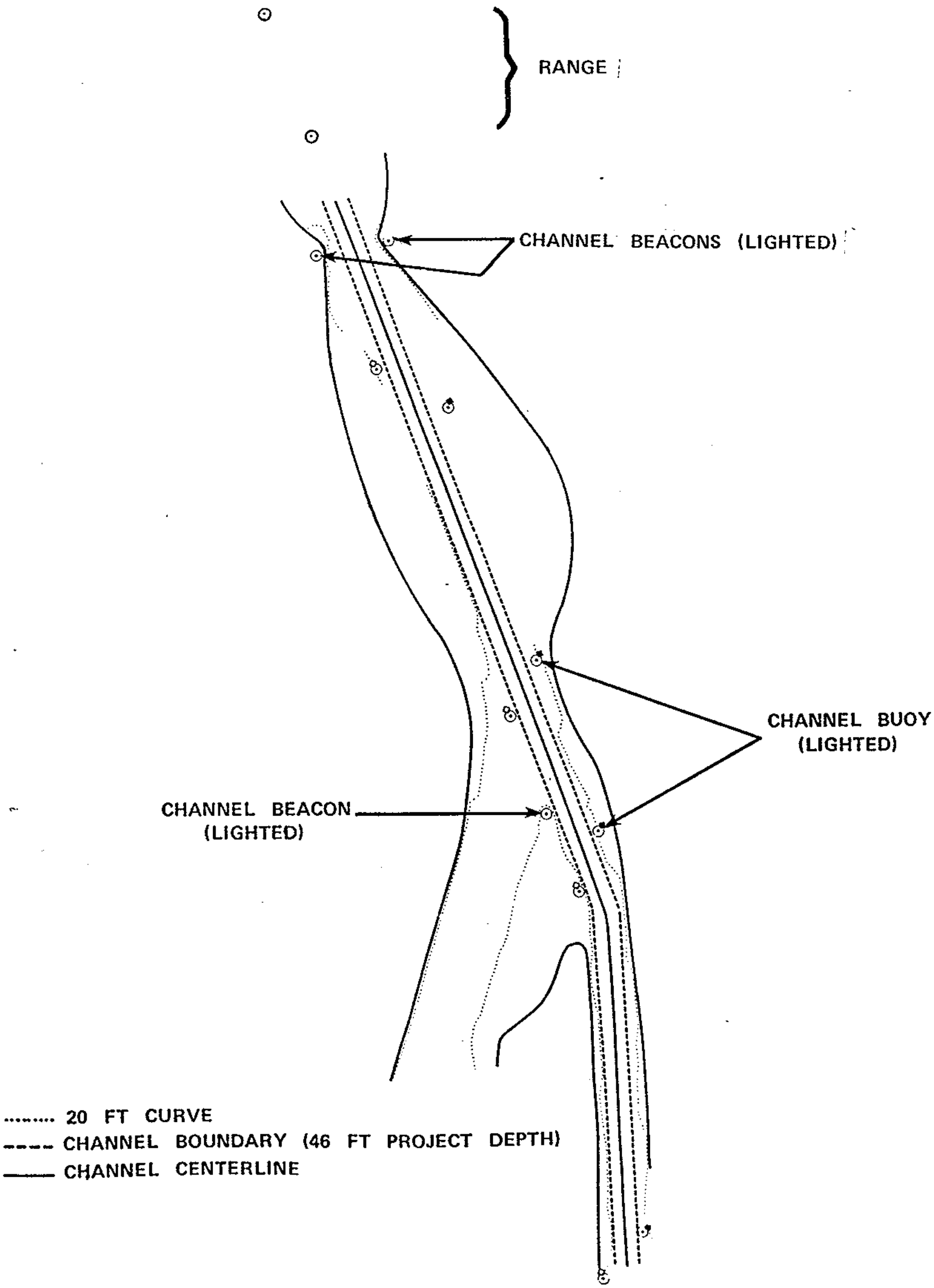


Figure 1. Visual Data Base Model

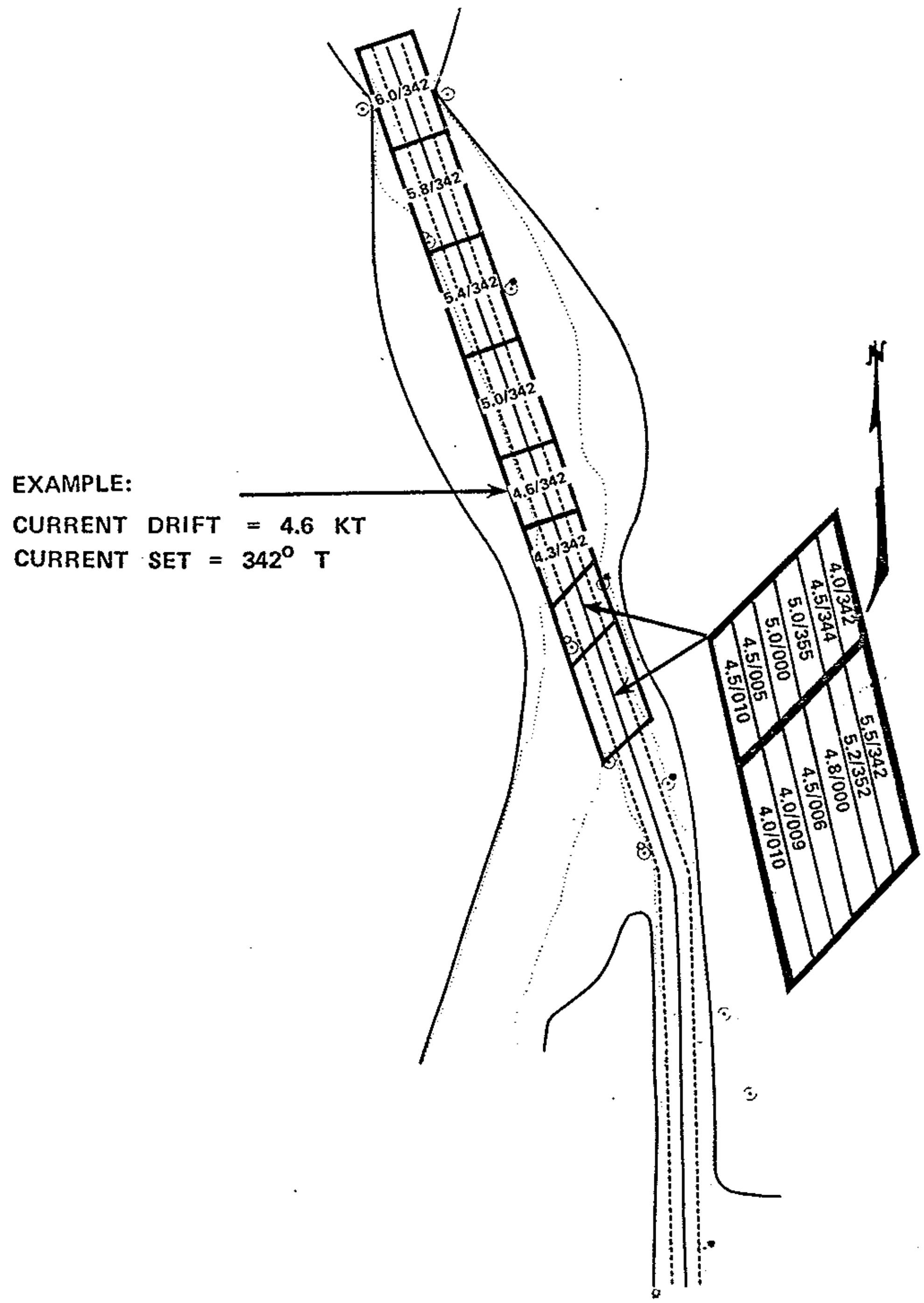


Figure 2. Current Model (Along Channel)

vectors as depicted are based upon a maximum reference velocity of 6 knots. Presimulation and familiarization runs demonstrated that the current velocities depicted in Figure 1 were too severe to allow the vessels to proceed within the channel at realistic crab angles (from the subjects' appraisal).

By adjusting the simulator's current multiplier, current speeds were reduced sequentially to 0.83 (5 knots), 0.75 (4.5 knots), and eventually 0.58 (3.5 knots) until subjects were able to transit successfully with crab angles no greater than 10 degrees. This was the limit of pilot credibility and even surpassed any previous experience. It might have been possible to coach them to carry in excess of 20 degrees of crab angle at the higher current levels but it was felt that this would have compromised the validity of the experiment in terms of the subjects' characteristics, i.e., they would no longer be engaging in behavior normal to their piloting experience.

The subject/pilots point out that although they do experience a 6 knot or better quartering current in their operating area, they are proceeding into a widened area at the time (originally intended as an anchorage) and do not attempt to maintain their course as the ship experiences the current. They purposely allow the ship to be set down somewhat to avoid passing close aboard ships moored along the side of the channel from which the current flows. Therefore, the crab angle assumed (approximately 7 degrees) is not totally corrective of the 6 knot current as is required in the experiment.

Bank Model

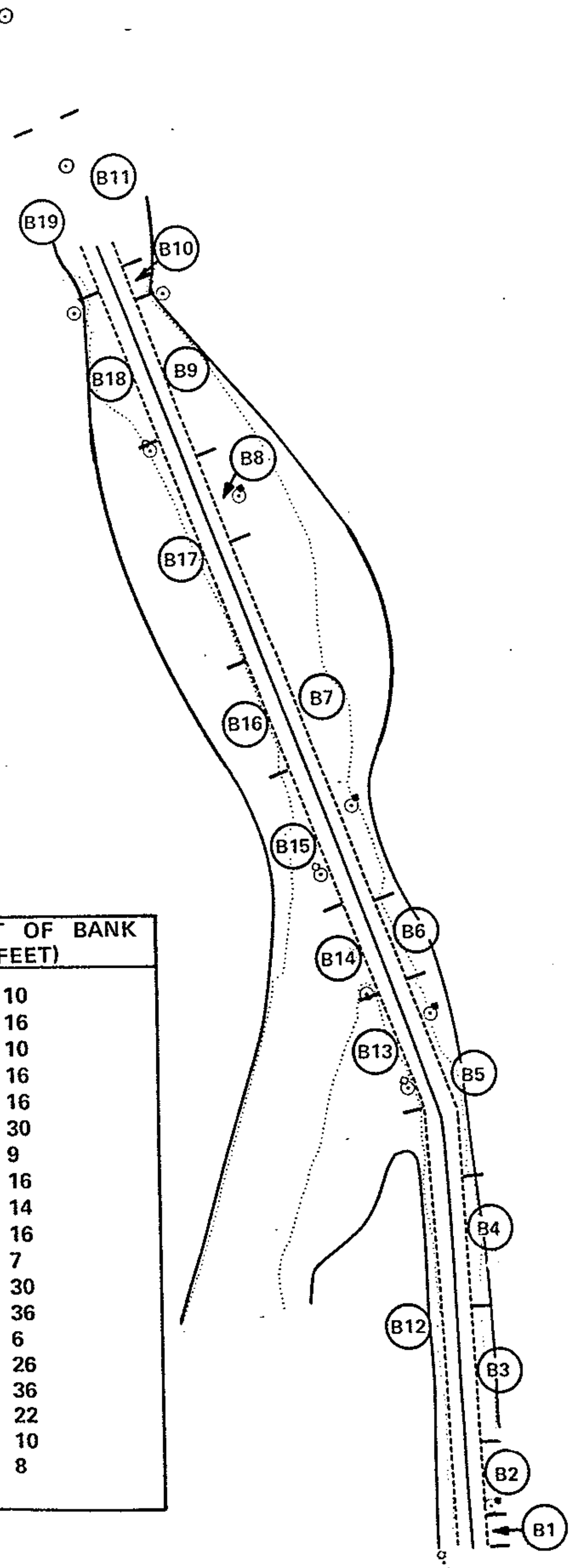
Banks were included in the experiment. The 19 bank segments of various heights are depicted in Figure 3.

Vessel Characteristics

The two ships used in the study were modeled by Dr. Haruzo Eda of Davidson Laboratory at Stevens Institute of Technology. The two ships were one 65,000 dwt tanker and one 89,000 dwt tanker. The principal physical dimensions of the vessels are as follows:

Length between perpendiculars (feet)	745	775
Beam (feet)	110	130
Deadweight capacity (L. tons)	65,000	89,000
Draft (feet)	40	40

Tests conducted on the mathematical models of the ships with 6-foot keel clearance (40-foot draft, 46-foot channel depth) for each ship, showed the larger ship to turn more slowly for equivalent rudder angles, requiring 80 seconds to turn 20 degrees, whereas the smaller vessel turned 20 degrees in 64 seconds. This data was taken from turning circle trials of the mathematical models of the two ships at full speed and is the elapsed time from the initiation of a 35 degree right rudder deflection. The smaller ship was also capable of faster acceleration and deceleration in comparison to the performance of the larger ship.



LOCATION	HEIGHT OF BANK (FEET)
B1	10
B2	16
B3	10
B4	16
B5	16
B6	30
B7	9
B8	16
B9	14
B10	16
B11	7
B12	30
B13	36
B14	6
B15	26
B16	36
B17	22
B18	10
B19	8

Figure 3. Bank Model

Bridge Layout

Two items of equipment present on the CAORF bridge which may have assisted the subject pilots in their experimental runs, were the speed log and rate of turn indicator. The inclusion of the log may be justified on the basis of the simulation's lack of visual cues as to through the water (as opposed to over-the-ground) speed. The ship's wake could not be viewed nor could the ship's hull motion past floating debris be noted. Similarly, the rate of turn instrumentation also supplemented the visual simulation as the lack of definition in the computer generated imagery may have reduced the effectiveness of perception of yaw through visual observation of the jackstaff's motion across objects on the horizon.

Instructions to Pilot/Subjects

Prior to the commencement of familiarization runs, pilots were briefed as to the purpose of the experiment, i.e., to determine difference in performance of two ship sizes in a specific channel. They were shown the chart and cautioned on the width of the channel, presence of banks, and placement of aids to navigation. The direction and magnitude of current was also stressed. The principal dimensions and characteristics of the two ships were noted.

The pilots were instructed to take their vessels down the channel as safely as possible. Considering the high ship's beam/channel width ratio in this scenario, these routing instructions do not conflict with the use of a channel centerline reference datum for performance measurement, as it was expected that the constraints of the narrow channel would preclude much range of individual routing strategy. On the basis of prerun questioning as to intended strategy and pilot comments from postexperiment interviews, this indeed was the case. Subjects were also informed that they were free to order any revolutions up to and including 64 rpm, and to make any adjustments within this upper limitation, at any time during the run.

Initialization

The experiment commences with the ship at midchannel between the first set of staggered buoys at the entrance to the inner channel leg, and on a heading of 000 degrees true, speed 3 knots.

Scenario Description

Following the subjects' ordering of increased revolutions at initialization, the ship proceeds down the first leg (000 degrees) experiencing only bank effects (no current). Following a 18 degree turn onto the second leg (342 degrees), a strong quartering current is experienced from the lighted daybeacon to port to the next black buoy, after which time the current follows the channel to the end of the experiment.

Data Collection

Ship's position, orientation and velocity data were collected automatically at 100 foot intervals by means of a computer program which provided the principal performance measure (crosstrack displacement) and supplementary measures at noted distance intervals along the channel from a specified reference point (the turn from leg 1 to leg 2).

Pilots' ship control behavioral measures (helm, course, and engine orders) were recorded manually as they occurred. Qualitative assessment of performance of all runs, familiarization and experimental, was conducted by analysts stationed on the bridge and at the CAORF human factors observation station.

Performance Measures

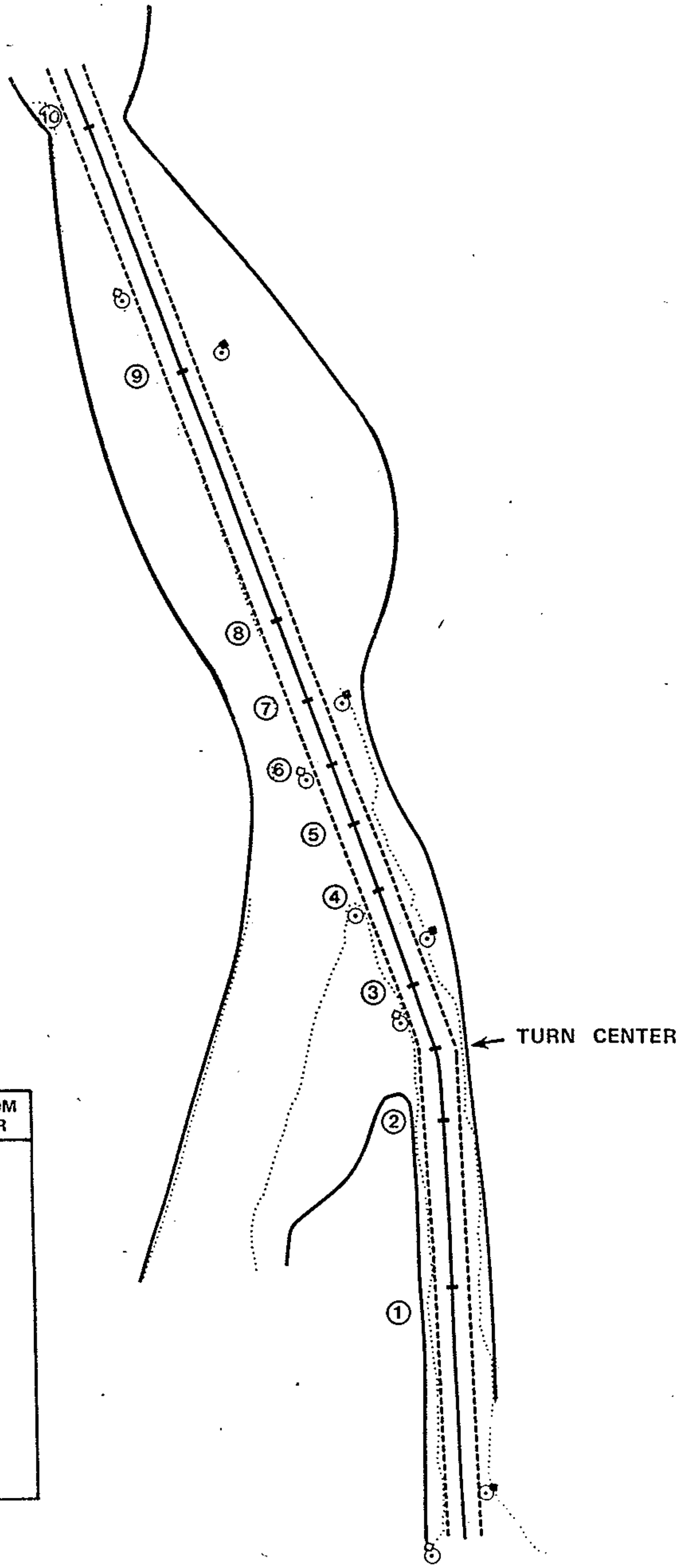
Two measures of shiphandling performance were employed in the analysis: crosstrack displacement of the ship's center of gravity (CG) from the channel centerline and minimum clearance of the ship's hull to channel edge. The channel edges are defined as the imaginary parallel lines defining the 100 meter wide project channel. The first measure is indicative of the "bodily" location of the subject vessels within the channel, while the latter is also sensitive to the position of vessel extremities due to the length and beam of the ships and their angular orientation in this relatively narrow channel.

The CG displacement calculations for each vessel were noted at ten points in the channel selected on the basis of their representation of either characteristic or critical segments of the transit. As depicted graphically and in tabular fashion in Figure 4, point 1 is representative of trackkeeping ability in the first leg; point 2 indicates position in setting up for the turn; point 3 marks position coming out of the turn; point 4 shows location in setting up for current; points 5 and 6 indicate position while in current flow; point 7 marks location on leaving current flow; points 8 and 9 represent position in regaining channel centerline; and point 10 represents trackkeeping ability. Distances of these points in nautical miles from turn center are the basis upon which CG displacement data (in feet) was extracted from the computer printout.

The channel edge clearance performance measure was a single rather than multiple point extraction of data, as is appropriate for such "closest point of approach" measures. That single point differed for each run and was noted by scanning the printed listing of CG displacement data, both to the left and right of channel centerline, and selecting for each run those points at which the ship was maximally displaced (bodily) from midchannel to the left and to the right. These two points are depicted (not to scale) in Figure 5 and roughly approximate CG displacement data analysis points 4 and 7. Displacement to the left near the daybeacon was purposeful as subject strategy was to position the vessel well to the left in anticipation of the eventual set to the right due to the current. Displacement to the right in the vicinity of the black buoy after experiencing the crosscurrent, however, was to be avoided as much as possible. The channel edge clearance calculation was made on the basis of a simplified rectangular waterline plan view of the two vessels in which length between perpendiculars constitutes the length of the rectangle, and vessel beam is the rectangle width. The center of the rectangle corresponded to the CG of the ship, and the angle formed by the axis of the rectangle's length and the channel heading was based upon ship's heading at the point of maximum CG displacement. The resultant determination of minimum clearance of port bow to left channel edge, and right quarter to right channel edge are considered as separate measures.

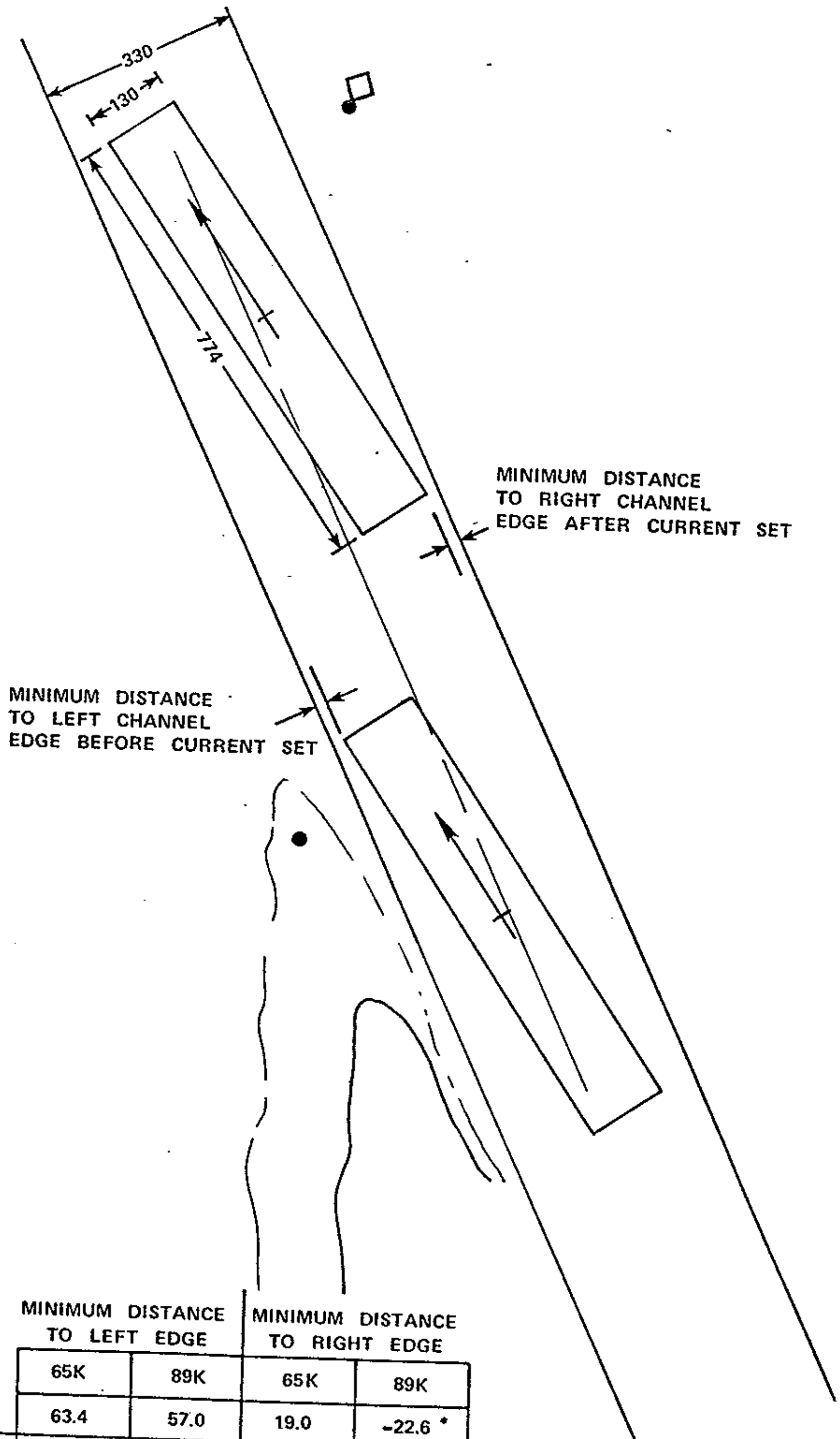
Channel Transit Graphics

Graphic display of representative channel transits from the study are presented in Appendix A. The first two figures of Appendix A show individual transits of the 65,000 dwt tanker while the final two figures show individual transits of the 89,000 dwt tanker.



POINT	DISTANCE FROM TURN CENTER
1	.4 nm
2	.1 nm
3	.1 nm
4	.35 nm
5	.45 nm
6	.55 nm
7	.65 nm
8	.80 nm
9	1.10 nm
10	1.50 nm

Figure 4. Data Analysis Points



	MINIMUM DISTANCE TO LEFT EDGE		MINIMUM DISTANCE TO RIGHT EDGE	
	65K	89K	65K	89K
MEAN	63.4	57.0	19.0	-22.6 *
STD DEV	46.1	50.2	41.5	36.9

*22.6 ft outside of right edge.

Figure 5. Channel Edge Clearance Model

Comparative Performance Analysis Between Ships

The experimental objective of this analysis is to establish whether there are statistically supportable differences in the transit performance of the two size ships when navigated outbound in experimental channel under the same environmental conditions by the same experienced pilots. To accomplish the analysis, comparison of the values of the two performance measures which are most clearly reflective of successful transits were calculated, i.e., crosstrack displacement of the ship's center of gravity from the channel centerline and clearance between the point on the ship closest to the channel edge and the channel edge as defined by the project dimension of the channel (100 meter width). The analysis does reveal statistically significant differences in performance between the ships. The differences occur in the recovery from the turn between the inner and outer channel legs and in the channel area where recovery occurs from the lateral displacement of the ship due to the crosscurrent experienced when entering the river.

Table B-1 in Appendix B lists the mean crosstrack displacement of the ship's center of gravity at each of the 10 data analysis points (refer to Figure 4). These displacements are also graphically shown in Figure 6 for visual comparison. Statistically significant differences occur in these displacements at data analysis points 3 and 8. The fact that significance occurred at the two locations indicates that either a difference in pilot strategy occurred or environmental factors induced a difference not controllable by the pilot strategy used. In fact, pilot strategy created the difference at the turn recovery (point 3), and environmental factors (crosscurrent) created the differences at point 8. Reference to Figure 6 reveals the pilots allowed the 65,000 dwt tanker to go wider (closer to the right channel edge) in recovering from the turn. This is due to the pilot's strategy which was to position both vessels to the left prior to entering the current. The 89,000 dwt ship, being perceived as less maneuverable, was kept closer to the left at all times while the 65,000 dwt vessel could be allowed a wider turn and still maneuver to the left before the onset of the current. At data point 4, just entering the current, Figure 6 shows no difference in the CG displacement of the ships. However, after reaching the maximum displacement to the left, (point 5) the influence of the current is greater on the large ship setting it further toward the right channel edge so that a statistically significant difference in the resulting trackline occurs. After exiting the crosscurrrent area, the displacement of the ship's CG for the two ships gradually converges for the remaining portion of the transit.

The second measure, minimum clearance to channel edge also shows a difference in the performance of the two ships when influenced by the crosscurrent. The values of the minimum clearance both to the left and right channel boundary are tabulated for each transit and summarized in Table 1. The crab angle of the ship has been included for each associated clearance and also summarized. Comparison of the mean values for clearance to the left edge as the ships set up for and entered the crosscurrent show little difference, as do the crab angles. After negotiating the crosscurrent, however, the mean minimum clearance to the right edge shows a statistically significant difference with the large ship set further right to the point where the mean position of the starboard point was outside the channel edge. There is also a difference in the resulting crab angle with the smaller ship able to maintain a higher favorable angle to counter the current effect.

Table 2 illustrates one of the causes of differences in the performance of the two vessels. The 89,000 dwt ship was slower to accelerate as demonstrated by the over-the-ground speed differences. This resulted in the larger ship being subjected longer

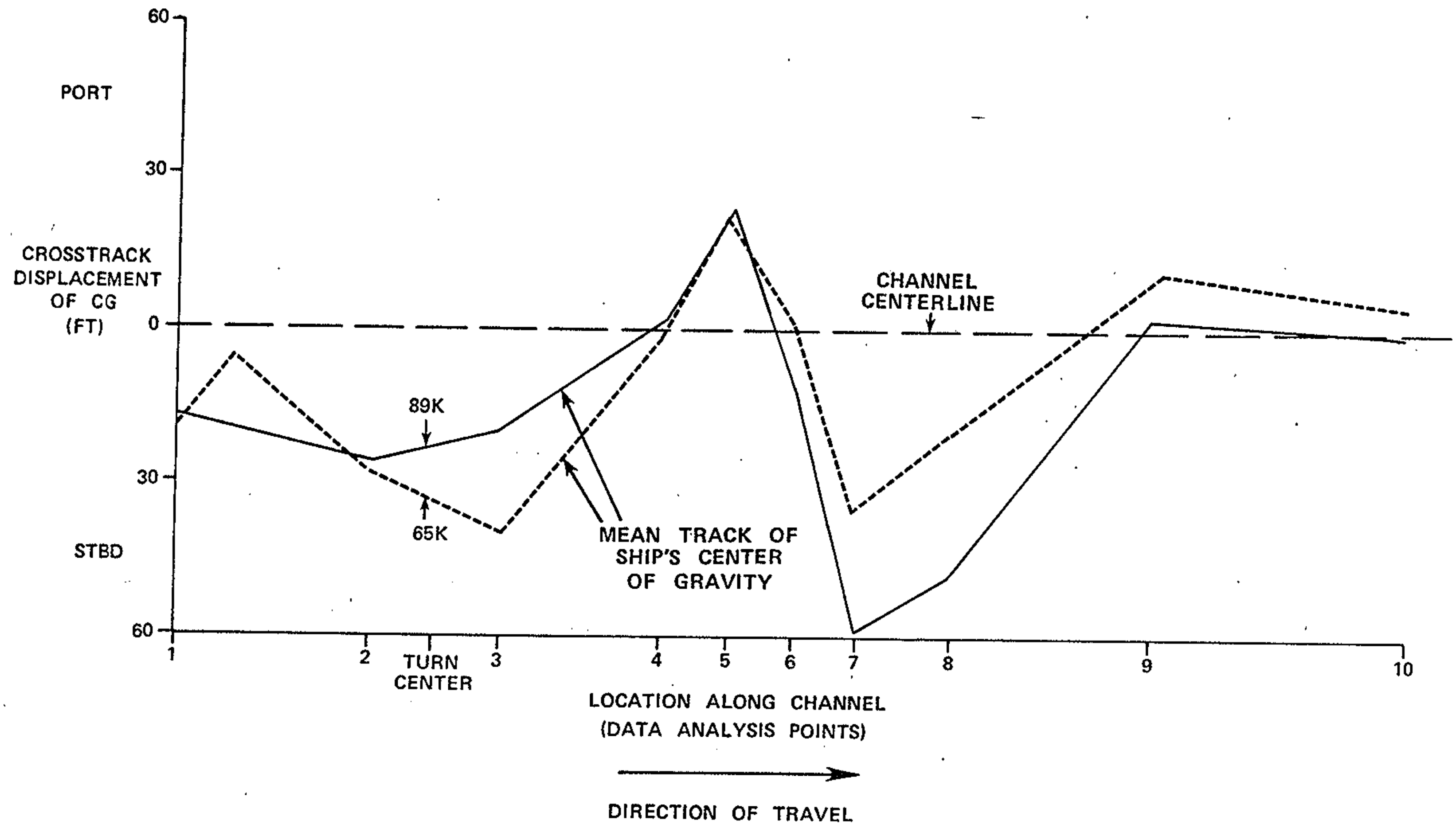


Figure 6. Graph of Mean CG Crosstrack Displacement for the Two Ship Sizes

TABLE 1. DESCRIPTIVE AND INFERENTIAL STATISTICS RELATING TO MINIMUM CHANNEL EDGE CLEARANCE AND CRAB ANGLE

MINIMUM DISTANCE FROM SHIP TO LEFT AND RIGHT SIDE OF CHANNEL

65K

RUNS (TRANSITS)	LEFT SIDE CLEARANCE	LEFT SIDE CRAB ANGLE	RIGHT SIDE CLEARANCE	RIGHT SIDE CRAB ANGLE
1	31.4	3.1	−16.5	4.3
2	−30.6	5.5	12.9	3.0
3	16.2	5.4	97.2	1.7
4	41.0	4.7	62.3	3.2
5	112.9	0.4	−11.4	7.6
6	96.4	4.1	22.5	6.2
7	102.4	3.4	17.1	6.8
8	108.7	1.4	21.9	6.8
9	63.4	1.0	40.1	5.3
10	102.0	0.1	−61.7	4.1
11	53.2	1.5	24.3	4.5
MEAN	63.4	2.78	19.0	4.85
STD DEV	46.1	2.0	41.5	1.85

89K

RUNS (TRANSITS)	LEFT SIDE CLEARANCE	LEFT SIDE CRAB ANGLE	RIGHT SIDE CLEARANCE	RIGHT SIDE CRAB ANGLE
1	− 4.7	6.6	13.8	4.2
2	−11.6	10.8	18.2	4.4
3	−26.0	5.9	46.7	2.8
4	62.0	4.6	− 0.4	6.3
5	122.2	1.9	−60.8	7.4
6	114.2	0.9	−54.8	8.4
7	84.7	4.7	−19.3	7.9
8	89.7	2.2	−35.1	7.1
9	53.1	0.6	−54.6	7.7
10	69.9	1.6	−47.1	5.3
11	73.7	3.0	−55.5	5.4
MEAN	57.0	3.89	−22.6	6.08
STD DEV	50.2	3.05	36.9	1.80

MINIMUM DISTANCE TO LEFT EDGE

	65K	89K	
MEAN	63.4	57.0	t=.311
STD DEV	46.1	50.2	F=1.19

MINIMUM DISTANCE TO RIGHT EDGE

	65K	89K		
MEAN	19.0	−22.6	t=2.48	∝ =.05
STD DEV	41.5	36.9	f=1.26	

CRAB ANGLE AT LEFT SIDE

	65K	89K	
MEAN	2.78	3.89	t = −1.01
STD. DEV.	2.0	3.05	F = 1.53

CRAB ANGLE AT RIGHT SIDE

	65K	89K		
MEAN	4.85	1.85	t = −1.57	∝ = .20
STD. DEV.	6.08	1.80	F = 1.03	

TABLE 2. MEANS OF ALONGTRACK VELOCITY

		MEAN SPEED		DIFFERENCE IN SPEED
		65	89	
DATA ANALYSIS POINTS	1	5.65	4.71	.94
	2	6.62	5.43	1.19
	3	6.74	5.49	1.25
	4	6.99	5.64	1.35
	5	7.28	5.85	1.44
	6	7.62	6.11	1.51
	7	7.91	6.37	1.54
	8	8.48	6.88	1.60
	9	9.18	7.51	1.67
	10	9.94	8.22	1.72

to the current; it also resulted in a larger athwartship component to the combination velocity vector of the ship's CG while subjected to current. Perhaps even more important is the difference between the speed through the water of the two vessels once in the current. Though not recorded by the data collection program, speed through the water was observed by means of the speed log indicator mounted in the bridge console. As vessels entered the quartering current, their over-the-ground speed would continue to rise, but a marked reduction in speed through the water would take place, due to the inertia of the vessels. Speed through the water would drop as low as 4 knots initially (a reduction of 2.5 knots or more). Consequently, the forces generated by any rudder action subsequent to the ship's entering the flow would be less effective than earlier. Although no data is available to test for statistical significance of the difference in through-the-water speed of the two vessel types in this critical segment of the channel, it is logical that the larger mass of the 89,000 dwt tanker would have resulted in a greater loss of through-the-water speed, and therefore less effective rudder control. With less maneuverability once in the current, and remaining in the crosscurrent longer than its counterpart, the 89,000 dwt vessel must either set up farther to the left prior to entering the current, or carry a larger crab angle while subject to the current, or both; the swing to the left to generate this crab angle must be generated, in part, prior to losing rudder effectiveness. To add to the larger vessel's difficulty, the current is felt earlier on her bow and later on her stern due to the greater length. The larger physical dimensions also contribute to the greater "swept path" for identical crab angles in comparison to the smaller ship.

A complementary approach to illustrating the performance differences of the two ships in negotiating the critical area of the channel where they were influenced by crosscurrent is to determine the relative channel width required for each ship size. A numerical index of swept path relative widths, which relates to the channel width requirements for each ship to transit the critical area, is given in Table 3. Values in the table were derived by using the left and right edge clearance values of Table 3 to calculate the mean and minimum channel width required to just contain the ship from its maximum displacement to the left side of the channel entering the current to its maximum displacement to the right side of the channel after current set. The minimum values were found by examining each transit for each ship size and recording the value from the one transit of each ship which used the minimum channel width. Inspection of Table 3 shows that the mean channel width used for the 89,000 dwt ship was nearly 50 feet greater than for the smaller ship and that the minimum channel width used for the larger ship was larger than the mean width for the smaller ship. These values along with the results from the other performance measures suggest that a wider channel is required for incident free navigation of the larger ship than for the smaller ship under the experimental conditions tested.

TABLE 3. COMPARISON OF MEAN AND MINIMUM CHANNEL WIDTHS USED

	65,000 dwt	89,000 dwt	Difference
Mean width	247.7	295.6	47.9
Minimum width	228.5	264.6	36.1

Postexperiment Interview Summary

All three pilots chose their initial strategies based upon their expectancy that this channel was not so unlike those with which they were familiar. All expected the bank effects to be dominant for the entire transit and approached the turn from the right rather than from the inside to the left. The intent was to have the bank cushion push the starboard bow off to the left, thereby assisting the rudder in the turn. They guarded against cutting the corner to the inside, risking a cushion which would push the bow to the right requiring left rudder to counteract this in addition to making the turn. One subject made his first run at less than full ahead so as to magnify the desired bank effect. In this technique of making the turn wide they were successful, although they also ended up to the right of center as they entered the current stream. This proved unacceptable as the bank to the right did not overcome the force of the current and subsequent runs consisted of attempts to get further and further to the left in advance of the current segment, even prior to the turn, and initiating a swing to the left to promote an adequate crab angle to carry the vessel through the critical area. In this the subjects succeeded, although in some instances at the expense of overcorrecting to the left resulting in a bank cushion sheer to the right, either prior to or while in the current. Both were equally disastrous as the vessel would be experiencing both the current and this sheer, setting it down to the right.

It terms of choice of route, strategies were identical for both ships. However, subjects reported starting their anticipatory swing to the left earlier with the larger more sluggish vessel. A larger crab angle for the 89,000 dwt tanker was sought by one pilot. All subjects felt that the larger ship responded more slowly to the rudder. All had piloted vessels of this size (89,000 dwt) and felt the handling characteristics of the simulated ship were realistic. The 65,000 dwt tanker simulation was also felt to be realistic and all had shiphandling experience with vessels of this class as a basis for judgement. In spite of the fact that the current posed such a problem for the subjects, they were unanimous in their feeling of its realism, and in the realism of the bank effects.

All subjects felt they would not hesitate to take the 65,000 dwt vessel out the channel under conditions identical to those experienced in the simulation. Subject recommendations regarding the design of the waterway were fairly homogeneous.

Gated buoys were preferred rather than the staggered configuration provided, and the buoys, if not positioned on the channel edge, should at least be equidistant in their placement from the channel edge. One subject also wanted a gate at the turn rather than after.

Sequential Changes in Effectiveness of Pilot Strategy

In spite of lengthy familiarization periods, subjects could not be given sufficient experience of the scenario to ensure consistent, incident free transits of 65,000 dwt tankers. The pilots were, in fact, learning throughout the experimental runs as indicated in their individual postexperiment accounts of maneuvering strategies.

Figure 7 represents graphically one index of navigation performance which reflects changes related to the pilots' sequence of runs with each ship. The index is calculated by summing the minimum left and right edge clearances for equivalent runs in the sequence with each ship for each pilot and dividing by two. This provides the average edge clearance for each pilot for the run as though the ship track had been centered in the channel. It is related to the pilots' goal of minimizing crosscurrent effect on ship track in the critical crosscurrent area of the channel. A larger average edge clearance indicates a more effective trackline strategy. In Figure 9 the average edge clearance mean value for the three pilots is plotted by run sequence for each ship. Inspection of the figure demonstrates an overall trend toward improvement for both ships and a tendency toward reduction in improvement between the final two runs for each ship.

CONCLUSIONS/RECOMMENDATION

The study shows a statistically significant difference between the transiting performance of the two size ships in a critical segment of the channel. Although this conclusion is based solely upon a comparative rather than absolute assessment of vessel class shiphandling performance, the individual values of the performance measures themselves may be instructive.

Minimum clearance to channel edge (Table 1) shows that all 11 transits of the 89,000 dwt vessel involved channel excursions while only four excursions occurred for the 65,000 dwt ship runs. The results show that increased channel width from a point just prior to the ships entering the current (near data point 3, Figure 4) to a point near data point 9 clearly would be beneficial to incident free navigation of the larger ship.

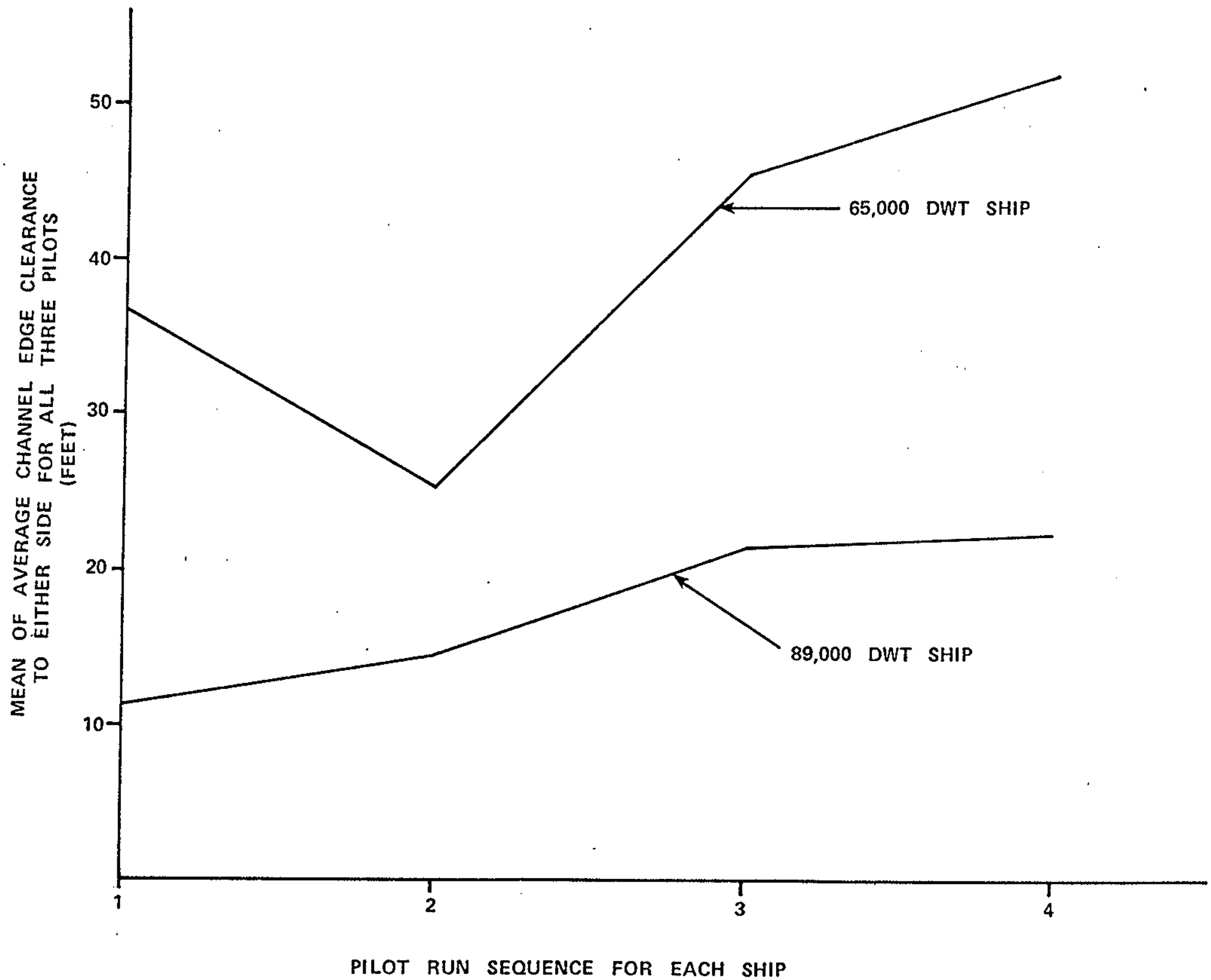


Figure 7. Measure of Pilot Strategy Effectiveness by Transit Sequence for Each Ship

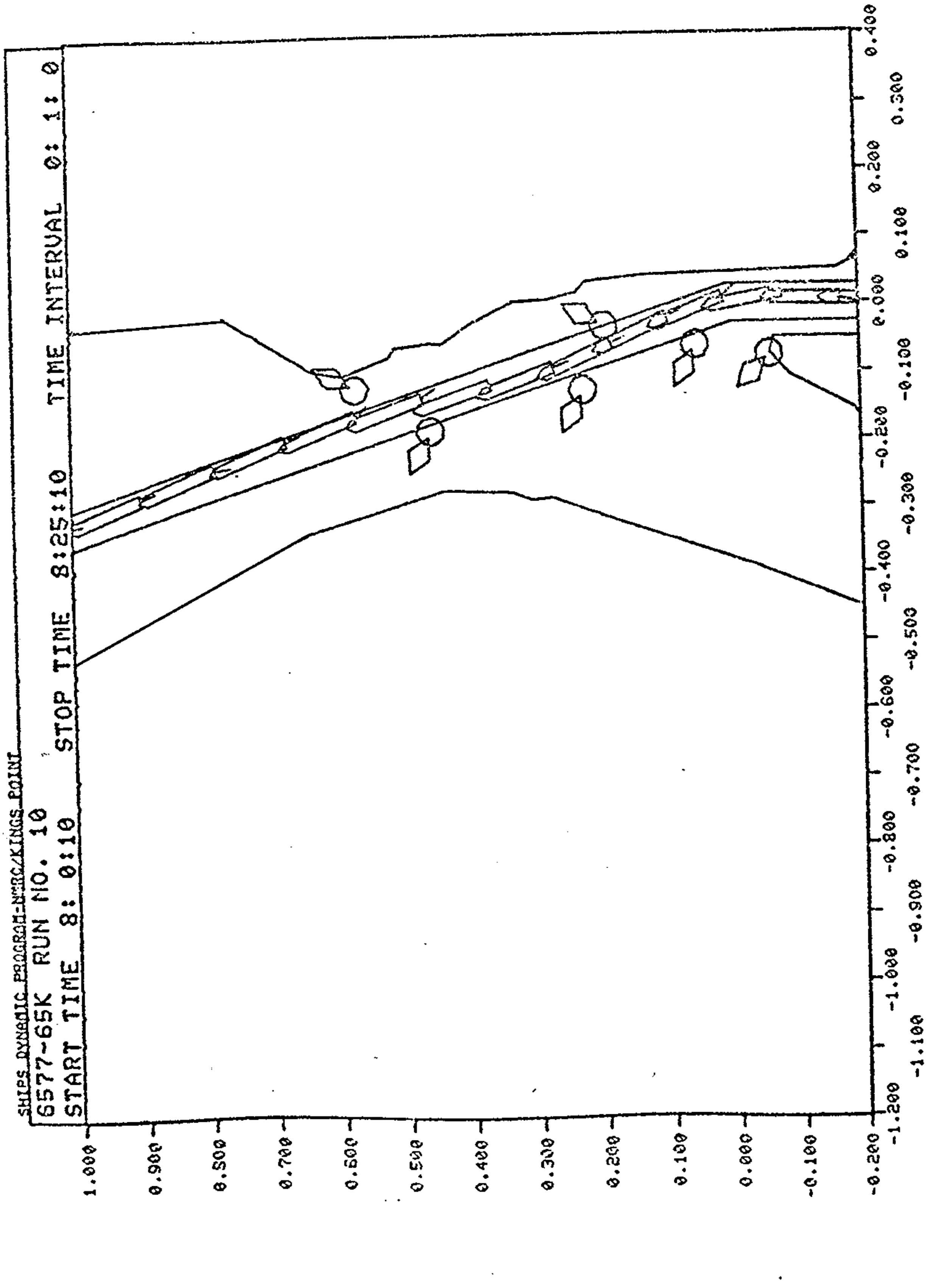

SHIPS DYNAMIC PROGRAM-NMRC/KINGS POINT
6577-65K RUN NO. 10
START TIME 8: 0:10 STOP TIME 8:25:10 TIME INTERVAL 0: 1: 0
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-1.200
-1.100
-1.000
-0.900
-0.800
-0.700
-0.600
-0.500
-0.400
-0.300
-0.200
-0.100
0.000
0.100
0.200
0.300
0.400

Figure A-1

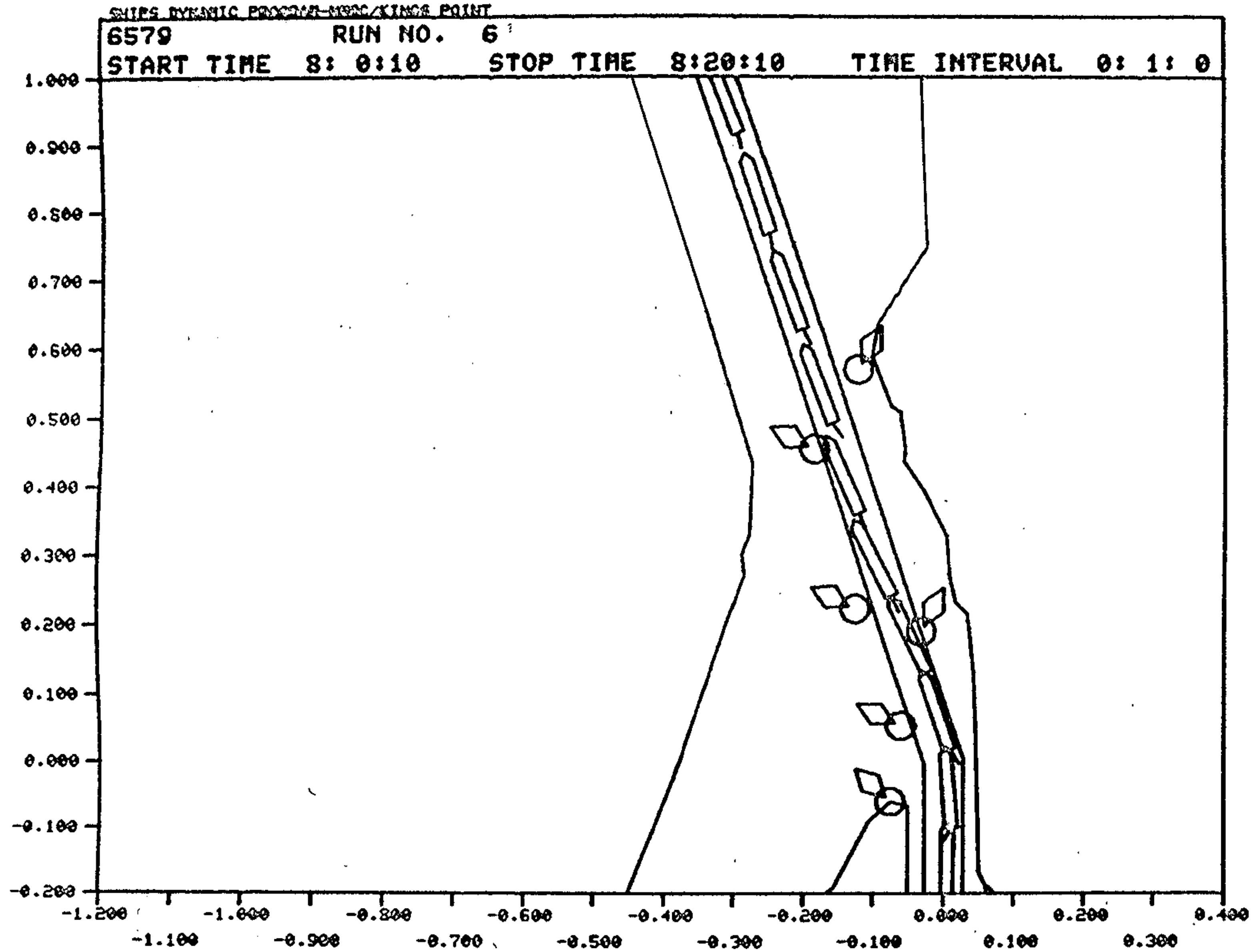

SHIPS DYNAMIC PROGRAM-MSRC/KINGS POINT
6579 RUN NO. 6
START TIME 8: 0:10 STOP TIME 8:20:10 TIME INTERVAL 0: 1: 0
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-1.200
-1.100
-1.000
-0.900
-0.800
-0.700
-0.600
-0.500
-0.400
-0.300
-0.200
-0.100
0.000
0.100
0.200
0.300
0.400

Figure A-2

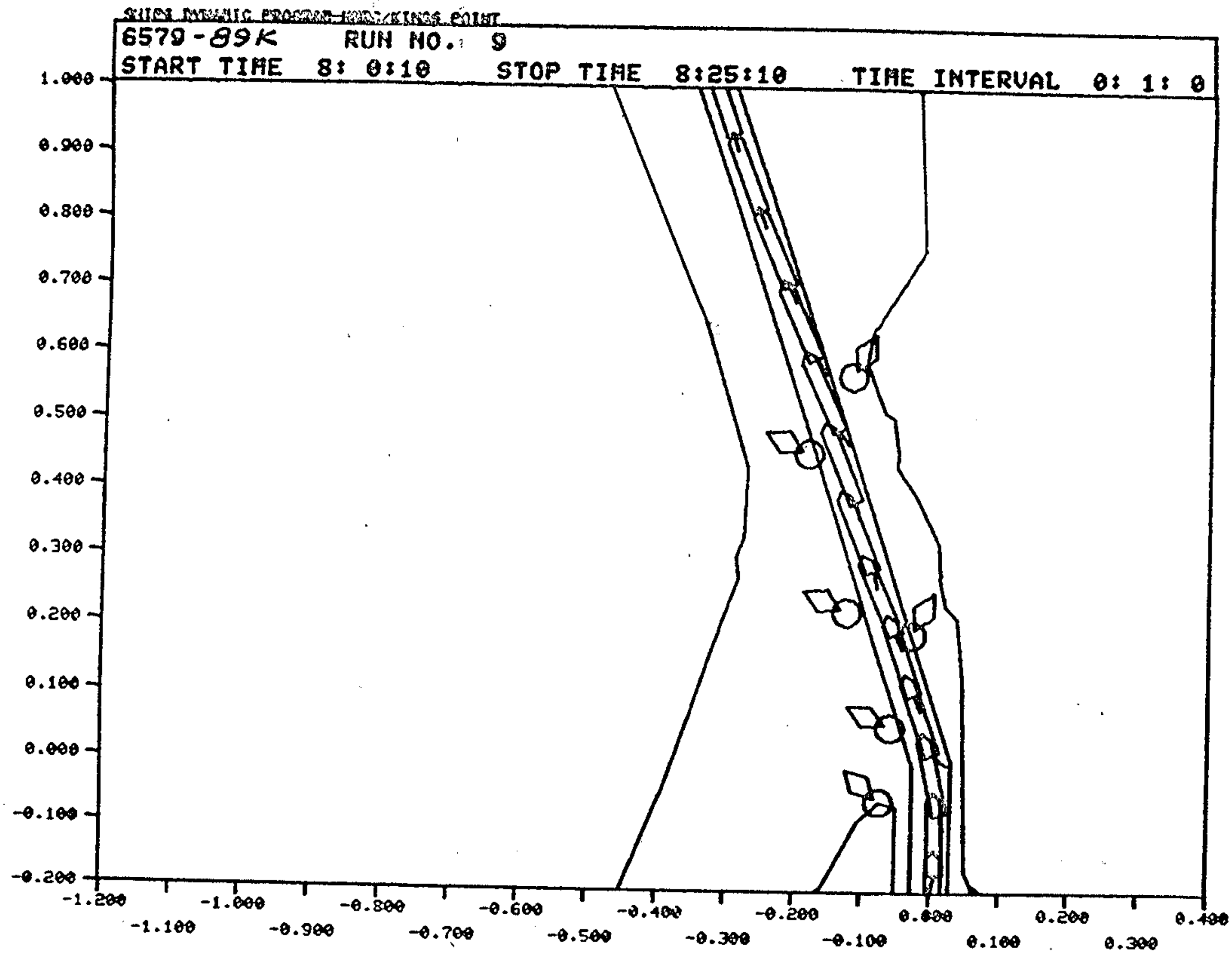

6579-89K RUN NO.: 9
START TIME 8: 0:10
STOP TIME 8:25:10
TIME INTERVAL 0: 1: 0
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-1.200
-1.100
-1.000
-0.900
-0.800
-0.700
-0.600
-0.500
-0.400
-0.300
-0.200
-0.100
0.000
0.100
0.200
0.300
0.400

Figure A-3

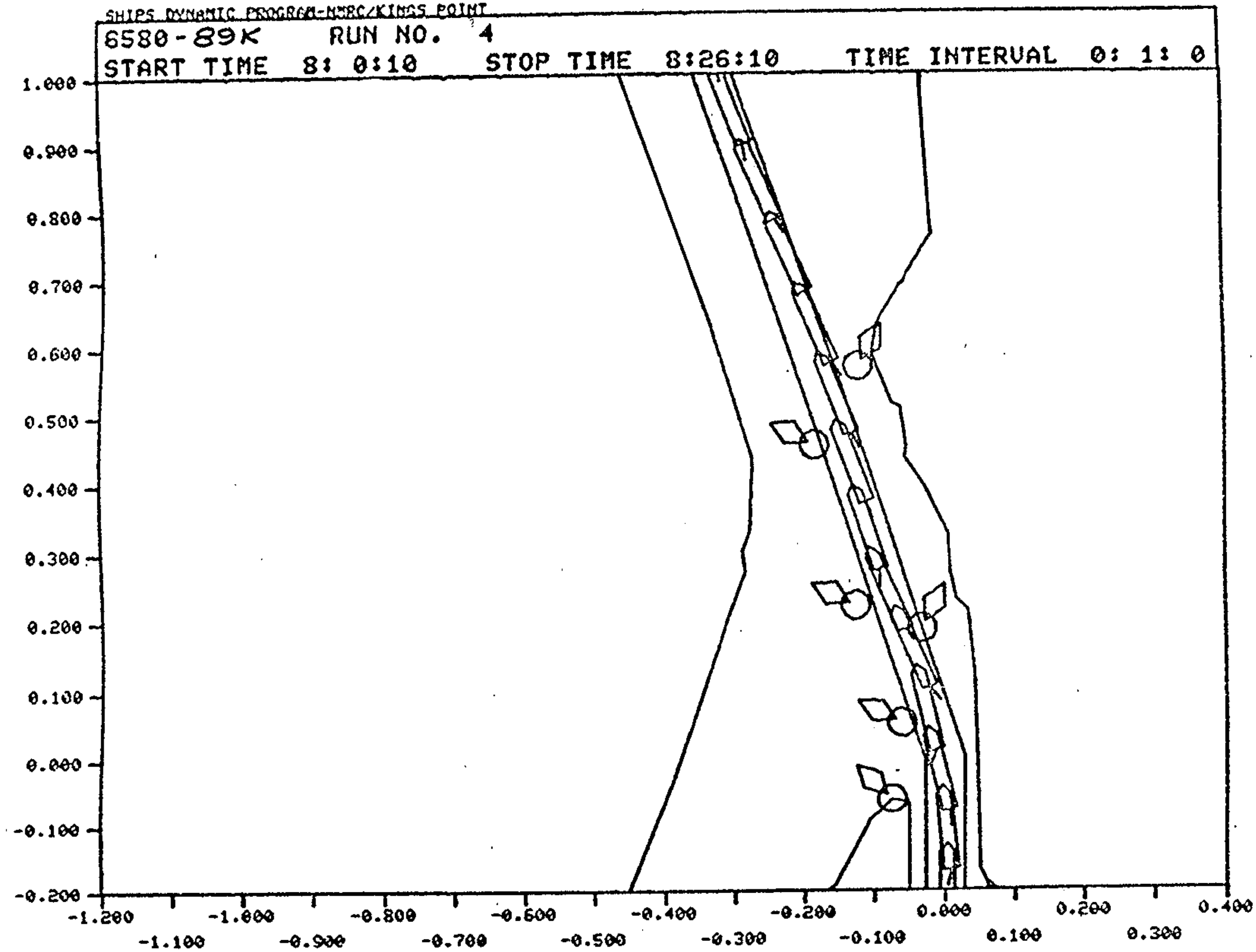

SHIPS DYNAMIC PROGRAM-NMRC/KINGS POINT
6580-89K RUN NO. 4
START TIME 8: 0:10 STOP TIME 8:26:10 TIME INTERVAL 0: 1: 0
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
-0.100
-0.200
-1.200
-1.100
-1.000
-0.900
-0.800
-0.700
-0.600
-0.500
-0.400
-0.300
-0.200
-0.100
0.000
0.100
0.200
0.300
0.400

Figure A- 4

Appendix B

STATISTICAL ANALYSIS

Inferential statistics were calculated for those two performance measures which were most clearly reflective of a successful transit, i.e., crosstrack displacement and channel edge clearance. In both cases a test was first conducted of the significance of the difference between the two sample variances, followed (if the null hypothesis was accepted ($\sigma_{65k} = \sigma_{89K}$)) by a test of the significance of the means of the two samples. It can be seen that a significant difference ($\alpha = 0.02$ or a 98 percent level of confidence) between sample variances for CG crosstrack displacement was found only at data point 10. The F ratios and t statistics, presented in Table B-1 and Table 1, were calculated using standard statistical tests.

Table B-1 lists the means and standard deviations of CG crosstrack displacement for the two ships at the 10 data analysis points. It can be seen that there is no significant difference in the performance of the two classes of vessels in the first leg (data points 1 and 2) or in the latter part of the second (points 9 and 10). However, there is a significant difference (90 percent confidence level) in their recovery from the turn. At data point 4, just entering the current and at points 5 and 6 as the current effect is being felt, no major differences in CG displacement are noted until data point 7 where the 89,000 dwt tanker is further to the right than the smaller vessel, and at data point 8 where the difference is significant at the 95 percent confidence level. The table of standard deviations (Table B-1) shows no significant difference in the degree of dispersion of individual run scores about the means, except at data point 10 (98 percent confidence level). The greater variance found for the 65,000 dwt ship at the end of the channel may be explained on the basis of better maneuverability. The pilots were able to adjust the course of the smaller vessel whereas the situation of the larger vessel, due to its more severe crosstrack displacement and poorer maneuverability, did not offer many ship control options that would lead to a greater dispersion of position following the current induced displacement.

Referring to Table 1 of the report, there was no statistically significant difference between the two ships' mean minimum clearance to the left side as they set up for the current, although the means for right channel edge clearance are significantly different at the 95 percent confidence level. The crab angle comparisons for the two ships at both the left and right channel edge calculations show the same results, although at a lower level of confidence (80 percent at the right side of the channel).

TABLE B-1. DESCRIPTIVE AND INFERENTIAL STATISTICS RELATING TO CG CROSSTRACK DISPLACEMENT

		MEAN				STD DEV			
		65	89	t		65	89	F	
DATA ANALYSIS POINTS	1	19.43	17.86	.46		7.38	8.51	1.33	
	2	28.11	25.58	.41		11.96	16.57	1.92	
	3	40.16	19.96	2.08	α.1	23.88	21.59	1.22	
	4	1.90	-2.13	.32		27.14	32.06	1.40	
	5	-21.48	-23.38	1.01		35.18	41.63	1.40	
	6	-1.34	10.96	-.60		48.0	48.25	1.01	
	7	35.47	58.9	-1.23		47.0	41.97	1.25	
	8	19.87	48.47	-2.16	α.05	36.18	24.84	2.12	
	9	-11.36	-1.99	-1.22		16.48	19.51	1.40	
	10	-4.77	1.18			20.99	8.72	5.74	α.02

MEANS AND STANDARD DEVIATIONS
OF CROSSTRACK DEVIATIONS (IN FT.)
FOR 65,000 AND 89,000
DWT TANKERS AT DATA POINTS 1-10