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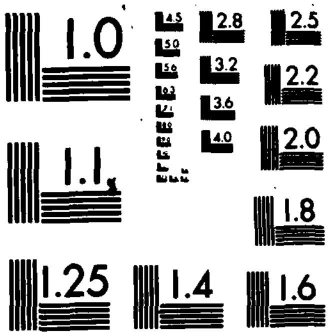
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CG-D-79-83

AIDS TO NAVIGATION RADAR I EXPERIMENT PRINCIPAL FINDINGS: PERFORMANCE IN LIMITED VISIBILITY OF SHORT RANGE AIDS WITH PASSIVE REFLECTORS

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North Stonington, Connecticut 06359

December 1983

Interim Report

Prepared for

U.S. Coast Guard
U.S. Department of Transportation
Office of Research and Development
Washington, D.C. 20593

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16. Abstract

This report describes an experiment conducted as a component of the United States Coast Guard's Performance of Aids to Navigation Project. The experiment evaluates the efficacy of floating aids (buoys) equipped with passive reflectors and the use of radar (3 cm) in a limited visibility. The following variables were evaluated: visibility (1-1/2 nm, 1/4 nm, zero nm); ship size (30,000 dwt versus 80,000 dwt); buoy arrangement in the turn and straight channel segment; wind and current. In addition, comparisons to previous experiments in this project were made to evaluate differences between piloting with radar in low visibility and piloting in adequate visibility without radar.

Differences in performance were most evident in the turn region while differences in the trackkeeping regions were less noticeable. In the turn region, performance suffered more in the low visibility conditions with radar than in the adequate visibility conditions without radar. Performance in the radar piloting scenarios was also worse in the lowest visibility condition in the turn. Pilots performed better with a smaller ship and with aid arrangements having higher density spacing. Finally, style differences in the use of radar were found and related to differences in ship track performance.

17. Key Words
Aids to Navigation, Buoy Arrangement, Limited Visibility, Piloting, Radar, Radar Piloting, Ship Size, Turnmarking, Visual Piloting

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We are grateful to the members of Northeast Marine Pilots, Incorporated, of Newport, Rhode Island who served as consultants and subjects in the experiment. We especially want to thank Captain Kenneth Warner, President, for his cooperation and Captain Michael Ball who served as presimulation consultant. This group's participation and their sharing of professional insight have made this experiment and this project possible.

PREFACE

The objective of the United States Coast Guard's Performance of Aids to Navigation Systems project is the preparation of guidelines for the design and evaluation of aid systems in restricted waterways. The Coast Guard's interest includes fixed and floating visual aids, radar, and radio aids. To provide quantitative data on which to base these guidelines, a series of experiments was done on two simulators, the Maritime Administration's Computer Aided Operation Research Facility (CAORF) at Kings Point, New York and a simulator developed for the project at Ship Analytics, Incorporated in North Stonington, Connecticut.

In 1982 at an interim point in the project, a draft manual was published summarizing completed components on the performance of visual and radio aids in a form useful as guidelines. "Draft SRA/RA Systems Design Manual for Restricted Waterways" is available from NTIS as AD-A113236.

The project is ongoing. The present phase of the work has included new simulator experiments on the effectiveness of turnmarkings for nighttime piloting and on the effectiveness of short-range aids (buoys) for radar piloting, on the effect of shiphandling factors on pilot performance. The present report is on short-range aids and radar piloting. A future experiment is planned investigating the special needs of the meeting traffic situation.

The continuing project includes two additional components meant to maximize the transfer of the findings to sea. To validate the USCG/SA simulator on which most of the experiments were done, ship track data was collected in Chesapeake and Narragansett Bays. A report comparing this data to simulator data is in preparation. A model implementation is in progress in Narragansett Bay. The validation data is a sample of performance at sea under present markings. After the markings are changed, ship track data will be collected again as a test of the manual evaluation.

A final SRA/RA design manual incorporating new data and experience with the draft manual is planned for 1985.

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

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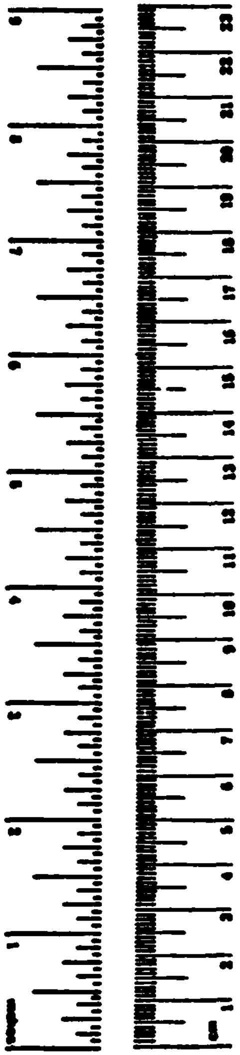
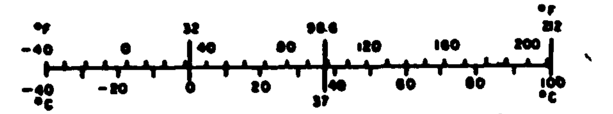
*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



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	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 experiment reported here contributes to the United States Coast Guard's Performance of Aids to Navigation Systems Program, which is meant to establish aid system design guidelines for U.S. ports. It is one in a series of experiments done on a simulator developed for the project at Eclectech Associates, Inc. in North Stonington, Connecticut. Earlier work on the project is summarized in a report entitled "Draft SRA/RA Design Manual for Restricted Waterways," available as AD-A113236 from NTIS, Springfield, Virginia 22161. The final product of the program will be a revision of this manual, incorporating new findings, including those of the present experiment.

The simulator experiments to date have emphasized adequate-visibility/visual-only piloting conditions. (A series of radio aids -- Loran C -- experiments were included in the project but they are not discussed in this report.) The present experiment extends the domain of the project and the forthcoming design manual to very-low visibility/radar piloting conditions, using a generic 3 cm radar, the pilots' own selection of radar methods, and aids with passive reflectors. Data collected under the conditions of present experiment is available to serve as a baseline in the evaluation of a variety of all-weather systems.

The effect on radar piloting performance of the following variables were evaluated.

visibility (1-1/2 nm, 1/4 nm, zero)

turnmarking (one, two, three buoys)

straight channel marking (gated or staggered)

ship size (30,000 versus 80,000 dwt)

current/wind (crosstrack versus none)

DEGRADATION IN PERFORMANCE WITH LOW VISIBILITY

Earlier adequate-visibility/visual-only experiments have identified a variety of variables and conditions representative of the piloting process. The present experiment included scenarios that replicated a sample of these conditions with very low visibility (1/4 nm, or just enough to see both buoys of a pair or all buoys marking a turn), available radar, and passive reflectors on the buoys. The following conclusions are supported:

- Performance is degraded in the lower visibility conditions despite the availability of radar. The primary difficulty was in the critical turn region. The pilots' tended to start and exit the turn later and to take longer to recover. Trackkeeping was not a special problem.

The observed degradation means that a thorough analysis of an aid system must include consideration of potential low visibility use.

- Performance in low-visibility/radar conditions, as it was in adequate-visibility/visual-only conditions, is dependent on the number of aids and their arrangement. Pilot performance in the turn region was worse for two-buoy turns than for three-buoy turns. There was little change in pilot performance in the trackkeeping region.

  For those conditions where the present guidelines for adequate visibility allow a choice of aid arrangements, low visibility may require the higher density arrangement, especially in the turn.

- Performance under very low visibility deteriorated more in the critical turn region for the 80,000 dwt ship than for the 30,000 dwt ship. This was true even for the well-marked three-buoy turn. Trackkeeping was not a special problem for either ship.

  Larger ships are a special problem in low visibility conditions. This problem is only minimally helped by additional aids; only operational restrictions on ship size in low visibility will make a meaningful difference in risk.

ENHANCEMENT IN PERFORMANCE WITH RADAR AVAILABILITY

To test the possibility that earlier adequate visibility conditions run without radar resulted in poorer than realistic performance for low buoy densities, an adequate visibility condition with radar was included here. There was an improvement in the immediate vicinity of the turn, probably because the pilots could add the exact range to the turn apex to the visual information available. It is unclear whether pilots would use the radar in this way at sea.

CURRENT AND WIND EFFECTS

All the conditions in this or earlier experiments were run with current and wind conditions that increased the difficulty of shiphandling. The inclusion here of a scenario without current and wind supports the following conclusions.

- The current and wind do increase the difficulty of shiphandling, especially in that part of the transit where they had the greatest crosstrack velocity, the turn pullout and recovery.

  The "design" current and wind conditions do contribute conservatism to the estimates of risk in the highest risk portions of a transit. They do this differentially among conditions, increasing the estimates more for such higher-risk conditions as low buoy density.

  For low visibility operations current and wind are factors to be considered. Operational restrictions on low visibility transits when these additional environmental problems are present would decrease risk.

BASELINE DATA FOR ALL-WEATHER NAVIGATION

One objective of the present experiment was to obtain a baseline of performance in zero visibility with traditional radar methods and aids with only passive reflectors. The inclusion of several representative scenarios support the following conclusions.

- Piloting in narrow channels with aid arrangements designed for visual piloting and with traditional radar methods is feasible, given qualified pilots and the 30,000 dwt ship. The larger ship is a special problem.

  The data collected under zero visibility with passive aids and traditional radar methods was planned to serve as a baseline for the potential evaluation of radar piloting with racons, other enhancements to radar piloting, or other types of all-weather systems.

THE PILOTS' USE OF RADAR

The pilots described their use of radar at sea; their use on the simulator was discussed, observed, and recorded. The following conclusions were supported.

- Pilots prefer visual methods, preferring not to sail under conditions that do not allow it. Under marginal conditions they do not combine methods but given dominance to one, using the other for confirmation. The one chosen for dominance is the one that is expected to be useful for most of the transit.

- There was considerable uniformity among the pilots and among scenario conditions in the use of radar features. The pilots all used the head-up display, the mechanical cursor, the heading flash, and either the variable range marker or the range rings. They used the lowest range scales, 1/2, 1.0, and 1.5 nm for the turn, going up to 3 nm in the straightaways. Only the frequency of changes in range scale was related to the difficulty of the scenario, with more frequent changes for the more difficult scenarios. There was no obvious relationship between feature use and ship track performance.

- All the pilots used course cursor piloting (cursor on the desired course, heading flash for comparison). There were differences in their facility with this method that were not related in any simple way to experience factors. These differences were reflected in the precision of ship track performance.

  The pilots' facility with radar makes a difference in the risk of low visibility transits. By extension, training is a possible way of decreasing the risk.

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LIST OF ILLUSTRATIONS

Section 1

INTRODUCTION

1.1 OVERVIEW OF THE AIDS TO NAVIGATION PROJECT

The United States Coast Guard is responsible for the design and maintenance of aids to navigation in U.S. harbors and channels. As a part of this responsibility, it is sponsoring a simulator-based research project to evaluate the effectiveness of aid systems, including visual aids, radio aids, and radar. The majority of the research has been done on a simulator designed and built for the project at Ship Analytics, Incorporated in North Stonington, Connecticut. The simulator is described here as Appendix A. The objective of the project is to develop design criteria for the placement of visual aids alone and in conjunction with radar and radio aids in restricted waterways. At an interim point in the project, the available findings were used to develop the "Draft SRA/RA Manual for Restricted Waterways"[1] demonstrating the use of such research system design.

The project is ongoing. More recent components include a completed experiment in nighttime visual piloting,[2] and two validation experiments and a model implementation that are in progress. The experiment reported here extends the domain of the project to radar piloting using aids with passive reflectors. The planning of this experiment has been described in an earlier technical memorandum.[3] A future experiment is planned investigating the problem of meeting traffic. The newer components will be included in a revised design manual planned for the spring of 1985.

1.2 THE SELECTION OF THE EXPERIMENTAL CONDITIONS

The present experiment had three objectives. The first was to extend the manual by providing performance data for selected conditions of very low visibility that requires the use of radar. Certain design conditions of the earlier experiments on which the manual is based were evaluated as well. The second objective of the experiment was to provide baseline of performance data using floating aids (buoys) with passive reflectors. This baseline would be available for the potential evaluation of other types of all-weather piloting. A third objective was to observe the pilots' preferred use of radar and to relate this use of ship track performance.

---

[1] W.R. Bertsche, M.W. Smith, K.L. Marino, and R.B. Cooper. "Draft SRA/RA Systems Manual for Restricted Waterways." U.S. Coast Guard, Washington, D.C., February 1982.

[2] J. Multer and M.W. Smith. "Aids to Navigation Turn Lights Principal Findings: Effects of Turn Lighting Characteristics, Buoy Arrangements, and Ship Size on Nighttime Piloting." CG-D-49-82 U.S. Coast Guard, Washington, D.C., February 1983. NTIS AD-A126080.

[3] L. Bergersen, G. Grant, J. Moynehan, J. Multer, and M.W. Smith. "Aids to Navigation Radar I Presimulation Report: Performance in Limited Visibility of Short-Range Aids with Passive Reflectors." U.S. Coast Guard, Washington, D.C., April 1981.

These objectives and the experimental conditions, or scenarios, selected to meet them are outlined in Table 1. They are entered into a variety of comparisons and discussions as outlined in Table 2. The aid arrangements for each scenario are illustrated in Appendix B.

1.2.1 Objective 1: Support of the Manual

The objective of support for the manual was met by viewing radar from two perspectives. First, it was hypothesized that when very short visibilities require a dependence on radar, performance may be degraded from that expected with visual piloting. A number of conditions expected, on the basis of the visual experiments, to have wide generality were selected for evaluation. As outlined in Table 1, Scenario 1 had a "standard" aid arrangement that had been run in several visual experiments. Scenario 2 differed in the turn arrangement. Scenario 3 included a larger ship, a condition found to be critically different in the visual experiments. Scenario 4 eliminated the "design conditions" of wind and current used in all the experiments. Second, it was hypothesized that when visibility is sufficient for visual piloting, the use of radar may enhance performance. Did the earlier visual experiments, run without radar available, show poorer performance than was realistic? For comparison with earlier visual performance, Scenario 6 with adequate visibility for visual piloting but radar available was included as listed in Table 1. (Scenario 5, also with adequate visibility, was dropped from the experiment.)

1.2.2 Objective 2: Baseline Data

Beyond comparing radar piloting with visual piloting conditions to investigate the degradation with low visibility/improvement with radar facets of this experiment, it was of interest to observe conditions of

TABLE 1. EXPERIMENTAL SCENARIOS

Scenario	Number of Turn Buoys	Straight Channel Marking (Long Spaces)	Ship Size (1,000 dwt)	Visibility (nm)	Wind/Current
Objective 1: Support of the Manual					
1	3	Gated	30	1/4	Design
2	2	Gated	30	1/4	Design
3	3	Gated	80	1/4	Design
4	3	Gated	30	1/4	None
6	1	Staggered	30	1-1/2	Design
Objective 2: Baseline					
7	3	Gated	30	0	Design
8	1	Staggered	30	0	Design
9	3	Gated	80	0	Design
Objective 3: Radar Techniques					
Radar techniques were observed in all experimental scenarios.					

TABLE 2. COMPARISONS AND DISCUSSIONS

Comparisons Within Radar Experiment (Section 2)	Scenarios
Visibility, low density marking	6 vs 8
Visibility, standard marking	1 vs 7
Visibility, larger ship	3 vs 9
Ship size, 1/4 nm visibility	1 vs 3
Ship Size, zero visibility	7 vs 9
Turn arrangement, 1/4 nm visibility	1 vs 2
Buoy density, zero nm visibility	7 vs 8
Wind/current	1 vs 4
Comparisons Between Radar and Visual Experiments (Section 3)	
Degradation with low visibility/radar, standard marking	1 vs O.S. Sc 1 vs T.L. Sc 1
Degradation with low visibility/radar, two-buoy turn	2 vs O.S. Sc 6 vs T.L. Sc 8,9
Improvement with radar, low buoy density	6 vs S.V. Sc 2
Degradation with low visibility/radar, larger ship	3 vs S.V. Sc 7
Use of Radar and Resulting Performance (Section 4)	
Use of the Data in the Manual (Section 5)	

increasing and total reliance on radar piloting. Scenarios 1 through 4 had a visibility of 1/4 nm since it was a feasible piloting condition which dictates the use of radar even under the most conservative design recommendations. These scenarios, in addition to allowing a comparison with previous visual piloting scenarios from earlier visual experiments, could be compared with the "pure" radar piloting scenarios in the present experiment.

To collect data on "pure" radar piloting, visibility was degraded to zero, depriving the pilot of all visual reference information, although this is not generally a feasible piloting condition. The three zero-visibility scenarios listed in Table 1 were run: with standard marking, low density marking, and an 80,000 dwt ship. These allowed comparisons with Scenarios 1, 3 and Scenario 6 and set a true baseline for possible later evaluation of radar piloting with racons, of other radar enhancements, or of other types of all-weather systems.

1.2.3 Objective 3: Observation of Radar Use

The third objective of this experiment was to observe the changes in radar piloting behavior under the different experimental conditions and to relate it to ship track performance. The radar display is a passive instrument that can provide a wealth of information, depending upon certain factors within the pilot's control. The pilot can manipulate the display image and has different techniques at his disposal that affect the interpretation of the image.

Broadening the scope of this experiment to include the human factors as an integral element in the pilot's use of radar will not require the addition of any scenarios. This experiment is not designed to manipulate these variables. Rather piloting behavior will be observed to see how pilots manipulate these variables as they would in the real world.

1.2.4 Comparisons and Discussions

The available experimental scenarios were sed in a variety of comparisons and discussions that are listed in Table 2. First, they re compared in Section 2 to indicate the effects of the following variables under radar piloting conditions:

- visibility (1-1/2 nm, 1/4 nm, zero)
- ship size (30,000 versus 80,000 dwt)
- turnmarking (one, two, three buoys)
- straight channel marking (gated or staggered)
- wind/current (design versus nominal)

Then, comparisons between the radar piloting conditions in the present experiment and visual piloting conditions from earlier experiments are made in Section 3. The observed use of radar and its relation to ship track performance is discussed in Section 4. The contribution of the new data to the planned design manual is discussed in Section 5.

1.3 THE CONSTANT CONDITIONS

When experimental scenarios are compared to evaluate the effects of one variable, this comparison is made in a context of other potential variables held constant across the two or more scenarios. It should be emphasized that the effects observed may be specific to that context. For this reason, it is necessary to exercise the same care in the selection and specification of the constant conditions among the scenarios as to the experimental conditions on which they vary. The constant conditions chosen here were similar to those used in previous experiments: a 500-foot wide channel with no bank effects, depth minimally adequate for ship size, and a 35-degree noncutoff turn. This similarity maximizes comparability between experiments.

The constant conditions are summarized in Table 3. Some conditions were not "constant" across all conditions. Notice that Scenarios 1, 2, and 4-8 were run with the smaller, 30,000 dwt ship. The remaining, Scenarios 3 and 9, differed by having the larger 80,000 dwt ship. Notice also that Scenario 4 omitted the wind and current that appeared in the others.

1. <u>Channel dimensions</u>. The constant scenario contains the same two channel segments that were used in the earlier experiments. These are illustrated in Appendix B. The segments are 2 and 2-1/2 nm long (the ship

TABLE 3. CONSTANT CONDITIONS: SCENARIOS 1, 2, 4-8

1. Channel dimensions:	500 foot width, 36-foot depth, 35-degree noncutoff turn
2. Environmental effects:	daytime following wind and current, slowing and changing to port quarter (except Scenario 4)
3. a. Ship for Scenarios 1,2,4-8:	30,000 dwt tanker with split house midships bridge with 45-foot height of eye ship speed 6.6 knots
b. Ship for Scenarios 3 and 9:	80,000 dwt tanker with rear house bridge with 80-foot height of eye ship speed 6.6 knots
4. Bridge:	helmsman engine order telegraph, gyrocompass repeater chart 16-inch PPI display of generic 3 cm radar
5. Visual scene:	ship bow, bridgewings buoys as required

will not transit the whole channel), 500 feet wide, and 36 feet deep under the 35-foot draft of the 30,000 dwt ship. There are no bank effects. The two segments are connected by a 35-degree noncutoff turn.

2. Environmental conditions. The experiment was run under daytime conditions. The wind and current are similar to those of earlier experiments and are illustrated in Figure 1. In the lower leg of the channel, there is a following wind averaging 30 knots and gusting. The wind maintains its average direction and speed throughout the scenario and is on the port quarter at the turn. The current changes from following in the first segment to the port quarter after the turn. It changes in speed as well as direction. For most of the scenarios, it is following at 1.4 knots at initialization, decreasing so that it is 0.7 knots on the port quarter as the ship exits the turn with a crosstrack component of 0.25 knots. The current continues to decrease as long as the scenario continues.

3. a. Characteristics of the 30,000 dwt ship. For most of the scenarios, the ship used is the 30,000 dwt tanker used in the earlier experiments. It is 595 feet long, 84 feet in beam, and has a 35-foot draft (in a 36-foot channel to make it relatively difficult to handle for its size). It has a split house with a midship bridge that puts the eyepoint 223 feet back from the bow, 75 feet ahead of the center of gravity, and 45 feet above the water. The information on this ship given to the pilots appears in Figure 2. The maneuvering characteristics of this ship are

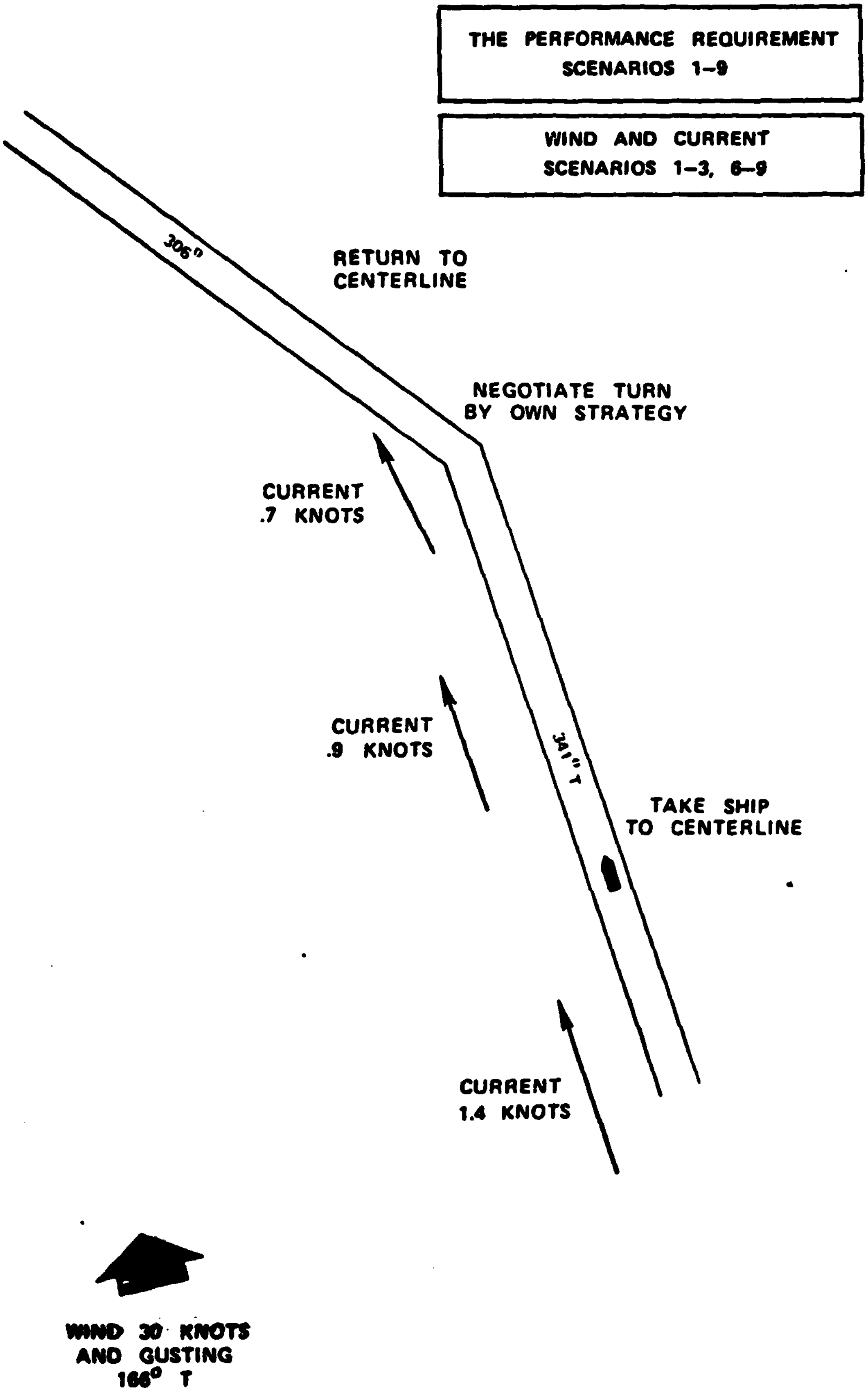
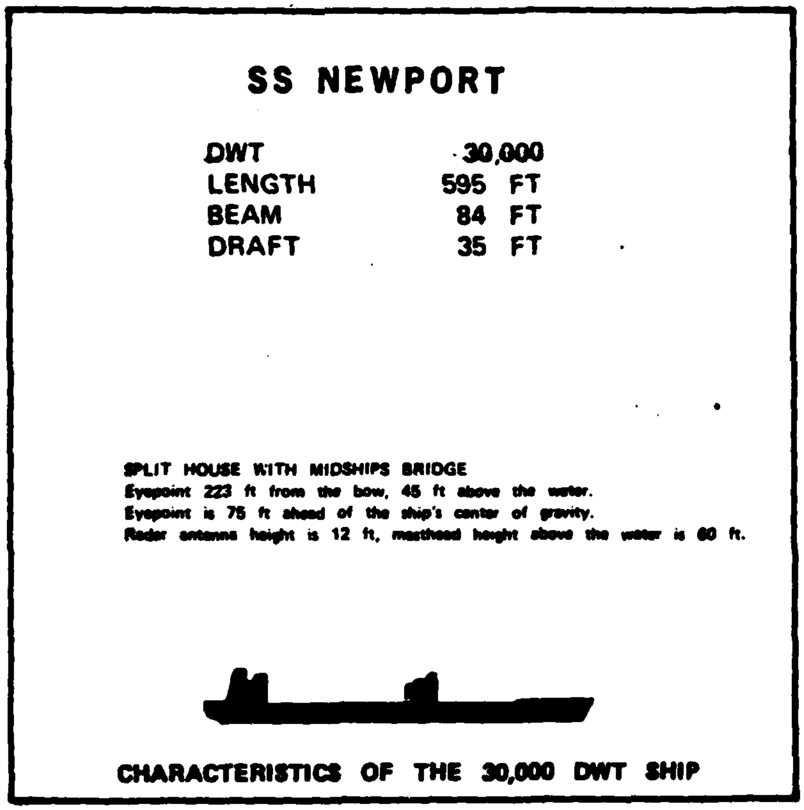


Figure 1. Performance Requirements and Wind and Current Effects

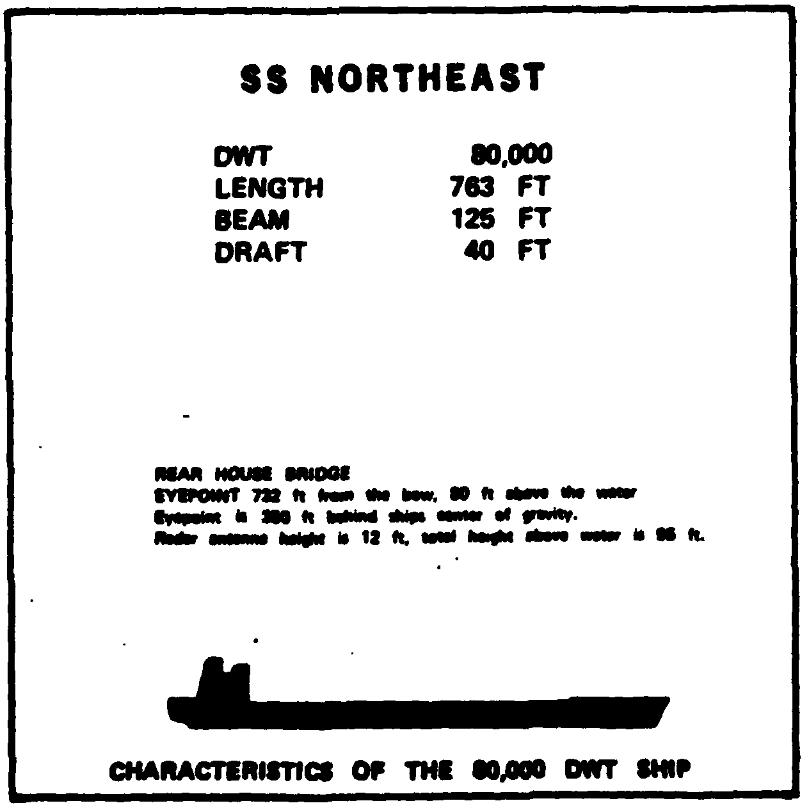


SS NEWPORT

DWT	30,000
LENGTH	595 FT
BEAM	84 FT
DRAFT	35 FT

SPLIT HOUSE WITH MIDSHIPS BRIDGE
Eyepoint 223 ft from the bow, 45 ft above the water.
Eyepoint is 75 ft ahead of the ship's center of gravity.
Radar antenna height is 12 ft, masthead height above the water is 60 ft.

CHARACTERISTICS OF THE 30,000 DWT SHIP



SS NORTHEAST

DWT	80,000
LENGTH	763 FT
BEAM	125 FT
DRAFT	40 FT

REAR HOUSE BRIDGE
EYEPOINT 722 ft from the bow, 80 ft above the water
Eyepoint is 380 ft behind ships center of gravity.
Radar antenna height is 12 ft, total height above water is 96 ft.

CHARACTERISTICS OF THE 80,000 DWT SHIP

Figure 2. Ship Characteristics

discussed and illustrated in the report on the earlier Ship Variables experiment, Appendices A and B there.[4]

3. b. Ship for Scenarios 3 and 9: The second ship to be run was the 80,000 dwt tanker used in the Ship Variables experiment. This ship is 763 feet long, 125 feet in the beam, with a 40-foot draft (in a channel adjusted to 41 feet). The bridge is a rear house with a viewing point 350 feet back from the center of gravity and 732 feet back from the bow. That viewing point is 80 feet above the water. The information provided for the pilot appears in Figure 2. The maneuvering characteristics of this ship are discussed and illustrated in Appendices A and B of the Ship Variables report there.[5]

4. The bridge conditions. In all cases, the pilot has the following bridge conditions available.

- a helmsman to receive his orders
- a gyrocompass repeater
- an engine order telegraph with the opportunity to change speed in the turn, if desired
- charts of the channel with the course, buoy locations, and wind and current conditions
- generic 3 cm radar information displayed on a 16-inch PPI

5. The visual scene. The visual scene for the scenarios consists of the bow of the ship which appears on the center screen with an eyepoint appropriate for the ship. Within each scenario, the buoys present at initialization vary in number and location with the requirements of Table 1. The buoys within each scenario, if visible, change in location on the screen in response to the ship's motion and disappear behind the bridgewings just before they pass abeam.

1.4 THE GENERIC 3 CENTIMETER (CM) RADAR

Generic 3 cm radar characteristics are delineated in Table 4. The selected characteristics of the USCG/SA generic 3 cm radar were derived from the general characteristics chapter of Wylie[6] and from review of commercial radar specifications supplied by Raytheon and Sperry. The rationale for selection of the characteristics is detailed by the next section.

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[4] W.R. Bertsche, D.A. Atkins, and M.W. Smith. "Aids to Navigation Principal Findings Report on the Ship Variables Experiment: The Effect of Ship Characteristics and Related Variables on Piloting Performance." U.S. Coast Guard, Washington, D.C., April 1981.

[5] Ibid.

[6] F.J. Wylie. "The Use of Radar at Sea." Annapolis, Maryland: Naval Institute Press, 1978.

TABLE 4. GENERIC 3 CM RADAR CHARACTERISTICS

0.8-degree horizontal beam width
20-degree vertical beam width, horizon polarized
0.06-microsecond pulse width
3600 pulses per second pulse repetition frequency
25 kilowatts nominal peak power, 5.4 watts power output for short scale operations

16-inch PPI display

Selectable display mode: head-up, north-up
Selectable range scales: 1/2 nm, 1, 1-1/2, 3, 6, 12, 24
Selectable range rings: 0.08 nm, 0.16, 0.25, 0.5, 1, 2, 4
Operator-selectable heading flash, electronic bearing line, variable range mark

1.4.1 Radar Characteristics Selection

Pulse repetition frequency (PRF) selected was 3600 pulses per seconds. This particular value was selected as representative of 3 cm radars due to its actual use by Raytheon.

Horizontal beam width (HZBW) of 0.8 degrees was selected as the most commonly found HZBW in marine 3 cm radars.

Vertical beam width selected was 20 degrees, horizon polarized. This figure, again, represents that most commonly found in 3 cm radars.

For the simulated pulse width, a value of 0.06 microseconds was selected as representative and, also, as that actually in use by Raytheon marine radars operating on short-range scales of 6 nm or less.

The nominal peak power of 25 kilowatts affects maximum range and resolution. For short range scale operations, an average power out level of 5.4 watts is assumed. This figure is also from Raytheon performance specifications.

The 16-inch plan position indicator (PPI) is almost universally available and is the one presently installed in the USCG/SA simulator.

An assumed radar antenna mast height of 12 feet was selected as representative for the installation because this height helps optimize the short scale operations of the radar. Commercial installations vary from a low of 1 foot to a high of 30 feet. It should also be noted that the combination of antenna height and placement impacts significantly on the actual minimum range performance of the installation and these calculated values will be varied accordingly for our 30,000 and 80,000 dwt tankers.

Selected antenna rotation rate for our presentation was 30 revolutions per minute (rpm). Actual rates vary from 24 rpm to a high of 33 rpm. The computer capability, however, updated the presentation every 2 seconds or 30 cycles per minute. This simulated rotation rate is representative and acceptable for purposes of this experiment.

To enhance the realism of the simulator environment in the low visibility radar navigation environment, effects of the following characteristics were incorporated into the video display:

- beam width
- pulse length
- PPI pulsation from PRF
- antenna height
- minimum range target loss

Most significant of the above mentioned effects was that of minimum range target loss in the reduced visibility environment. A simplified diagram of the generic 3 cm radar "blind zone" is contained in Figure 3.

The USCG/SA generic 3 cm radar offered the user a choice of heads-up or north-up mode. Selectable range scales, range rings, head flash, electronic bearing line, and variable range mark were available as desired.

1.5 THE PERFORMANCE REQUIREMENTS

As with the constant conditions described before, the observed performance is specific to the task the pilot was instructed or required to perform. The instructions given to the pilot appear in Appendix C.

The performance requirements for Scenarios 1 through 9 are summarized in Figure 1. The ship was initialized 1.8 nm below the turn and 100 feet to the right of the centerline at a speed through the water of 6.6 knots. At that point there was a following current of 1.4 knots and decreasing, and a following wind of 30 knots and gusting. The pilot has time to study the available visual scene, the radar, and orient himself (he had studied the chart and it was available to him) before it was necessary to maneuver the ship. The pilot was instructed to take the ship to the centerline of the first leg. He could then leave the centerline when ready to negotiate the turn by his own strategy, which could include temporarily increasing the engine rpm. As he entered the new leg, the wind and current were on his port quarter. The current had decreased in velocity to 0.7 knots with a crosscurrent component of 0.25 knots. The pilot was asked to bring the ship to the centerline of the new leg. Maintaining the centerline at the beginning of the second leg required a drift angle of approximately 3 degrees, a requirement that decreased as the crosstrack velocity of the current decreased. The wind maintained its average velocities. Most of the scenarios ended 2-1/2 nm beyond the turn or in approximately 34 minutes. Scenario 2, where the interest focused on the turn, was shorter.

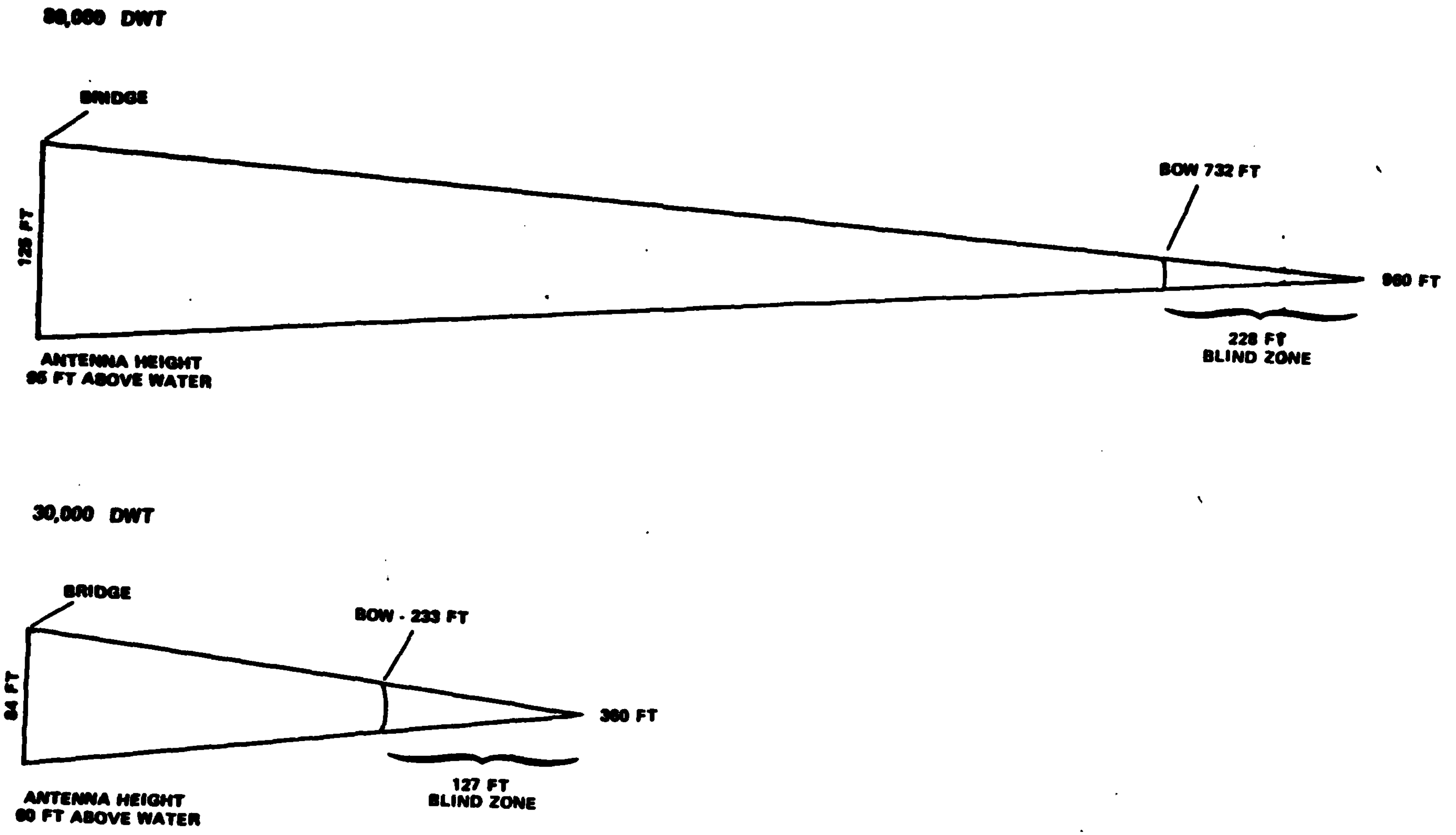

Figure 3. Blind Zones for Generic 3 cm Radar

1.6 SUBJECTS AND PROCEDURES

1.6.1 Subjects

Subjects were recruited from Northeast Marine Pilots, Inc., Newport, Rhode Island. The majority of them have been in the earlier simulation experiments. One pilot was brought in for an early presimulation run through the experiment and contributed to the final planning. Eight additional pilots were subjects for the actual experimental runs. Each pilot ran through all the experimental conditions in one day.

During the running of the experiment, it was observed that the pilots who varied in license and experience, also varied in their ability to handle the tankers under low visibility/radar conditions. To reduce the pilot-caused variability, only the performance of five state-licensed pilots were included in the analyses in Sections 2, 3, and 5. The heterogeneity of the complete group, with its greater range of performance, was an asset for the analysis of radar use in Section 4.

1.6.2 General Procedures

Each pilot's day consisted of the following events:

- a briefing that included instructions to the pilot that appear as Appendix C
- the experimental runs described as below (interrupted by lunch)
- informal day long discussion guided by the postsimulation questionnaire that appears as Appendix D

Because of the pilots' past difficulties in running more than one ship in an experimental day, special consideration was given to the order of runs. It was assumed that randomizing the scenarios would result in a bias in favor the easier-to-handle and more-frequently run 30,000 dwt ship. To avoid such a bias and more realistically measure performance with the 80,000 dwt ship, the pilot was allowed to prepare himself for it. The 30,000 ship was run first, all the scenarios with it were completed before changing ships, and each ship had its own familiarization run. The exact order appears in Table 5.

It was decided that performance at each level of visibility would be most realistically measured if the pilot was allowed, again, to prepare himself for the most difficult conditions. In the real world a pilot would not be in control of an unfamiliar ship in an unfamiliar channel in restricted visibility. Therefore, within each series of runs with a given ship, the runs were arranged in decreasing order of visibility, as in Table 5. This means that the zero visibility runs to be used as baseline data for radar enhancements, represent the best that can be expected with traditional radar and passive aids. The run of scenarios with the 30,000 dwt ship and 1/4 nm visibility; Scenarios 1, 2, and 4; were randomized.

TABLE 5. ORDER OF SCENARIOS FOR SUBJECTS

	Run Number										
Subjects	FAM	1	2	3	4	5	6	7	FAM	8	9
	Scenario Number										
1	30	6	1	4	2	8	7	7	80	3	9
2	30	6	4	1	2	7	8	8	80	3	9
3	30	6	2	4	1	8	7	7	80	3	9
4	30	6	4	2	1	7	8	8	80	3	9
5	30	6	2	1	4	8	7	7	80	3	9
6	30	6	1	2	4	7	8	8	80	3	9
7	30	6	4	1	2	8	7	7	80	3	9
8	30	6	1	4	2	7	8	8	80	3	9

1.7 THE PERFORMANCE MEASURES AND DATA ANALYSIS

1.7.1 Performance Measures

A variety of performance measures were collected for use in evaluating the scenario conditions. They included the following classes:

1. The primary measure was the crosstrack position of the ship's center of gravity as a function of alongtrack position during the transit of the channel. When the ship's center of gravity crossed the data lines illustrated in Figure 4, its position was automatically recorded by the computer along with other related measures.

2. The pilot's course, rudder, and engine orders were recorded by an operator at a computer terminal. When they were entered, the computer added measures of ship's status.

3. A postsimulation questionnaire allowed the pilot to comment subjectively on the conditions of each scenario and on his strategies. This questionnaire was the pilot's contribution to the preliminary observation report prepared immediately after the data collection phase.

1.7.2 The Descriptive Analysis of the Primary Data

The principal descriptive analysis is a compilation of data on the position of the ship's center of gravity. The basic measure of its crosstrack position is treated as illustrated in Figure 5. The crosstrack mean and standard deviation of the runs used are calculated at each data line for the set of conditions to be described. The first set of axes shows the means; the second, the standard deviation. On the last set of axes is a "combined plot" which shows the band formed by the mean and two standard deviations to either side of it against the boundaries of the channel. The band encloses 95 percent of expected transits under the experimental conditions sampled. The placement (mean) and width (standard deviation) of this band within the boundaries of the channel are together a quantitative

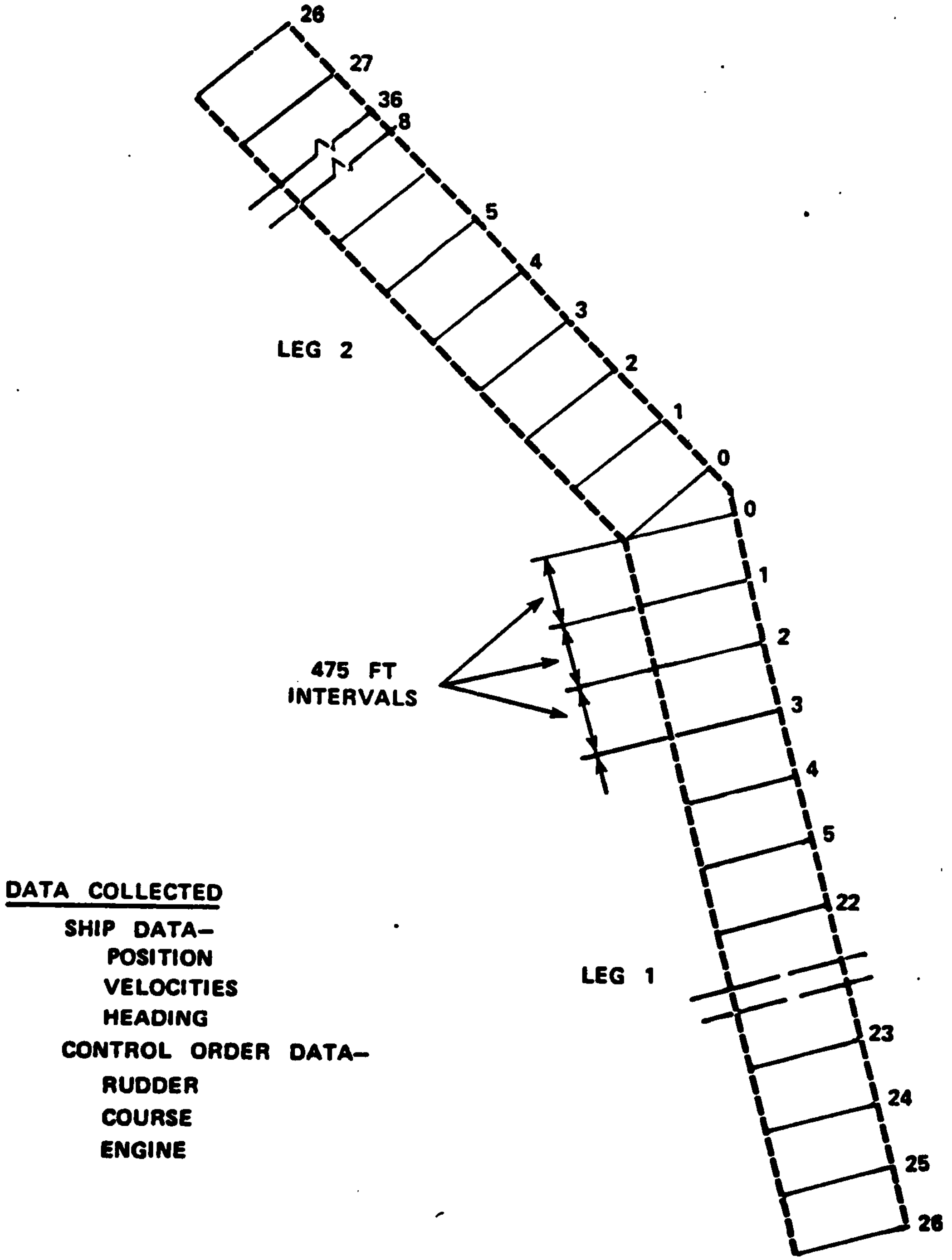

Figure 4. Data Collection Lines

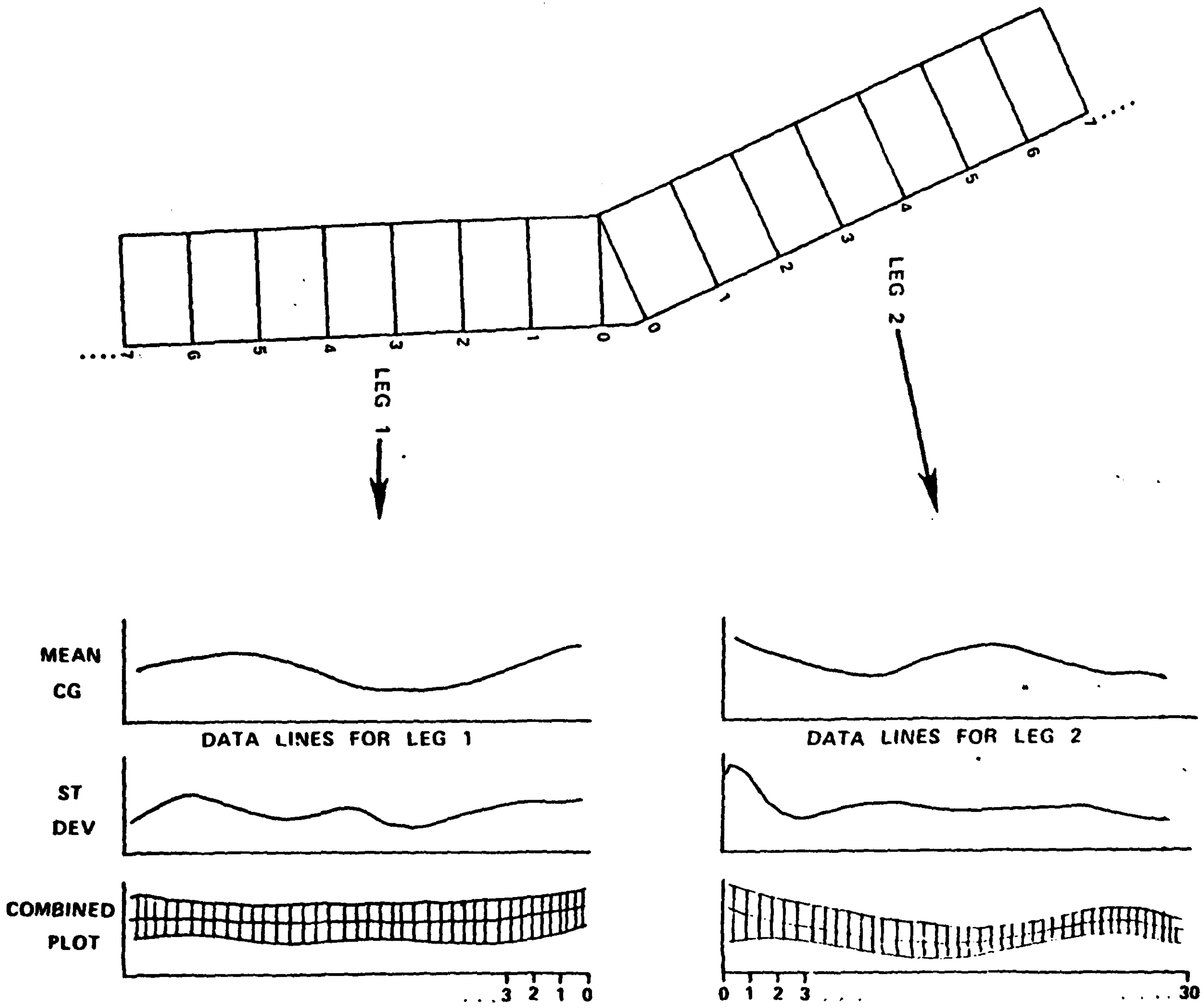

Figure 5. Descriptive Analysis of Crosstrack Action

description of the set of transits under these conditions, and, therefore, of the performance of the buoy arrangements.

The trackkeeping portions of the scenario are the easiest to interpret. It is assumed that, because of instructions, the pilots are attempting to keep the ship on the designated track, here, the centerline. The distance of the mean off the centerline and the spread measured by the standard deviations are indications of the performance of the buoy arrangement for the conditions sampled. Therefore, the best buoy arrangement is one that puts the mean of the distribution on the trackline and minimizes the standard deviation. Performance in the maneuvering portions is more difficult to interpret. The distribution of crosstrack positions in the maneuvering portions contains the variations in pilots' strategies as well as the performance of the buoys in guiding them in those strategies.

There is an assumption in this discussion that the precision in piloting performance that a buoy arrangement affords is related to the safety of that channel: a safely marked channel is one that results in a distribution of transits that is well within the channel boundary for both trackkeeping and maneuvering. It should be reemphasized that these measures are derived from an experiment and not a real-world situation. They are measures of performance under the experimental conditions (the experimental design and the simulation) used. For application to real-world channels, they must be considered relative measures of the performance of buoy arrangements or channel conditions. The interpretation of these performance measures as probability of grounding, for example, would be incorrect pending validation of such interpretation in the real world.

1.7.3 THE INFERENTIAL ANALYSIS OF THE DATA

The selection of the inferential tests to be made required several considerations. The experimental conditions have already been arranged in pairs that are summarized in Table 2. Between these pairs, tests can be made on every data line for an exhaustive exploration of the differences, or critical data lines can be selected to represent scenario events.

Adequate descriptions of the data require both the mean and the standard deviation as described in Section 1.7.2. Tests can be made of either of these statistics. They were made by the procedures which are described in McNemar.[7]

- When means from two conditions were compared, a t-test was used.
- The standard deviations of the conditions were compared in pairs dictated by the logic of the experiment. They were compared as variances, using variance ratios, or an F-test.

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[7] Q. McNemar. Psychological Statistics, Fourth Edition. John Wiley and Sons, Inc., New York, 1969.

Section 2

EVALUATION OF PERFORMANCE DIFFERENCES IN RADAR PILOTING

2.1 INTRODUCTION

Prior research of the aids to navigation project has identified a number of variables which are significant in evaluating piloting performance under visual conditions. In this section, the availability of radar information is taken as a constant condition and quantitative performance differences attributable to the following variables are examined:

- the different visibility conditions (1-1/2 nm, 1/4 nm, zero)
- ship size impact under low visibility conditions
- buoy arrangement performance under low visibility conditions
- wind and current effects under low visibility conditions

The data in this section is based on five pilots who were homogeneous in having state licenses and experience with large tankers. They were not homogeneous as to style of radar use. The relationship of style of radar use to ship track performance is discussed in Section 5.

2.2 THE EFFECT OF VISIBILITY ON RADAR PILOTING PERFORMANCE

Within the experimental design, three sets of scenarios readily lend themselves to an assessment of the impact of visibility on piloting performance. The impact of visibility were evaluated in the comparisons shown in Table 2

Combined plots of the first scenarios to be compared are contained in Figure 6A.* A comparison plot of Scenario 6 and Scenario 8, in which performance of the 30,000 dwt ship was assessed under a straight channel marking configuration and a one-buoy turn, is detailed by Figure 6B. Scenario 6 provides 1-1/2 nm visibility and Scenario 8 provides zero visibility. As can be seen from Figure 6B, under radar piloting conditions the crosstrack mean for Leg 1 is closer to the centerline for Scenario 8 (zero visibility) than for Scenario 6 (1-1/2 nm visibility). For Leg 1, Scenario 8 also has a lower standard deviation up to the turn.

In the turn itself, only one buoy marks the turn point. Passing through the turn, the track for both ships stays well within the channel for both the 1-1/2 nm visibility condition and the zero nm visibility condition. However, the pilots stayed closer to the center of the channel in the 1-1/2 nm visibility condition through the pullout region. In the pullout region the crosstrack mean and standard deviation are both within 30 feet of the center of the channel for the 1-1/2 nm visibility condition while these measures remain within 70 feet for the zero visibility condition. In the

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*To maintain the integrity of Section 2 text, all the accompanying figures would follow the text.

trackkeeping region of Leg 2, it was expected that the longer visibility condition would result in better performance for this group. Contrary to expectations, performance was worse for this group. The crosstrack mean was consistently closer to the right channel edge for the 1-1/2 nm visibility condition. These differences were statistically significant. The crosstrack standard deviation was also consistently smaller, although the differences were relatively small.

Why the pilots in the 1-1/2 nm visibility condition should perform better than the pilots in the zero nm visibility condition in the turn, but worse in the less difficult trackkeeping region is not clear. One possible hypothesis to explain these results lies in the order in which the scenarios were presented. The pilots were given advanced notice that the scenarios would be presented in order of decreasing visibility (see Table 5). Consequently, the pilots may have used the trackkeeping portions of Scenario 6 as additional practice to prepare themselves for the lower visibility turn. The one-buoy turn may have been sufficiently difficult to require the pilots to pay close attention to the navigational task at hand in order to avoid going out of the channel. In this relatively challenging situation the pilots in the 1-1/2 nm visibility condition may have piloted primarily by visual reference to obtain crosstrack information and used radar as a secondary source of information to obtain alongtrack information. In the trackkeeping regions, however, the task demands were not as great as in the turn and thus require less work on the part of the pilots to navigate safely. To prepare for the lower visibility scenarios that followed, they may have piloted primarily by radar and in doing so, ignored some of the visual information that was available.

The second visibility comparison is found in Figure 7A, showing the combined plots for Scenario 1 (1/4 nm visibility) and Scenario 7 (zero nm visibility) when transiting a channel marked with long-spaced gates and a three-buoy turn marking. In the comparison plot of Figure 7B, there is again a faster initial move toward the centerline in the lower visibility condition. By Data Line 10 of Leg 1, performance for mean trackkeeping becomes essentially the same in both scenarios until the turnpoint. For this same segment, however, the lower visibility condition exhibits a slightly higher standard deviation. At the turn, the crosstrack mean stays closer to the channel center for the 1/4 nm visibility condition than for the zero nm visibility condition. The crosstrack standard deviation is smaller for the zero nm visibility conditions, however. Neither of these differences are statistically different. Performance following the pullout region is similar for both visibility conditions. The crosstrack mean is actually closer to the center of the channel for the zero visibility condition than for the 1-1/4 nm visibility condition. These differences are statistically significant in the trackkeeping region without crosscurrent. The standard deviations for these two scenarios coincide at about Data Line 12 and thereafter crisscross with generally equal magnitudes. It appears from this comparison that while turnmaking performance is degraded for this channel marking under zero visibility, it is nevertheless a satisfactory marking scheme for visual and radar piloting under low visibility.

The final visibility comparison lies in Scenario 3 (1/4 nm) and Scenario 9 (zero) where the impact of visibility on the larger, less maneuverable

80,000 dwt ship is examined in the context of long spaced, gated channel segments with a three-buoy turn marking configuration as depicted in the combined plot of Figure 8A.

As can be seen in the comparison plot contained in Figure 8B for Leg 1, the crosstrack means are virtually identical up to the turnpoint, however the standard deviation is somewhat larger for the zero visibility scenario (Scenario 9). It is following the turn that discernible differences appear. For Scenario 9 (zero nm visibility) while the crosstrack mean returns to the center of the channel more quickly than in Scenario 3, the envelope within which 95 percent of all tracks would fall, indicates a substantial risk of exiting the channel on the right hand side. Once recovery is achieved at Data Line 13, about 1 nm after turn in Leg 2, the crosstrack mean becomes essentially the same with the standard deviations crisscrossing at equal levels of magnitude.

Overall, the 30,000 dwt ship suffers some performance degradation in the turn as visibility decreases but performance remains at acceptable levels due to the ship's maneuverability. For the 80,000 dwt ship however, even with an excellent turnmarking configuration, in a zero visibility environment turnmaking performance degrades to levels posing substantial danger of egress from the marked channel and possible grounding. This is due to the poorer maneuverability of the vessel which coupled with turnmaking of radar piloting and the effects of wind/current cause greater crosstrack displacement levels in the turn and recovery region.

2.3 THE EFFECT OF LOW VISIBILITY AND SHIP SIZE ON PERFORMANCE

Comparison of performance differences between the 30,000 dwt ship and the 80,000 dwt ship were made in the same channel and turn marking configurations under two visibility conditions, 1/4 nm and zero nm visibility. Combined plots for Scenarios 1 and 3 are contained in Figure 9A.

The comparison plot for the two ships in a 1/4 nm visibility environment is contained in Figure 9B. As can be seen Leg 1, mean trackkeeping and associated standard deviations are quite similar with no statistically significant differences shown, although the 80,000 dwt ship does move to the centerline a little before the 30,000 dwt ship. It is in the turn, recovery and Leg 2 regions where the differences manifest themselves. The 30,000 dwt ship transits through the turn with a crosstrack mean that stays closer to the centerline than the larger ship. The 80,000 dwt ship, on the other hand, has a crosstrack standard deviation that is statistically smaller than that of the 30,000 dwt ship. Taken together these measures indicate that the 80,000 dwt ship has more difficulty maneuvering through the turn. In Leg 2 trackkeeping performance the 30,000 dwt ship achieves a lower overall standard deviation due to its inherently greater maneuverability. Considering the long-spaced arrangement present, however, the 30,000 dwt ship achieves a satisfactory level of trackkeeping, turning and recovery performance, with radar, in this visibility condition. Performance of the 80,000 dwt ship is satisfactory for trackkeeping but unsatisfactory for turnmaking in this comparison. The availability of visual cues in the turn to supplement the radar display, allowing more precise evaluation of lateral displacement in the channel is the most likely reason for these performance levels.

Reducing the available visibility to zero nm in Scenarios 7 and 9, as depicted in the combined plots of Figure 10A accentuates the effects of the larger, less maneuverable ship. As can be seen from the comparison plot of Figure 10B, the 80,000 dwt ship exhibits crosstrack mean that skirts the edge of the right hand channel boundary while the mean stays well within the channel for the 30,000 dwt ship. Examination of the standard deviation shows that the turnmaking performance of the 80,000 dwt ship differs by a factor of about 3 magnitudes from the 30,000 dwt ship. By Data Line 17, however, the standard deviation for the 80,000 dwt ship returns to a magnitude level approximating 30,000 dwt ship performance levels.

Overall, while the 30,000 dwt ships stay within the channel through the turn and the trackkeeping regions at 1/4 nm visibility, the turnmaking performance level of the 80,000 dwt ship is so degraded in zero visibility conditions that there is a considerable risk going out of the channel in the turn.

2.4 THE EFFECT OF LOW VISIBILITY AND BUOY ARRANGEMENT ON PERFORMANCE

Using the 30,000 dwt ship, two separate evaluations of buoy arrangement in a low visibility environment are possible. One comparison focuses on turn marking exclusively, while the other evaluates both straight channel marking and turn marking.

Combined plots of Scenarios 1 and 2 are detailed by Figure 11A. The comparison plot for Scenario 1 (three-buoy turn) and Scenario 2 (two-buoy turn) is contained in Figure 11B where both have 1/4 nm visibility and long-spaced gates marking the straight channel segments for a 30,000 dwt ship. Performance throughout the first leg is essentially the same for both scenarios with a performance divergence first evident at the turnpoint.

Performance differences between three-buoy turns and two-buoy turns show the same trends whether piloting by visual references only or with visual references and radar. Differences in performance appear in the pullout region. The crosstrack mean stays closer to the centerline and the standard deviation is lower for the the three-buoy turn. The fact that the crosstrack mean is further to the right is probably due to the lack of a pullout buoy. At Data Line 10, about 0.8 nm after the turn, the crosstrack mean is similar for both turns while the standard deviation levels remain greater for the two-buoy turn. For best turnmaking performance levels to be achieved, a three-buoy turn is preferable to a two-buoy turn.

Scenario 7 (three-buoy turn, gated channel) and Scenario 8 (one-buoy turn, staggered channel) provide the next evaluation of buoy arrangement on performance, in a zero visibility environment. Figure 12A contains the combined plots of these scenarios. Figure 12B details the comparison plot for these conditions which contains no significant differences for Leg 1 trackkeeping ability with these two configurations. Similarly, the crosstrack mean shows no discernible difference for the two configurations in the turn although the standard deviation level for the one-buoy configuration is somewhat, but not significantly, higher. In the trackkeeping region performance does not differ in any practical way, although the standard deviation is higher in the staggered marking arrangement. Despite the zero visibility conditions for both scenarios the ship tracks remain within the channel. This suggests the following two inferences. First, safe trackkeeping is possible under the zero visibility conditions of this experiment. Secondly, radar enhances the performance of staggered aid arrangements.

2.5 EFFECT OF WIND AND CURRENT PERFORMANCE

The performance levels of Scenarios 1 and 4 where the variable of interest is the presence/absence of the design wind and current conditions is detailed by the combined plot of Figure 13A. The comparison of Scenario 1 (design wind and current) to Scenario 4 (no wind and current) as detailed by the comparison plot of Figure 13B discloses the anticipated performance pattern. Performance under 1/4 nm visibility is more precise in the absence of wind and current than in its presence. Scenario 4 has smaller values both in the mean and in the standard deviation, both in the turn and trackkeeping regions. The fact that the mean in Scenario 4, with and current, is displaced to the right of Scenario 1, without wind and current suggests that the wind and current together can have a powerful effect upon ship track performance.

2.6 SUMMARY AND CONCLUSIONS

The availability of radar information has a significant impact on piloting performance over the range of situations where inadequate or less than optimal visual information is available to a pilot. Discrete operational inferences may be made from the performance data, the comparisons within the experiment and comparisons to previous simulations within the overall design limitations i.e., a 500 foot channel with no bank effects, lack of traffic vessels, and negotiation of a 35 degree noncutoff turn. Of the variables examined, the analysis of the results disclose a weighting of the variables in the following descending order of importance:

- Ship size
- Visibility
- Buoy arrangement in the turn
- Wind and current

2.6.1 Ship Size

The 30,000 dwt ship performance is acceptable with 95 percent of all expected transits being within channel boundaries in all visibility conditions and buoy arrangements.

The 80,000 dwt ship trackkeeping performance is adequate under gated channel marking arrangements but turnmaking performance is marginal with the optimal turnmaking examined by the experiment at a visibility condition of 1/4 nm. Under zero nm visibility conditions however, 80,000 dwt ship turnmaking performance is deficient with the inference being drawn that operational restrictions on transits of this size vessel should be imposed where turnmaking would be required under visibility conditions of 1/4 nm or less.

2.6.2 Visibility

Acceptable and safe performance levels where 95 percent of expected transits will be within channel boundaries can be attained even under zero nm visibility conditions by a 30,000 dwt ship under all the straight channel and turnmarking configurations examined. Under 1/4 nm visibility conditions, the 80,000 dwt ship can achieve acceptable and safe performance levels given gated straight channel segments, but has marginal turnmaking even when given a three-buoy turn. Under zero nm visibility conditions the 80,000 dwt ship, even given an optimal channel/turnmarking configuration, has an inherently high risk of going out of the channel following the turn. While acceptable and safe performance levels are achievable in the straight channel segments, the turn performance data indicates such a likelihood of a grounding that transits involving 35-degree turns should be precluded in a 1/4 nm or less visibility environment.

2.6.3 Buoy Arrangement in the Turn

The gated straight channel marking configuration with a three-buoy turn marking arrangement produces the best performance levels under all visibility conditions for the 30,000 dwt ship. It is acceptable for 80,000 dwt ship trackkeeping, but not for turnmaking under visibility conditions of 1/4 nm or less. The two-buoy turnmarking arrangements is likewise acceptable under all visibility conditions for a 30,000 dwt ship but not for the 80,000 dwt ship at visibility conditions of 1/4 nm or less. The long spaced staggered arrangements is acceptable for the 30,000 dwt ship under all visibility conditions. However, given the performance of the 80,000 dwt ship even under an optimal arrangement in a zero nm visibility environment, the one-buoy turn must be evaluated as deficient to meet the informational needs for piloting an 80,000 dwt ship in a low visibility environment.

2.6.4 Wind and Current

The presence of wind and current affects the performance of the 30,000 dwt ship under all visibility conditions but not to such a degree as to render its impact significant in comparison to other factors.

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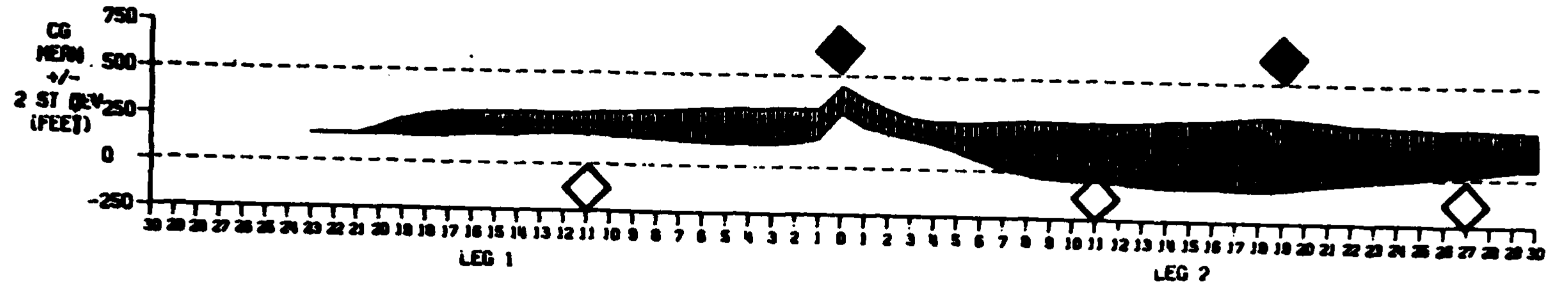
SCENARIO 6: 1 - BUOY, STAGGERED, 30K DWT, 1-1/2NM VISIBILITY



SCENARIO 8: 1 - BUOY, STAGGERED, 30K DWT, 0NM VISIBILITY

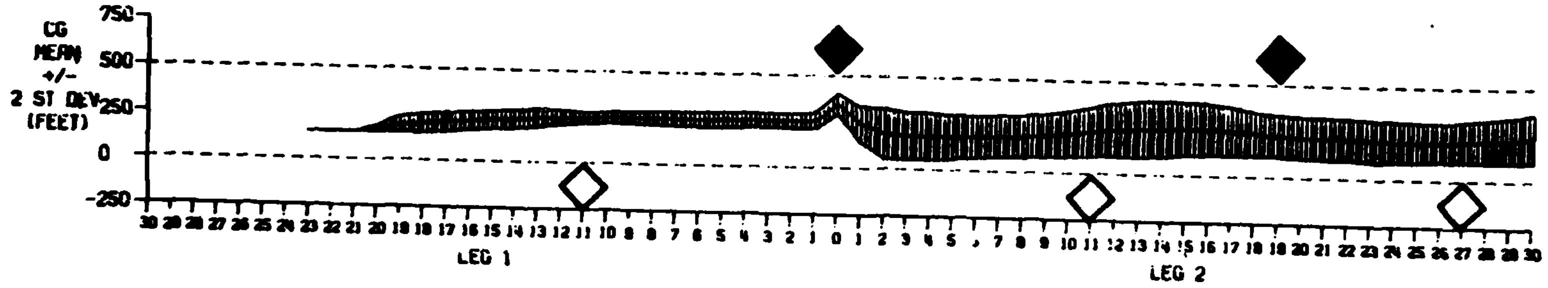


Figure 6A. Combined Plots for Visibility, Low Density Marking

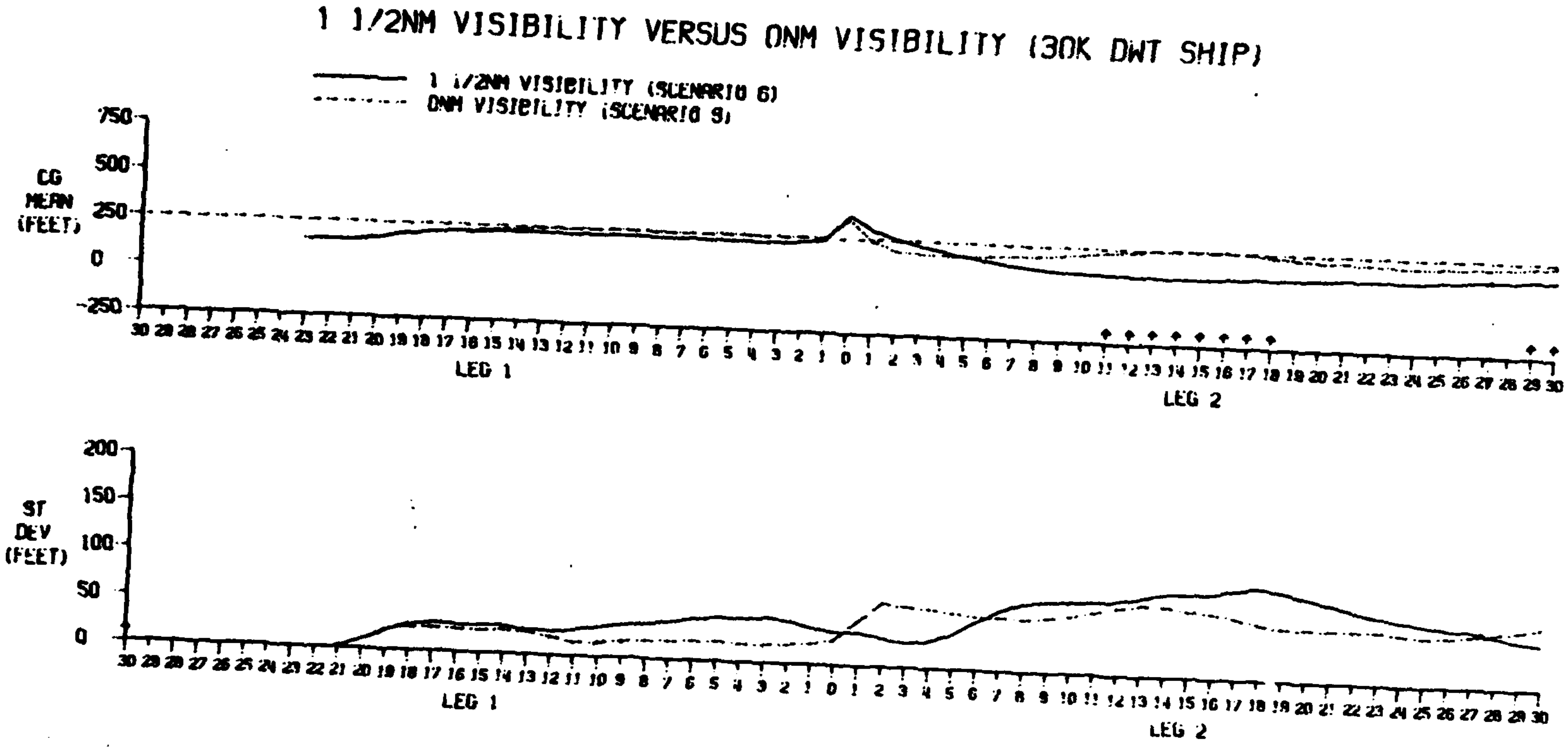
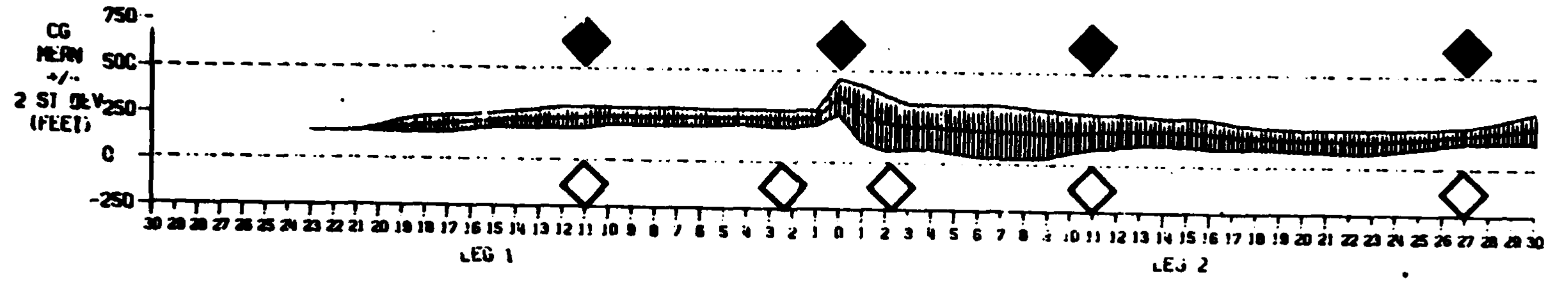


Figure 6B. Comparison Plot for Visibility, Low Density Marking

SCENARIO 1. 3 - BUOYS, GATED, 30K DWT, 1/4NM VISIBILITY



SCENARIO 7: 3 - BUOYS, GATED, 30K DWT, 0NM VISIBILITY

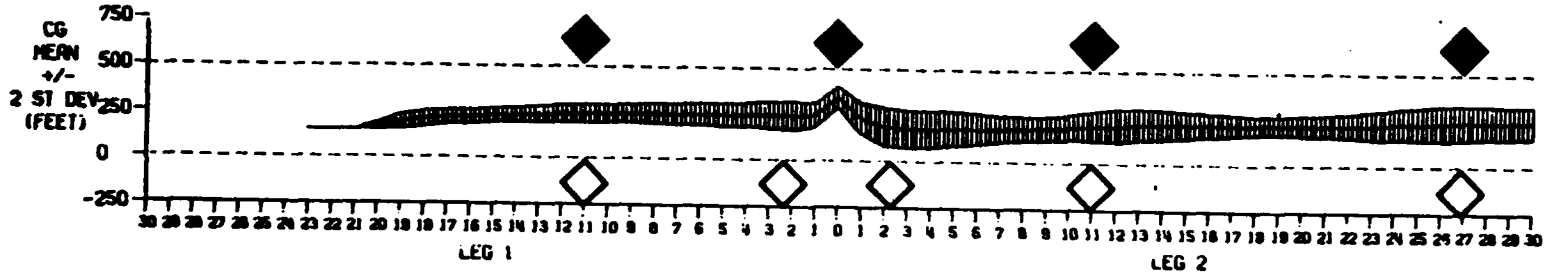


Figure 7A. Combined Plots for Visibility, Standard Marking

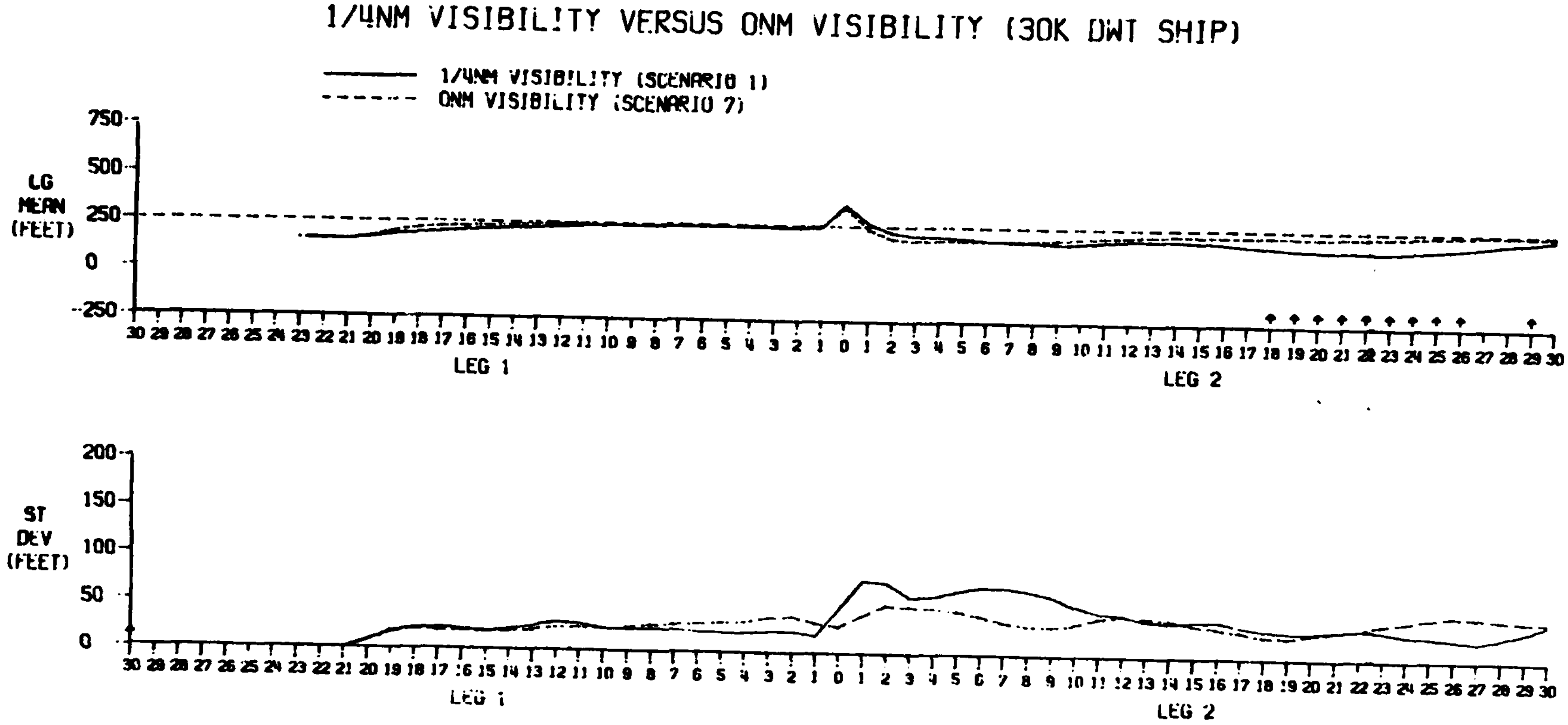
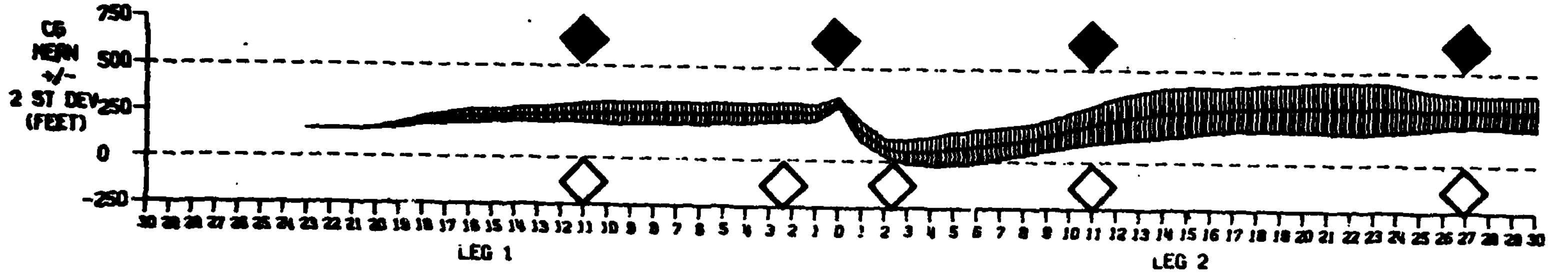


Figure 7B. Comparison Plot for Visibility, Standard Marking

SCENARIO 3: 3 - BUOYS, GATED, 80K DWT, 1/4NM VISIBILITY



SCENARIO 9: 3 - BUOYS, GATED, 80K DWT, 0NM VISIBILITY

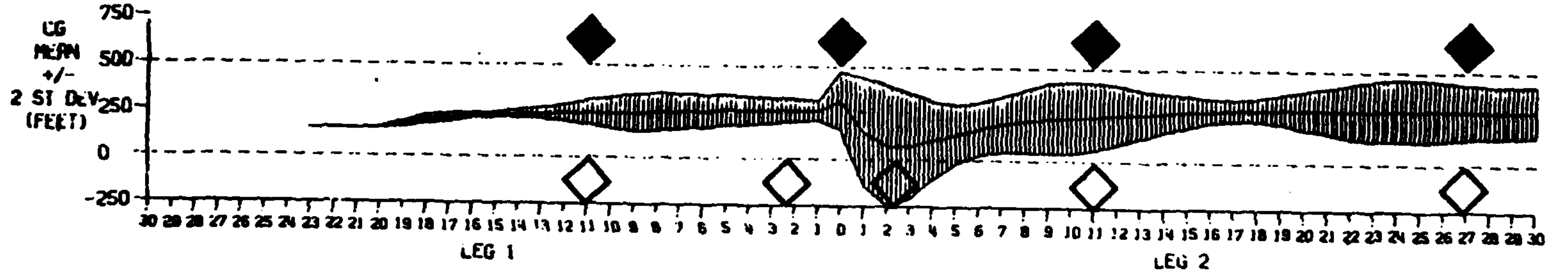


Figure 8A. Combined Plots for Visibility, Larger Ship

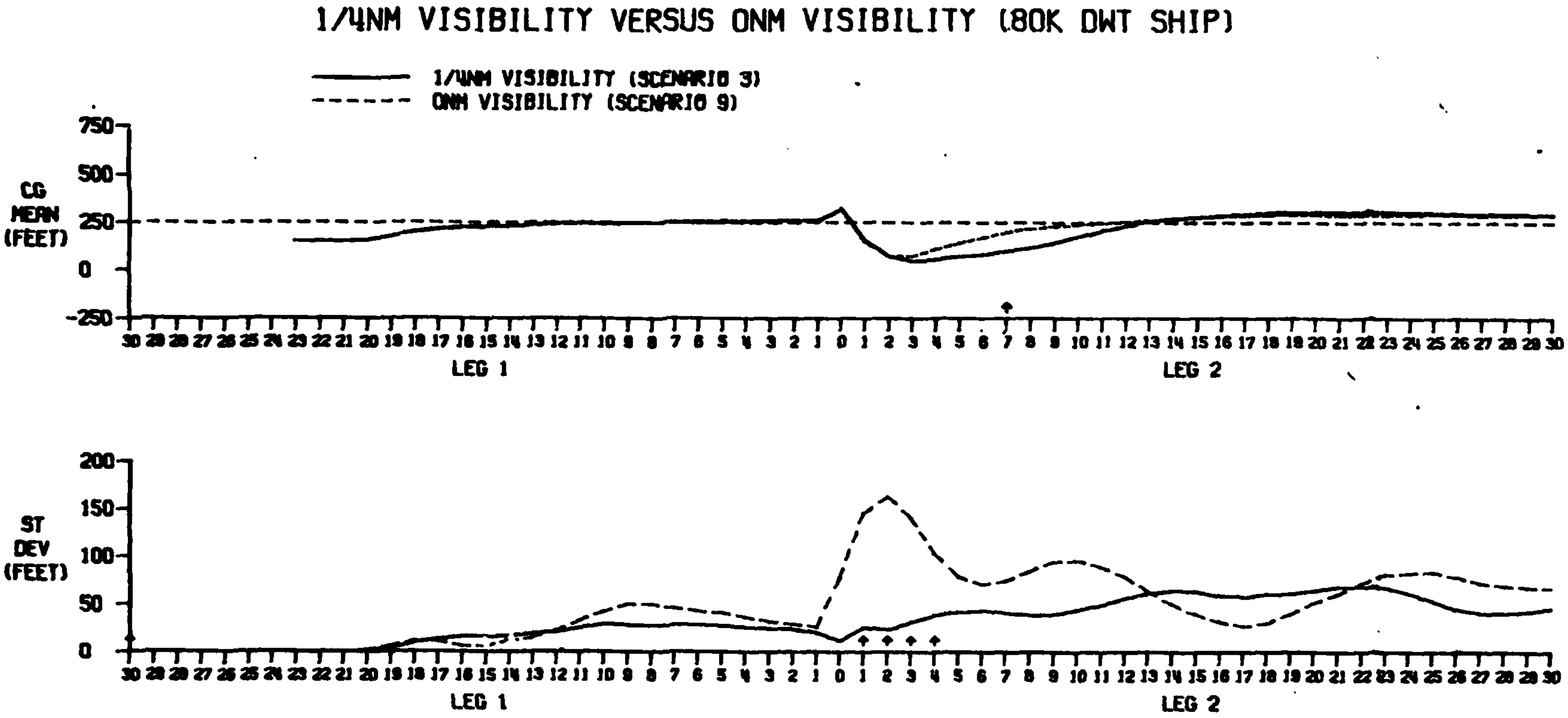
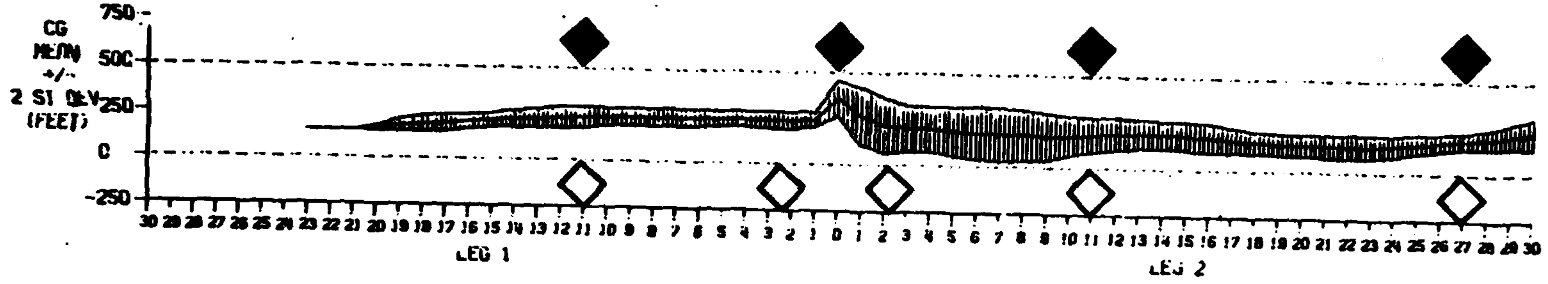


Figure 8B. Comparison Plot for Visibility, Larger Ship

SCENARIO 1: 3 - BUOYS, GATED, 30K DWT, 1/4NM VISIBILITY



SCENARIO 3: 3 - BUOYS, GATED, 80K DWT, 1/4NM VISIBILITY

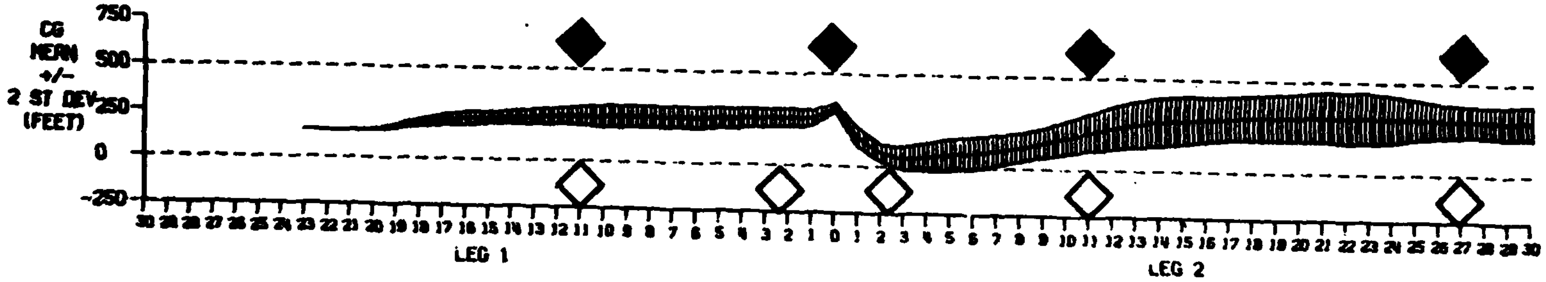


Figure 9A. Combined Plots for Ship Size, 1/4 nm Visibility

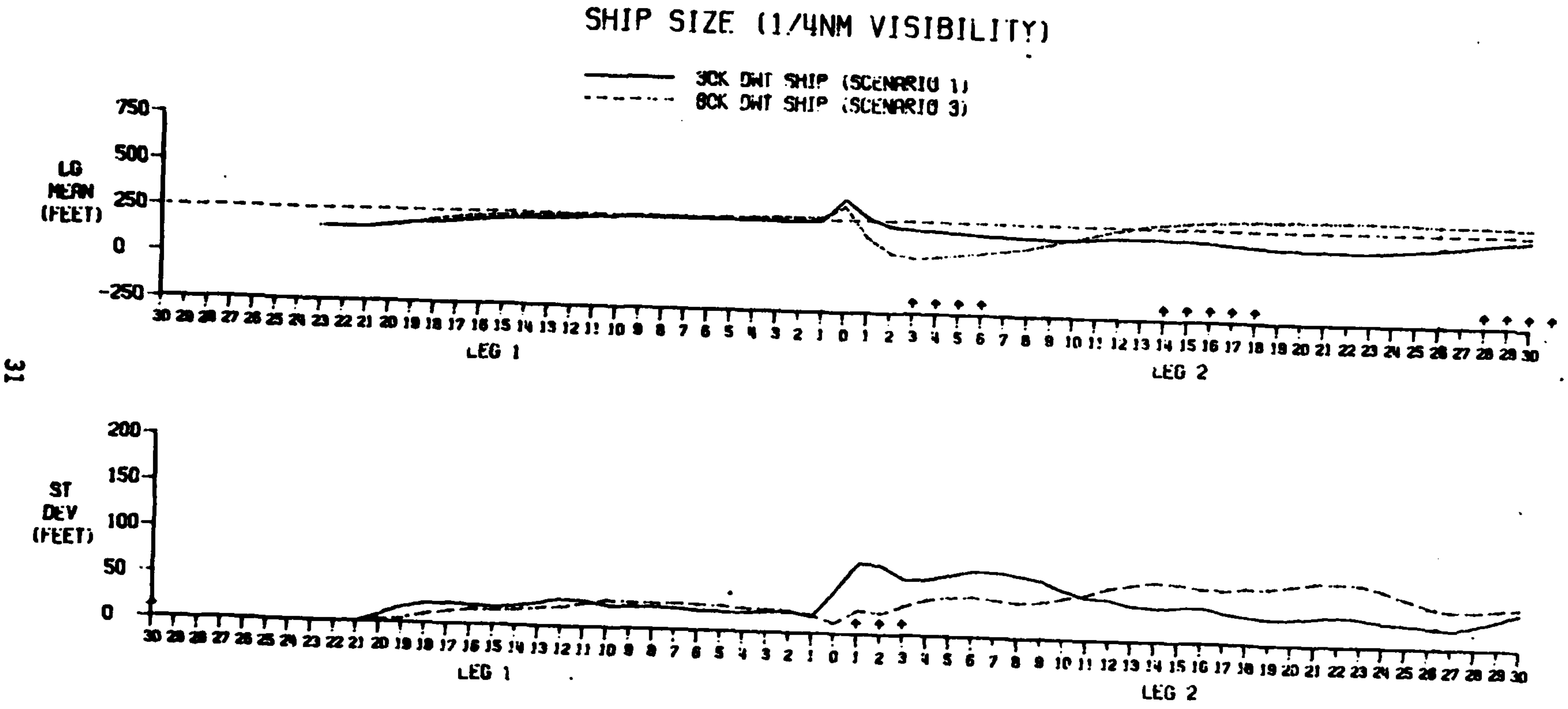
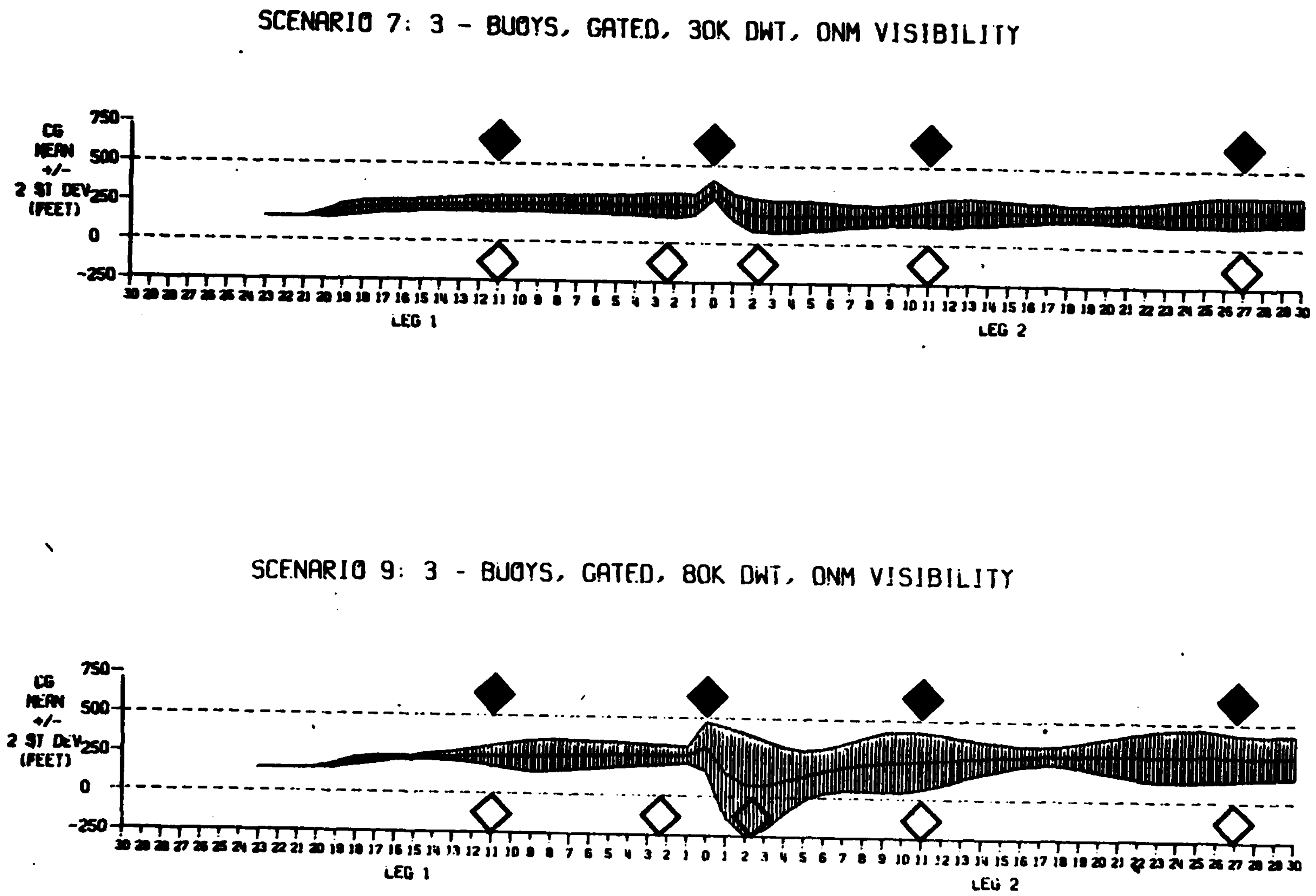


Figure 9B. Comparison Plot for Ship Size, 1/4 nm Visibility


SCENARIO 7: 3 - BUOYS, GATED, 30K DWT, 0NM VISIBILITY

SCENARIO 9: 3 - BUOYS, GATED, 80K DWT, 0NM VISIBILITY

Figure 10A. Combined Plots for Ship Size, Zero nm Visibility

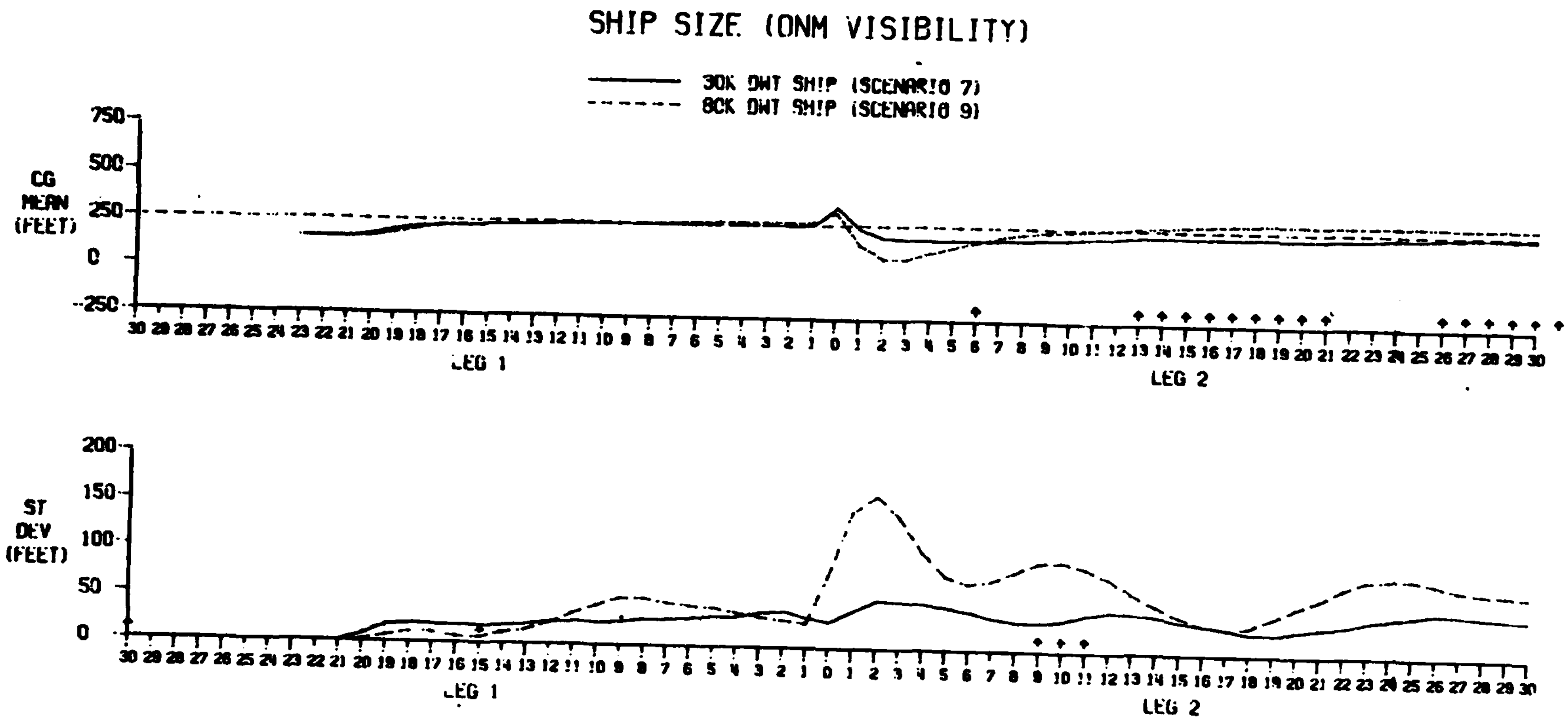
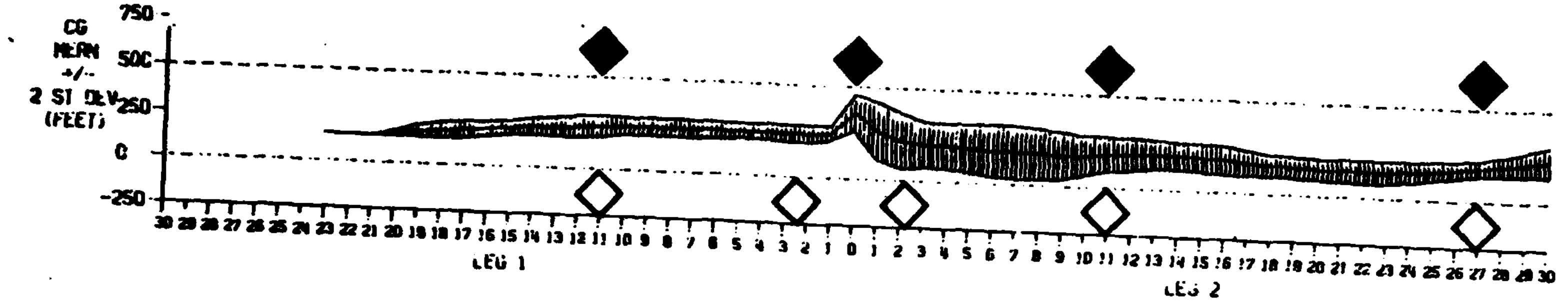


Figure 10B. Comparison Plot for Ship Size, Zero nm Visibility

SCENARIO 1. 3 - BUOYS, GATED, 30K DWT, 1/4NM VISIBILITY



SCENARIO 2. 2 - BUOYS. GATED. 30K DWT. 1/4NM VISIBILITY

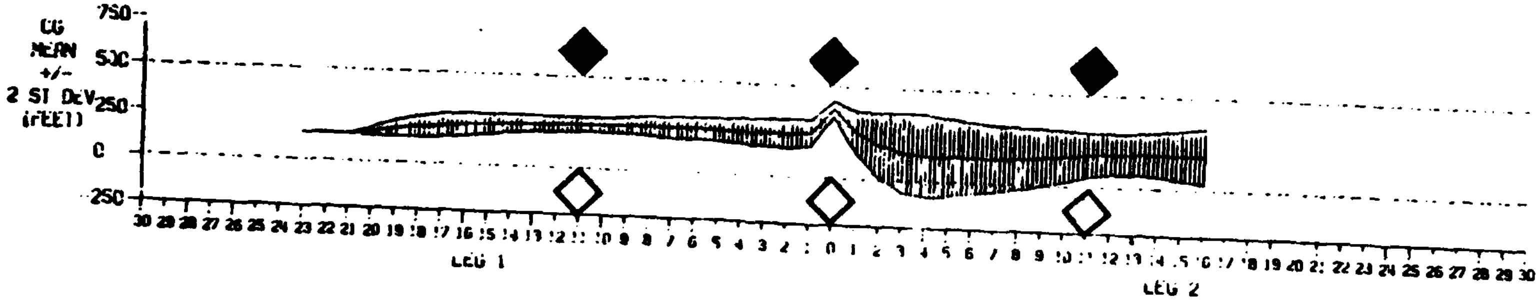


Figure 11A. Combined Plots for Turn Arrangement, 1/4 nm Visibility

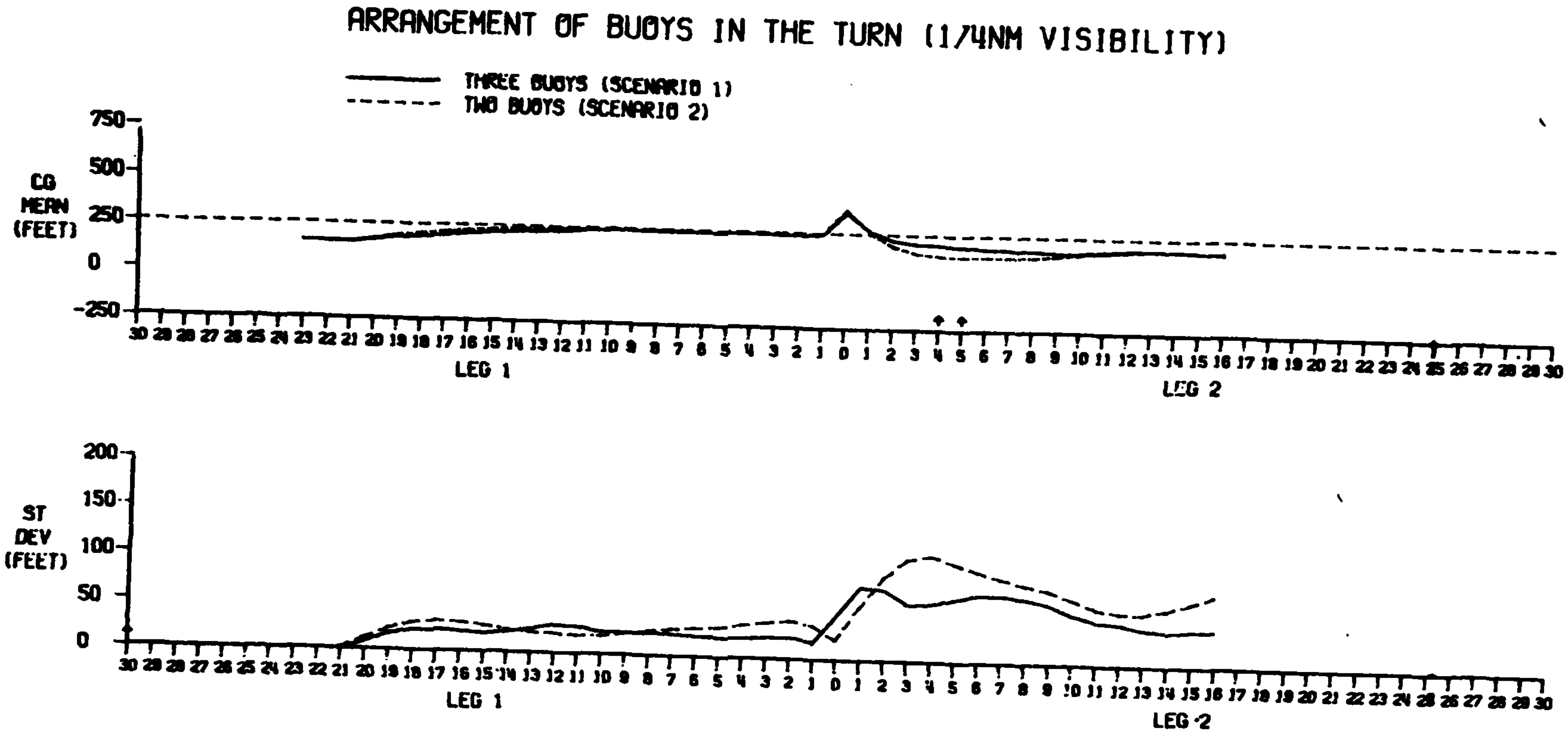
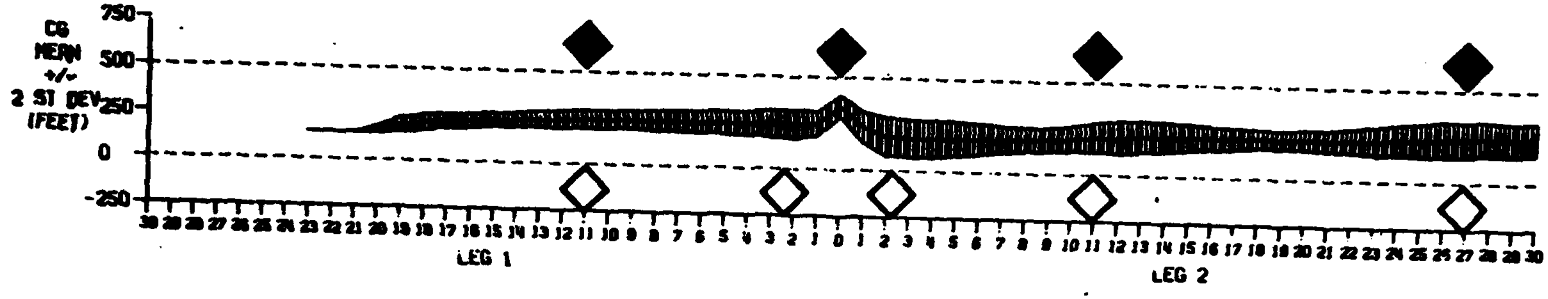


Figure 11B. Comparison Plot for Turn Arrangement, 1/4 nm Visibility

SCENARIO 7: 3 - BUOYS, GATED, 30K DWT, ONM VISIBILITY



SCENARIO 8: 1 - BUOY, STAGGERED, 30K DWT, ONM VISIBILITY

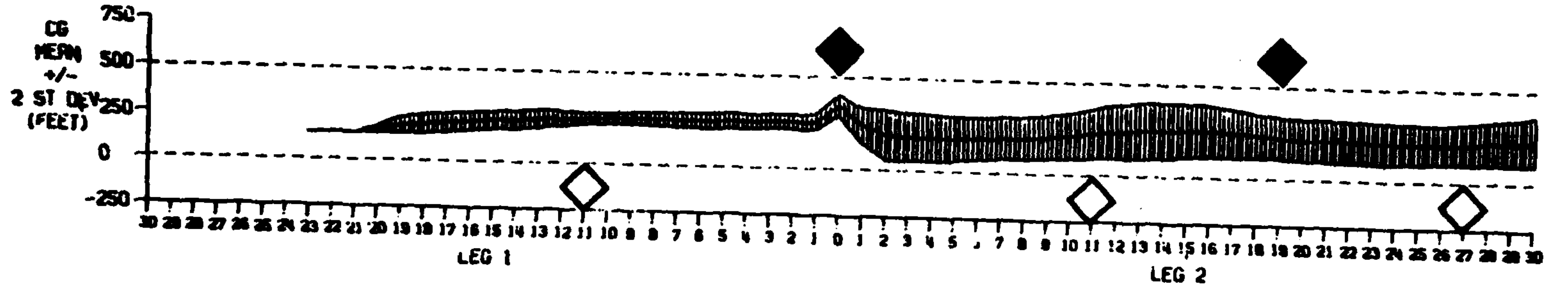


Figure 12A. Combined Plots for Buoy Density, Zero nm Visibility

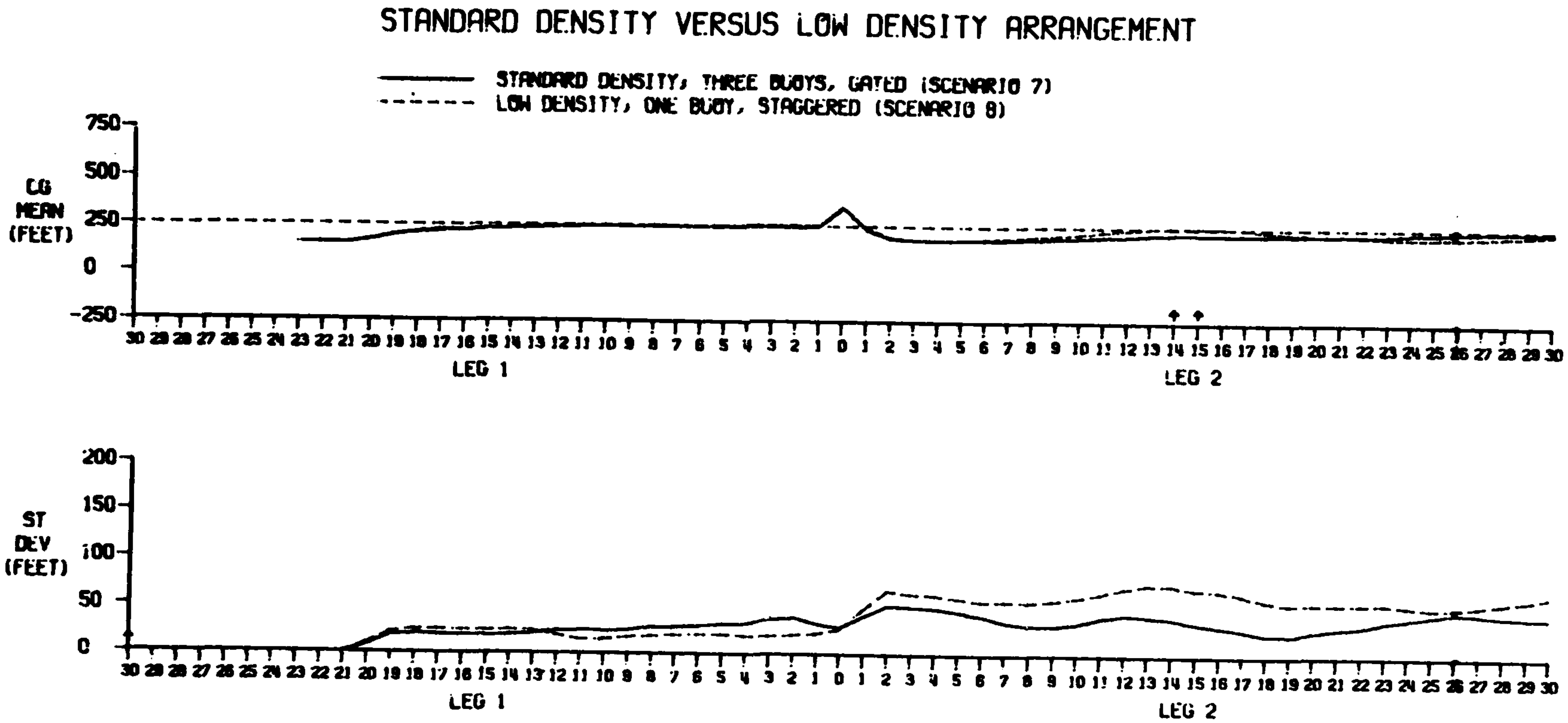
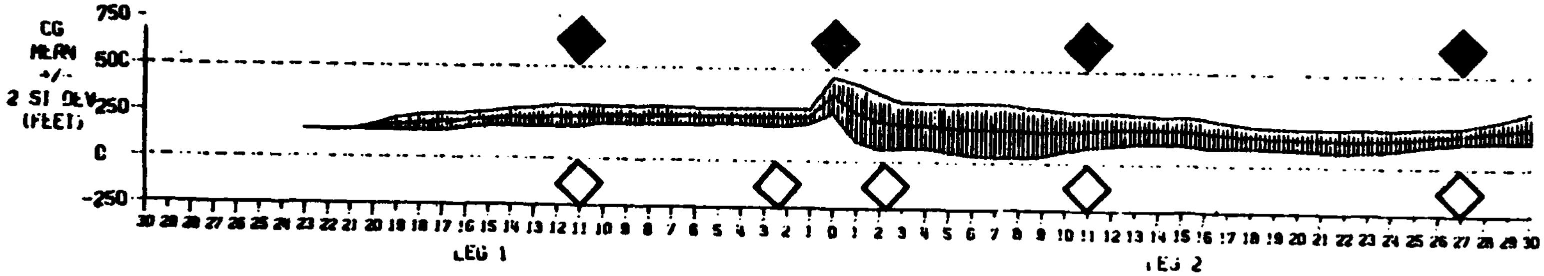


Figure 12B. Comparison Plot for Buoy Density, Zero nm Visibility

SCENARIO 1. 3 - BUOYS, GATED, 30K DWT, 1/4NM VISIBILITY



SCENARIO 4: 3 - BUOYS, GATED, 30K DWT, 1/4NM VISIBILITY, NO WIND/CURRENT

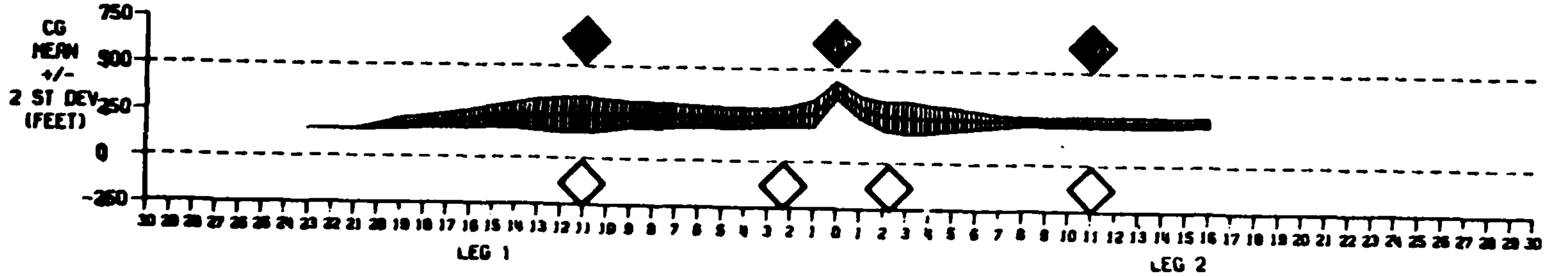


Figure 13A. Combined Plots for Wind and Current

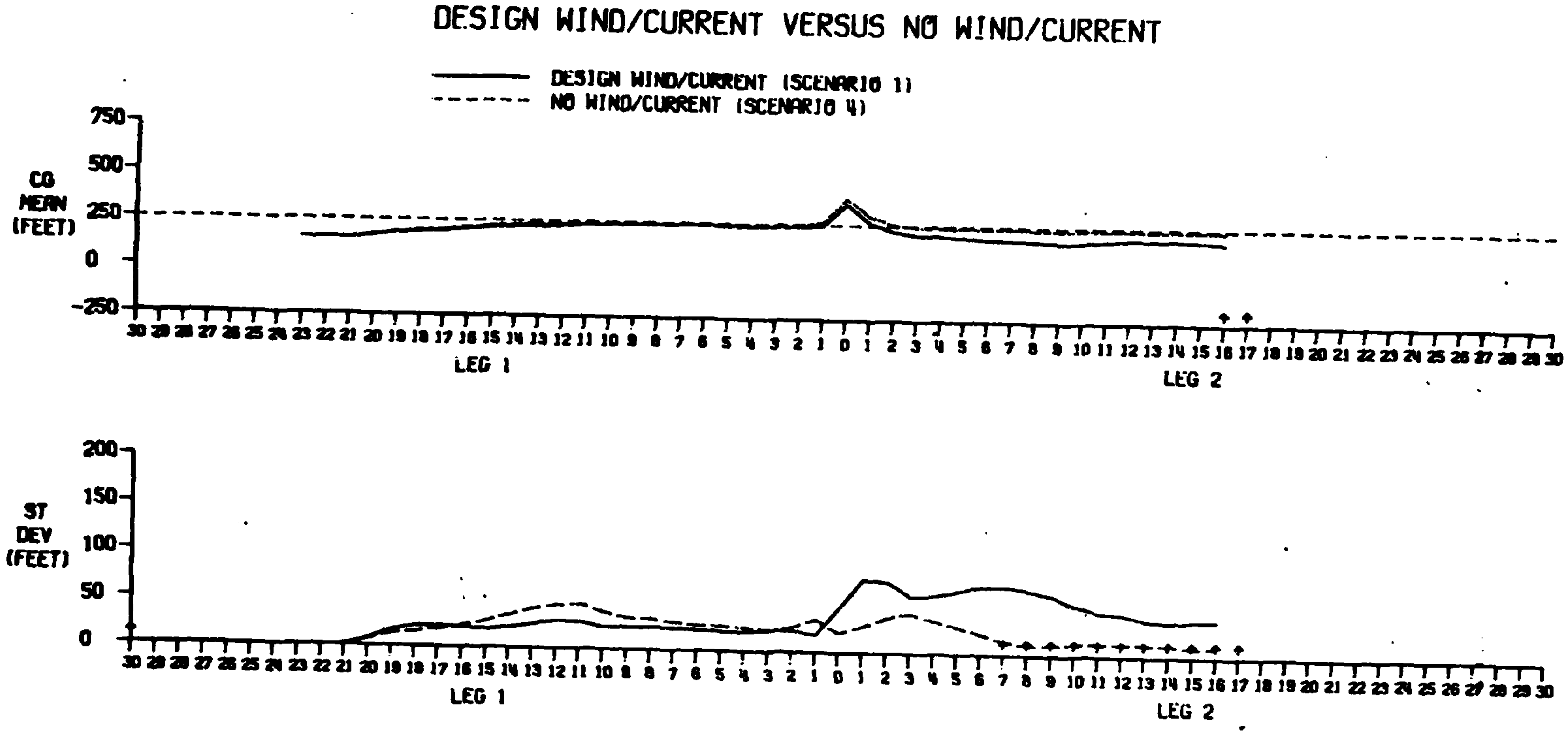


Figure 13B. Comparison Plot for Wind and Current

Section 3

PERFORMANCE DIFFERENCES BETWEEN RADAR PILOTING AND VISUAL PILOTING

3.1 INTRODUCTION

The following comparisons between the Radar 1 experiment and the visual piloting experiments represent an attempt to broaden the scope of the SRA/RA design manual to take into account the use of radar as described in Section 1.2. In all the previous visual experiments, performance was evaluated under visibility sufficient to see the next aid or pair of aids (1-1/2 nm). Radar was not available to the pilots during these experiments. The first two comparisons, listed in Table 6, were designed to address the question of how performance would be affected under more restricted (1/4 nm) visibility than found in the previous visual piloting experiment, but with radar available. The third comparison in Table 6 addresses the question: what contribution does radar make to performance when visibility is sufficient (1-1/2 nm) for visual piloting? Finally the fourth comparison attempts to answer the question of how radar will contribute to performance in piloting an 80,000 dwt ship with restricted visibility (1/4 nm) and radar.

The scenarios from the previous visual piloting experiments were not specifically designed to evaluate the differences between radar and visual piloting. However, the experimental conditions in the Radar I experiment have been designed so that certain scenarios can be compared to scenarios in three previous visual piloting experiments. The constant conditions are similar enough to compare performance between piloting with radar and visual piloting without radar.

3.2 PILOTING IN LOW VISIBILITY WITH RADAR VERSUS VISUAL PILOTING ONLY

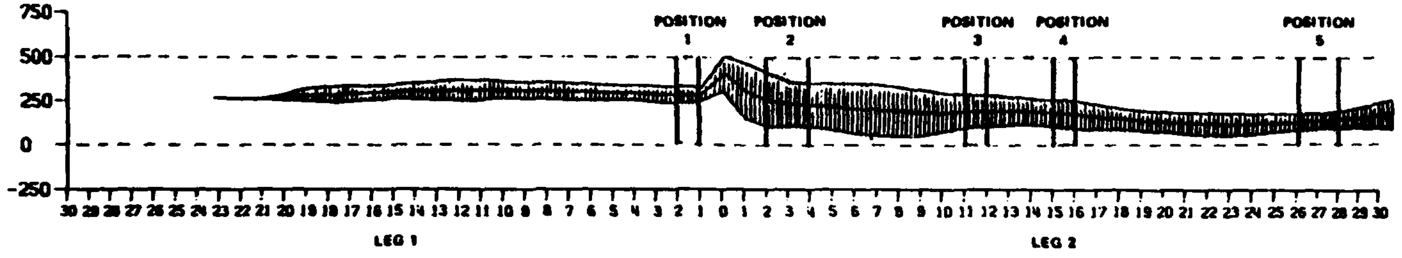
The first two comparisons in Table 6 show the respective means and standard deviations for five positions in the channel that are representative of the differences between radar and visual piloting under restricted visibility (1/4 nm) with radar and visual piloting under conditions (1-1/2 nm) sufficient for piloting without radar. Figure 14 illustrates the three-buoy comparison and Figure 15 illustrates the two-buoy comparison. In the approach to the turn, performance for the radar piloting group is almost identical to the visual piloting group for both the three-buoy and two-buoy turns. Figures 14 and 15 illustrate the negligible differences in the approach. Differences in piloting performance in the approach to the turn, as indicated in the column labeled position 1 of Table 6, are within 20 feet or less for both the crosstrack mean and crosstrack standard deviation for the three-buoy and two-buoy comparisons between radar and visual piloting performance. This difference remains negligible for the 80,000 dwt ship comparison as well.

Unlike the approach, meaningful differences between radar and visual performance appear as a function of the turn buoy arrangement. This is also illustrated in Figures 14 and 15 comparing radar piloting under 1/4 nm visibility and visual piloting under 1-1/2 nm visibility in a three-buoy and two-buoy turn, respectively. The results from this experiment are consistent with the findings from previous visual piloting experiments; that the

TABLE 6. COMPARISON OF CROSSTRACK MEAN AND STANDARD DEVIATION SCORES (IN FEET) BETWEEN RADAR AND VISUAL PILOTING EXPERIMENTS

			Position									
			1		2		3		4		5	
Comparison	Experiment	Scenario	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
VISUAL VERSUS RADAR												
Three-buoy, gated	Radar I (1/4 nm visibility)	1	13	23	49	60	66	46	65	39	65 ↷	21
	One Side (day)	1	-6	31	37	32	79	28	83	40	9	19
	Turn Light (night)	1	17	36	8	56	--	--	--	--	--	--
Two-buoy, gated	Radar I (1/4 nm visibility)	2	11	40	98	108 ↷	72	60 ↷	62	67 ↷	--	--
	One Side (day)	6	-17	31	109	28	92	23	98	33	--	--
	Turn Light (night)	8&9	13	39	28	67	--	--	--	--	--	--
VISUAL VERSUS VISUAL AND RADAR												
One buoy, staggered	Radar I (1-1/2 nm visibility)	6	22	45	28 ↷	26	132	76	141	90	104 ↷	60
	Ship Variables	2	24	35	78	51	83	42	70	61	15	73
VISUAL VERSUS RADAR												
With 80,000 dwt	Radar I (1/4 nm visibility)	3	-12	24 ↷	202 ↷	32	43	50	-32	64	-45	41
	Ship Variables	7	-35	60	112	50	13	93	1	95	-43	28

Arrows indicate statistically significant comparisons at $p<0.10$ (two-tailed test)



Position 1 = trackkeeping without crosscurrent before initiating turn
Position 2 = pull-out from turn before crosscurrent component becomes an important factor
Position 3 = Recovery from turn with influential crosscurrent component
Position 4 = Trackkeeping with crosscurrent
Position 5 = Trackkeeping without crosscurrent

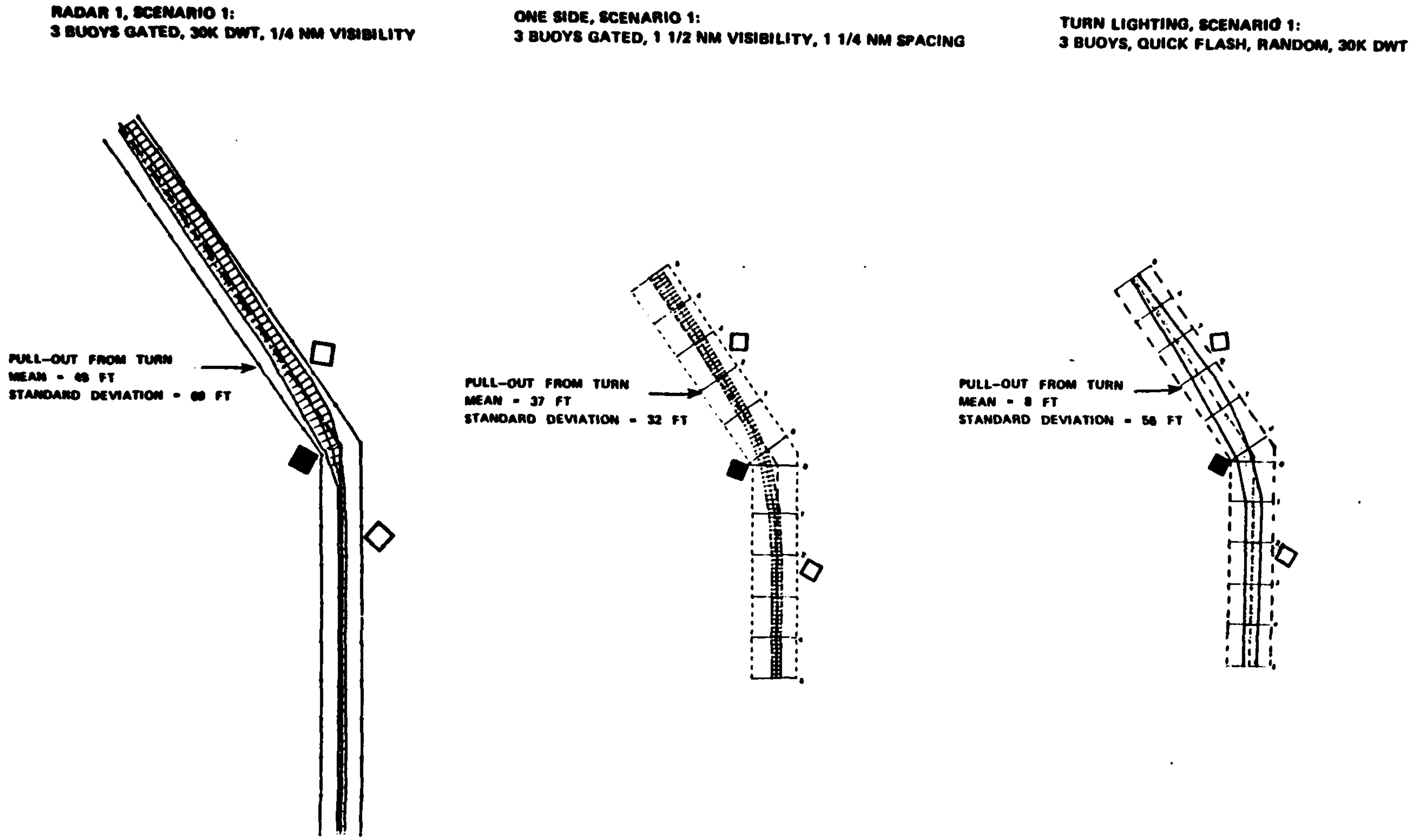


Figure 14. Turnplot Comparison Between Radar Piloting and Visual Piloting in a Three-Buoy Turn

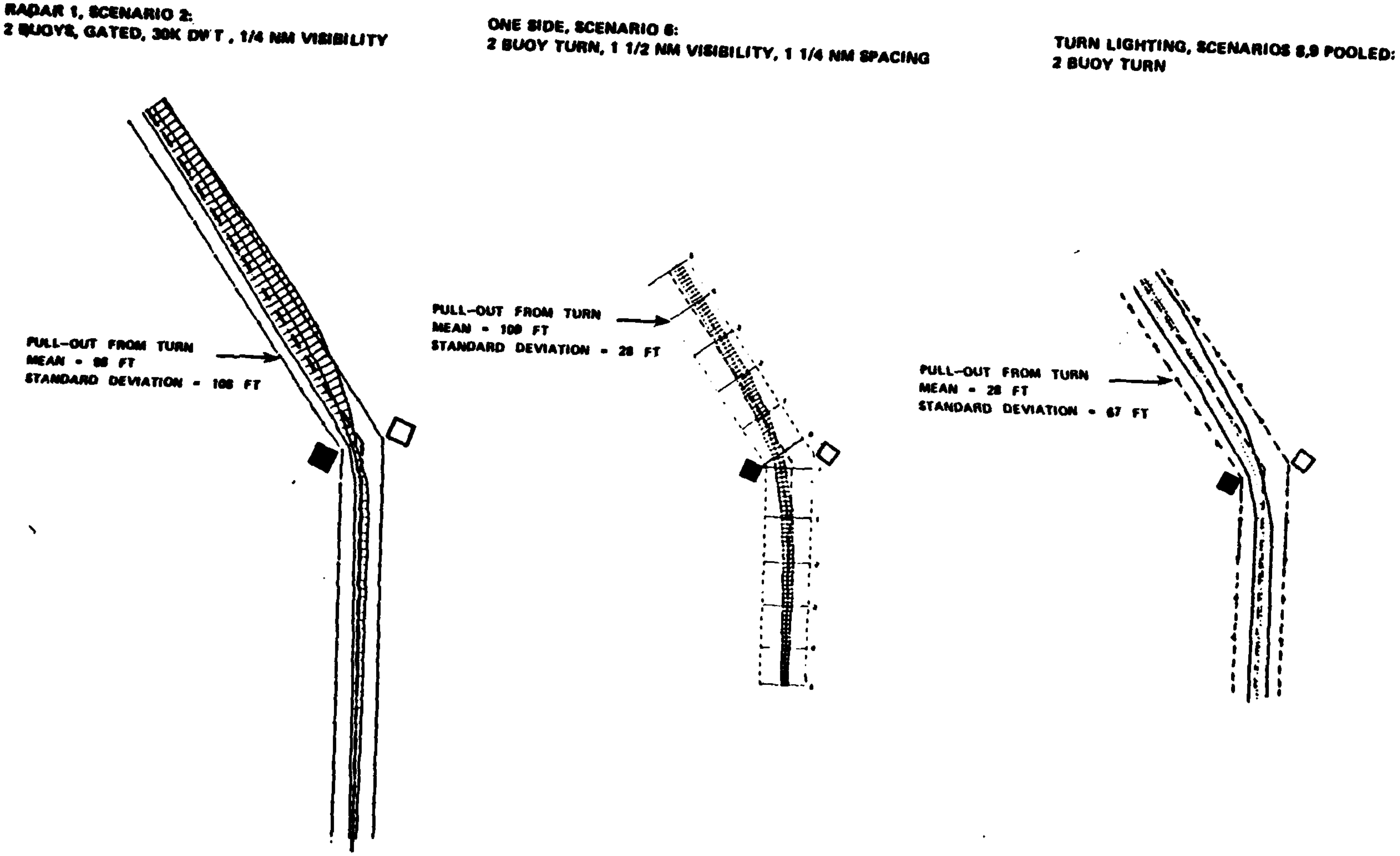


Figure 15. Turnplot Comparison Between Radar Piloting and Visual Piloting in a Two-Buoy Turn

three-buoy turn is easier to negotiate than the two-buoy arrangement. The results are shown in Position 2 of Table 6. The crosstrack means are closer to the center of the channel through the pullout region for the three-buoy turns than for the two-buoys turns.

There is an interaction effect between the type of turn and performance in radar and visual piloting, illustrated in Figure 16. In the pullout region (Data Line 1 to Data Line 6) the standard deviation in the three-buoy turn is smaller for the visual piloting group, but these differences are statistically insignificant. The crosstrack mean increased for both groups in the two-buoy condition although the differences .between the radar piloting group and the visual piloting group did not change in any statistically or practically meaningful ways. In the two-buoy turn the standard deviation increased for the radar piloting group while this measure decreased slightly for the visual piloting group. The difference in the two-buoy turn is statistically significant and suggests that the two-buoy turn is more difficult for the radar piloting group than for the visual piloting group. As the turn plot in Figure 15 showing where 95 percent of the experimental runs should fall suggests some of the transits would fall outside the channel for the radar piloting group. Thus, while the performance for radar piloting deteriorates with turn buoy arrangement, at 1/4 nm visibility, it remains relatively stable for visual piloting under moderate visibility of 1-1/2 nm.

The poorer radar piloting performance in the two-buoy turn compared to the three-buoy turn is probably due to the lack of a pullout buoy. The pilots in three-buoy turn are able to use the pullout buoy as an additional visual reference in recovering from the turn. In the two-buoy condition this option is not possible. It is worth noting that the difference in the two-buoy turn was maintained as far as 7,125 feet down Leg 2. This is illustrated in Figure 17. The lack of a pullout buoy may make it more difficult to estimate the net effect of forces such as wind and current acting on the vessel as they come out of the turn. Consequently, it takes significantly longer to compensate for the effects of the crosscurrent. Thus, the data confirms the pilots' comments that visual references to the buoys serves as an important secondary source of navigational information. Under low visibility conditions, the pilots say they use the visual sighting of the buoys to assist in course correction. Without this information, critical operations like maneuvering through a turn are much more difficult and more prone to error.

In the three-buoy and two-buoy comparisons with the nighttime conditions (Turn Light) illustrated in Figures 14 and 15, the same trends exist that were found in the daytime conditions. Performance is well within the channel boundaries in both turn arrangements although the three-buoy arrangement is superior to the two-buoy arrangement. The pilots navigating under nighttime conditions through the turn, exhibited smaller but not statistically significant crosstrack means than the daytime groups. This was true for both turns compared to the daytime comparisons, however the magnitude of the differences in the comparisons between radar piloting and nighttime conditions are smaller. Perhaps the most important finding in the nighttime comparisons is the fact that pilots in both the nighttime conditions and the conditions with restricted visibility plus radar tend to

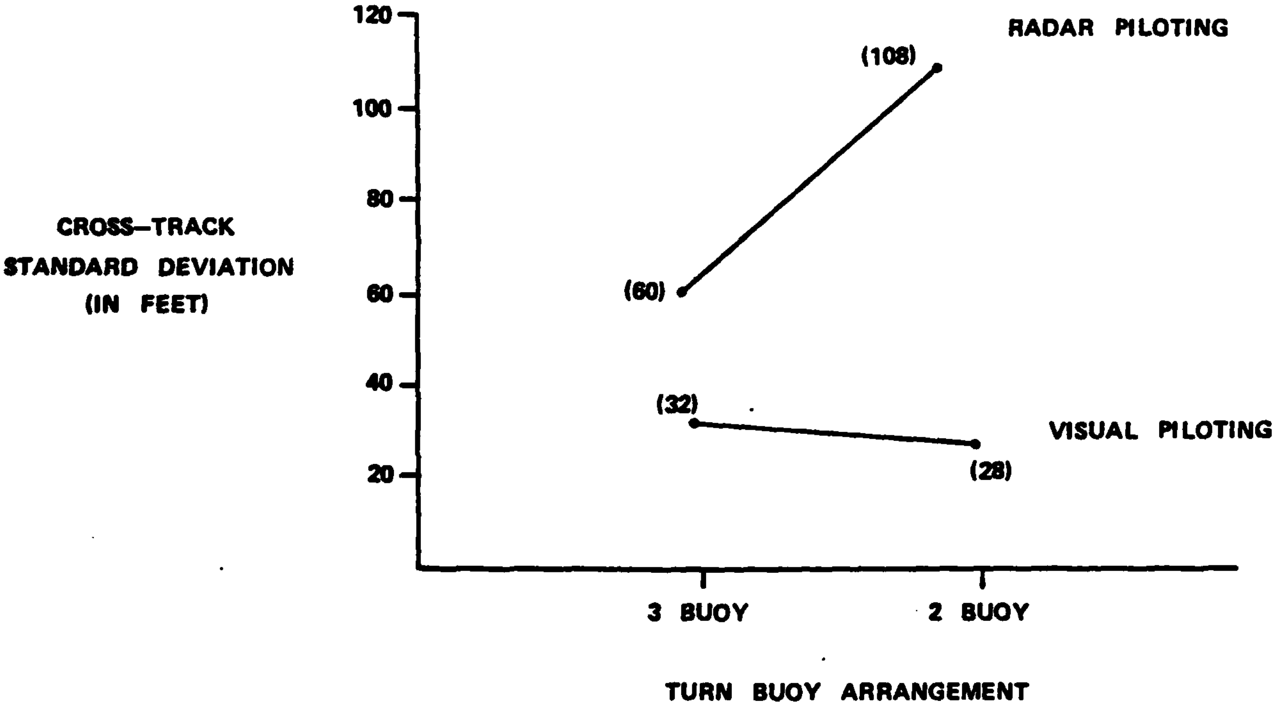
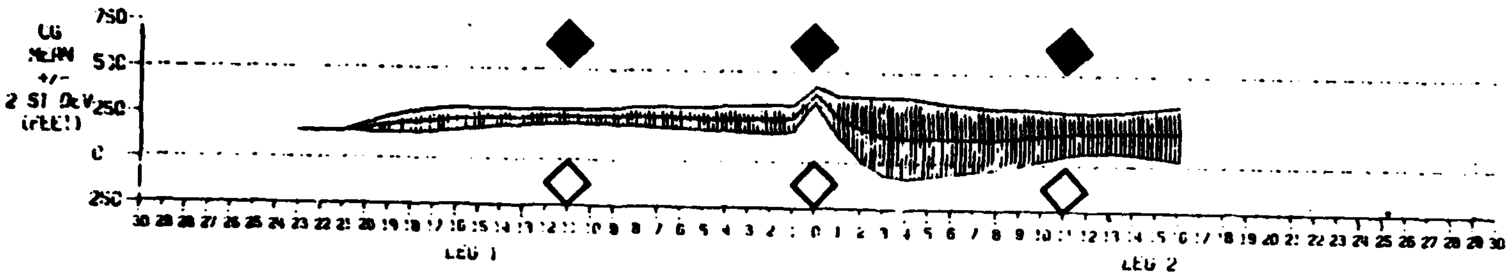


Figure 16. The Effect of Two-Buoy Arrangement and Type of Piloting on the Crosstrack Standard Deviation

RADAR 1, SCENARIO 2:
2 BUOYS GATED, 30K DWT, 1/4 NM VISIBILITY



ONE SIDE, SCENARIO 6:
2 BUOY TURN, 1 1/2 NM VISIBILITY, 1 1/4 NM SPACING

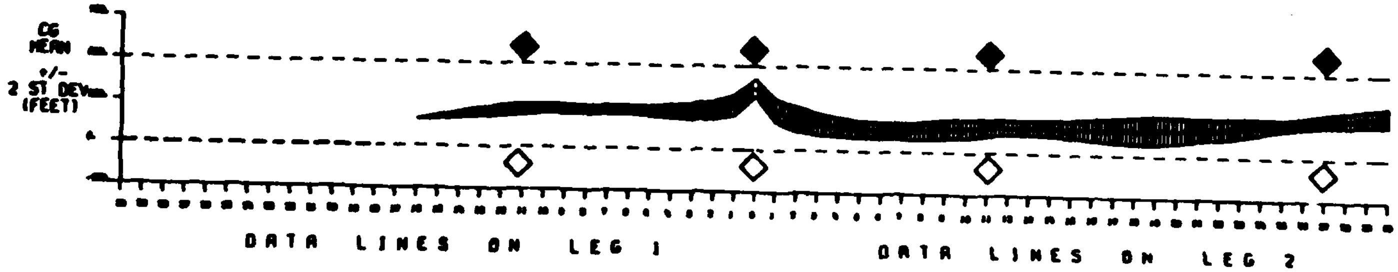


Figure 17. Combined Plot Comparison Between Radar Piloting and Visual Piloting in a Channel With High Density Spacing and a Two-Buoy Turn

initiate the turn later (closer to the turn buoy) than when daytime visibility is sufficient for navigating by visual references. Figures 14 and 15 illustrate that in both the three-buoy and two-buoy turns, pilots in the nighttime conditions and restricted visibility conditions initiate their turning maneuver at approximately Data Line -1, approximately 475 feet before the turn. In both turns pilots in the daytime conditions where radar is unnecessary begin their turning maneuver at Data Line -2, approximately 950 feet before the turn. This behavior may be due to the greater uncertainty as to where the turn buoy is in relation to ownship. Consequently, the pilots wait longer, until they are more confident of where the turn buoy is located.

3.3 THE CONTRIBUTION OF RADAR TO PERFORMANCE UNDER ACCEPTABLE VISUAL PILOTING CONDITIONS

Does performance improve with the addition of radar under acceptable visual piloting conditions? More specifically, does a relatively low density aid arrangement such as a one-buoy turn with staggered spacing in the straight channel segments improve with the opportunity to use radar? The comparison between Scenario 6 in the Radar I experiment and Scenario 2 in the Ship Variables experiment addresses this question. It evaluates the contribution of radar to visual piloting under relatively good (1-1/2 nm) conditions. Figure 18 illustrates the comparison between visual piloting with radar available and visual piloting only under 1-1/2 nm visibility in a channel with one-buoy turn and a staggered buoy spacing in the channel legs and Table 6 shows the crosstrack means and standard deviations for this comparison. Passing through the turn the radar piloting group has a smaller, but not statistically different, standard deviation than the visual piloting group. The crosstrack mean stays closer to the turn buoy, a difference that is statistically significant. Visual piloting with radar through the turn under good visibility thus appears to be better than visual piloting through the turn.

In the pullout and trackkeeping regions of Leg 2, performance between the two groups diverges. The radar piloting group has greater difficulty in recovering from the effects of the turn in the trackkeeping region (see Figure 19). The standard deviation for the radar group is larger throughout most of Leg 2, but this difference is not statistically or meaningfully significant. The mean for the radar piloting group is further to the right side of the channel than the visual piloting group throughout Leg 2. Although this difference is not statistically significant, the mean of the radar piloting group is sufficiently far enough to the right so that some transits (between 7% and 12%) may go out of the channel.

In summary, while performance for the visual plus radar group is as good or better through the turn as the visual piloting group, it suffers somewhat in the trackkeeping region of Leg 2. It is surprising that performance should be relatively good through the more difficult turn maneuver and deteriorate as the demands of the trackkeeping task in Leg 2 decrease. This result may be due to order effects. It is assumed that at 1-1/2 nm visibility pilots prefer to navigate primarily by visual references with radar acting as a secondary source of information. While this assumption appears to be reasonable in light of the pilots comments that radar serves

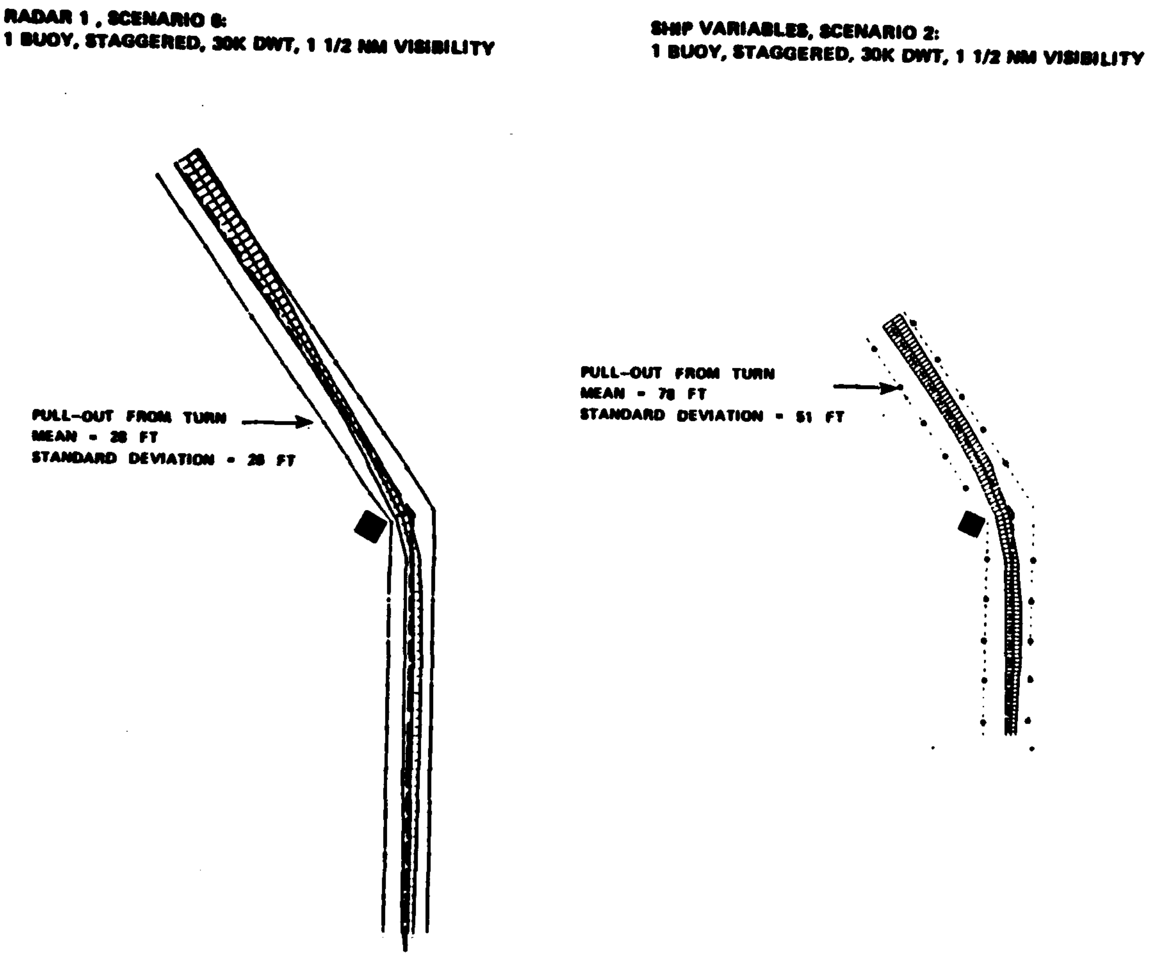
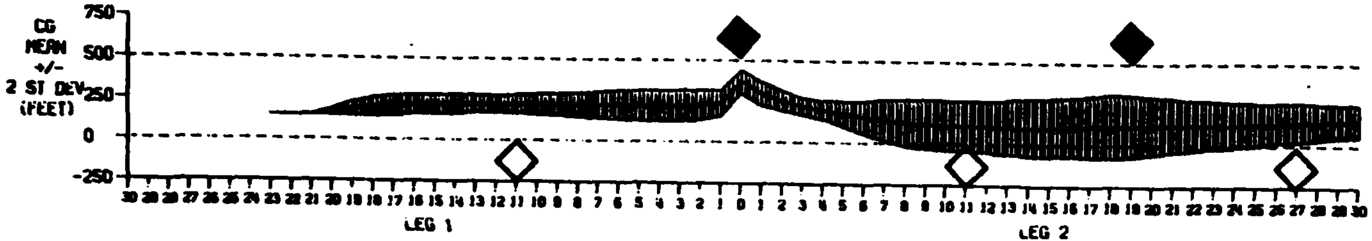


Figure 18. Turnplot Comparison Between Radar Piloting and Visual Piloting in a One-Buoy Turn

RADAR 1, SCENARIO 6:
1 BUOY, STAGGERED, 30K DWT, 1 1/2 NM VISIBILITY



SHIP VARIABLES, SCENARIO 2:
1 BUOY, STAGGERED, 30K DWT, 1 1/2 NM VISIBILITY

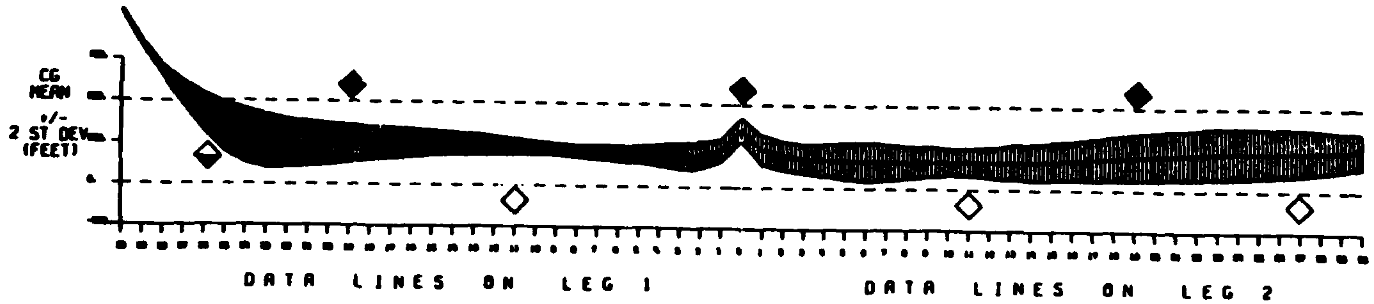


Figure 19. Combined Plot Comparison Between Radar Piloting and Visual Piloting in a Channel With Low Density Spacing and a One-Buoy Turn

as an auxiliary source of feedback under "good" visibility, it may have been violated. The scenarios were presented in a sequence of decreasing visibility. The 1-1/2 nm visibility scenario was presented first followed by the 1/4 nm visibility condition and zero nm visibility condition. Given the knowledge that they would be required to transit the experimental channel under such poor visibility conditions later in the experiment, the pilots may have used Scenario 6, the "good" visibility condition to prepare themselves for the more limited visibility scenarios.

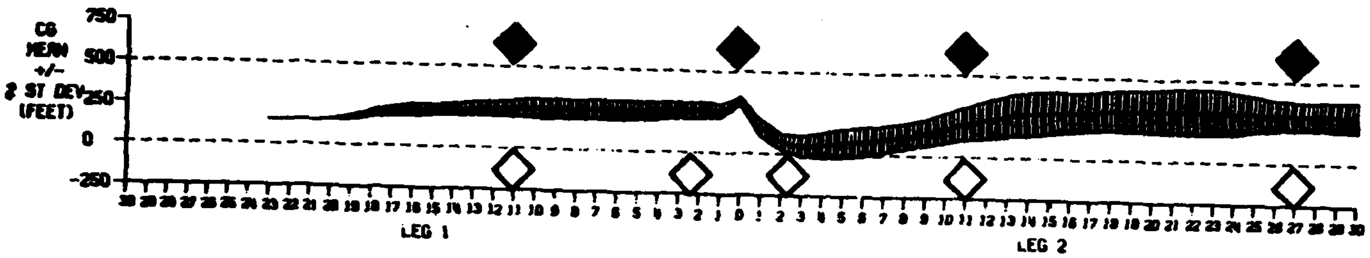
The pilots may be navigating using both visual and radar displays through the turn, the most difficult portion of the scenario and using the less demanding trackkeeping regions to prepare themselves for the lower visibility scenarios that follow. In that context, they may pilot primarily by radar and use the buoys as visual references to provide feedback regarding their radar piloting performance. Thus, their performance may not reflect piloting behavior that would be exhibited under conditions where visibility was not expected to deteriorate. Although any conclusion regarding comparison with Scenario 6 of the radar experiment must be made with this qualification in mind, this situation is not unrelated to the real-world. Pilots are aware of changing visibility conditions in the real-world. The performance observed here may reflect how the pilot takes these changing circumstances into account.

3.4 PERFORMANCE DIFFERENCES AS A FUNCTION OF THE 80,000 DWT SHIP

The following comparison between Scenario 3 of the Radar 1 experiment and Scenario 7 of the Ship Variable experiment, shown in Table 6 and illustrated in Figure 20, was designed to measure how the 80,000 dwt ship differentially affects the performance of radar piloting and visual piloting. For the 30,000 dwt ship the standard deviation is smaller through the turn and in the pull-out region for the visual piloting group as illustrated in the three-buoy turn with straight channel spacing comparison of Figure 14. Overall, the differences in the 30,000 dwt comparison between radar and visual piloting are negligible. This is not true for the 80,000 dwt comparison. For the 30,000 dwt ship the crosstrack mean is similar in the pull-out region for both groups. For the 80,000 dwt ship however, the differences in the crosstrack means are statistically significant. The crosstrack mean for the radar piloting group comes close to going out of the channel in the pull-out region while it stays well within the channel boundaries for the visual piloting group.

These results suggest that differences between radar piloting and visual piloting will grow as ship size increases. This means that the differences in performance in recovery from the turn will become more pronounced as the size of the ship increases. It is hypothesized that for the 80,000 dwt ship a two-buoy turn should show even larger differences between radar piloting and visual piloting with the crosstrack mean for the radar piloting group, very likely, exiting the right channel edge. The fact that the crosstrack standard deviation in the turn is lower for the larger ship than the smaller ship in the radar piloting group but not in the visual piloting group is not as expected. The lower standard deviation may reflect a smaller number of strategies open to the pilots to maneuver through the turn. Due

RADAR 1, SCENARIO 3:
3 BUOYS GATED, 80K DWT, 1/4 NM VISIBILITY



SHIP VARIABLES, SCENARIO 7:
3 BUOYS GATED, 80K DWT, 1 1/2 NM VISIBILITY

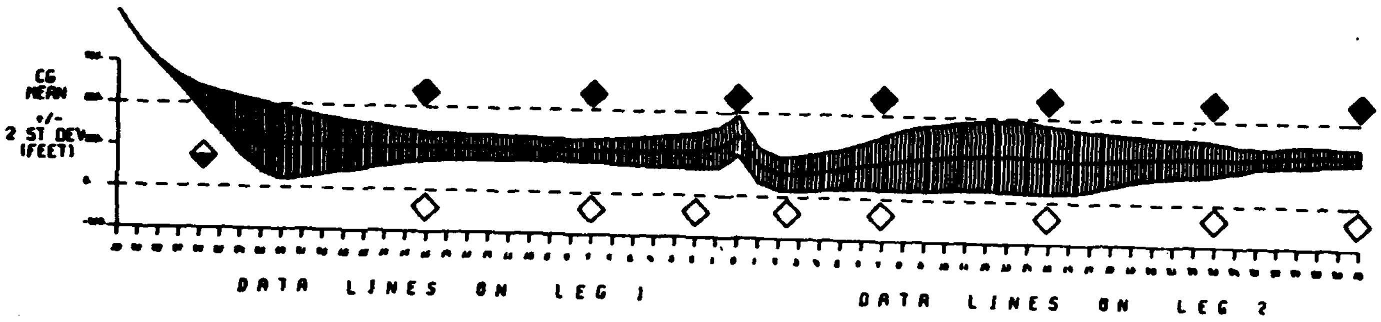


Figure 20. Combined Plot Comparison Between Radar Piloting and Visual Piloting With an 80,000 dwt Ship

to the handling characteristics of the larger ship there is a smaller tolerance for error. With low visibility and reliance on radar in the turn there may be fewer ways to negotiate the turn than when visibility is good and radar piloting is unnecessary. Consequently, the pilots are more likely to choose the same strategy and performance becomes more uniform.

There is another reason that radar piloting performance of the 80,000 dwt ship appears deceptively good. The ship's crosstrack mean and the envelope enclosing 95 percent of the pilot's performance under the sampled conditions is based upon the ship's center of gravity. Using the ship's center of gravity the probability of going out of the channel is approximately 7 percent in the pull-out region. However, by taking into account half the adjusted beam width (79 feet) the part of the ship closest to the right side of the channel, the probability of going out of the channel in the pullout region increases to approximately 92 percent. Changing the basis upon which the mean is measured does not alter the small standard deviation within which 95 percent of all performance would fall, but it does indicate more realistically the probability of grounding.

It is worth noting that the trackkeeping performance of the radar piloting group improves considerably following recovery from the turn. By the time the pilots have reached the first set of gated buoys 1-1/4 nm down Leg 2 they are well within the channel. Their trackkeeping performance then remains comparable to the visual piloting group. This evidence along with similar performance between the two groups in the approach to the turn suggests that trackkeeping performance does not deteriorate with visibility even for the larger ship. Thus, trackkeeping does not appear to be as sensitive to changes in ship size as is maneuvering through the turn.

3.5 CONCLUSION

From comparisons between radar piloting performance and visual piloting performance it was possible to identify several behavioral features that distinguished radar piloting from visual piloting. In all daytime comparisons between radar piloting and visual piloting, the radar piloting group tended to initiate their turn closer (about 475 feet) to the turn. This is illustrated in Figures 14, 15, 18, and 20. In each case, the visual piloting group initiated their turn maneuver around Data Line -2. The group with radar initiated their turn maneuver at approximately Data Line -1. They also recovered from the effects of the turn later. The average recovery from the turn in the pullout region took place about 475 feet later in the pullout region for the radar piloting group than for the visual piloting groups. The later recovery for the radar piloting group is probably due to the later initiation of the turn since the actual distance between the initiation and recovery from the turn is equivalent for both groups. Overall, performance remained superior for visual piloting compared to radar piloting through the turn and the pull-out where the visual piloting groups were less likely to go out of the channel. The only exception to this generalization was in the 1-1/2 nm visibility conditions. In that situation, the visual plus radar group performed better than the visual only group in the turn and performed worse in the pullout and trackkeeping regions. Finally, in the trackkeeping region of the channel radar piloting performance remained similar to visual piloting, although the radar piloting group consistently stayed further to the right of the channel, then the visual piloting groups.

In general, radar piloting performance in 1/4 nm visibility was more sensitive to aid arrangements and ship size in the turn. As these conditions became more severe performance deteriorated faster for radar piloting than it did for visual piloting. Phrased another way, the sensitivity to the placement of navigational aids in the turn increased at a faster rate for radar piloting than for visual piloting. In the trackkeeping regions radar piloting performance was not as sensitive to changes in aid arrangement, and ship size, as it is in the turn. Thus in the 1/4 nm visibility conditions radar piloting performance was good as a visual pilots performance in the approach, but deteriorated faster in the turn and pullout region where the difficulty of the task increased. The following recommendation follow from these performance differences.

- Channels that are to be marked for restricted visibility (1/4 nm or less) should be marked conservatively in the turn. Three-buoy turns are preferred to two-buoy or one-buoy turns.
- In restricted visibility the use of radar reduces the need to mark the trackkeeping region more conservatively, than in unrestricted visibility.

Section 4

EVALUATION OF RADAR USE

4.1 INTRODUCTION

As one of the objectives of this experiment the use of radar was observed under the different experimental conditions and related to performance in an effort to gain a better understanding of how radar plays a role in the piloting process. The following section assesses manipulation of the radar display and group differences in the use of radar. It is hoped that this exploration of radar use, as an electronic aid and its interaction with visual aid placement will assist in the systematic evaluation of aids to navigation.

The data in this section is based on the performance of all eight subjects run in this experiment. The heterogeniety of license, experience, and ability that interfered with the evaluation of experimental conditions was an asset when the objective was observation of pilots' behavior.

In fulfillment of this objective, the pilots' use of radar was observed in the following ways:

a. Recording by computer of changes in status of the display image. This included the following:

- display mode (head-up, north-up)
- range selection (1/2, 1, 1-1/2, 3, 6, 12, 24) nautical miles
- variable range marker
- electronic bearing line
- range rings

b. Visual observation of the pilot's use of the radar display. This included use of the following piloting techniques:

- course cursor piloting
- parallel cursor piloting
- scope head plotting

c. Pilots completed a questionnaire designed to address the relationship between the radar display and the visual scene. Pilots commented on their choice of technique, the manipulation of the radar display, and the strategy that lay behind it.

4.2 MANIPULATION OF RADAR FEATURES

Manipulation of the radar display features was recorded by computer to learn empirically if any patterns might emerge between radar display use and ship track performance. Manipulation of the display features was generally similar for all pilots and for all scenarios except for range selection. All pilots enabled the head-up display mode and heading flash. Given a choice between a north-up display mode and a head-up display mode all the pilots preferred the head-up display because it presented the relationships among the buoys with reference to the ship's heading. This image preserves the relative relationships between ownship and the aids to navigation as they would exist in the visual scene and the real world. The fact that the visual scene provides no information in the zero nm visibility condition did not change the pilots' preference. All the pilots enabled the head-up display regardless of the visibility. The heading flash was used to estimate the distance from the channel edge and to estimate the discrepancy between actual heading and the desired course. Use of the electronic bearing line (EBL) was negligible. Instead, the pilots used the mechanical cursor to mark the desired course. The pilots used either the variable range marker (VRM) or range rings (RR) to estimate distances at which to initiate maneuvers in the turn.

Range scale selection was the only display feature that was manipulated with any degree of variability over the course of experiment. The column in Table 7 labeled "scenario total" shows the distribution of changes in range scale for each scenario. In general, the number of changes in scale range reflected the difficulty of the scenario. The more difficult scenarios, those with zero visibility or the 80,000 dwt ship (e.g., Scenarios 3, 7, 8, and 9), resulted in the greatest number of changes, while the earlier scenarios (Scenarios 1, 2, 4, and 6) resulted in fewer changes in range scale.

For the most part the range scale selected was between 1/2 nm and 3 nm (see the row labeled "range scale cumulative total"). The pilots switched back and forth depending upon their informational needs. Figure 21 shows how the displays appear at the different range scale. For example, in the turn most pilots preferred to use the three lowest range scales (1/2 nm, 1.0 nm, and 1.5 nm) in order to gain the most precise information about relative motion, rate of turn, and distance between the buoys, etc. In the pullout region, the pilots would switch to the 3 nm scale to gain more global information about intended course. This alternating between "short" and "longer" range scales as the vessel passes through the channel appears to satisfy the demand for different types of information needed to monitor and control the ship's track under low visibility conditions.

4.3 GROUP DIFFERENCES IN RADAR PILOTING

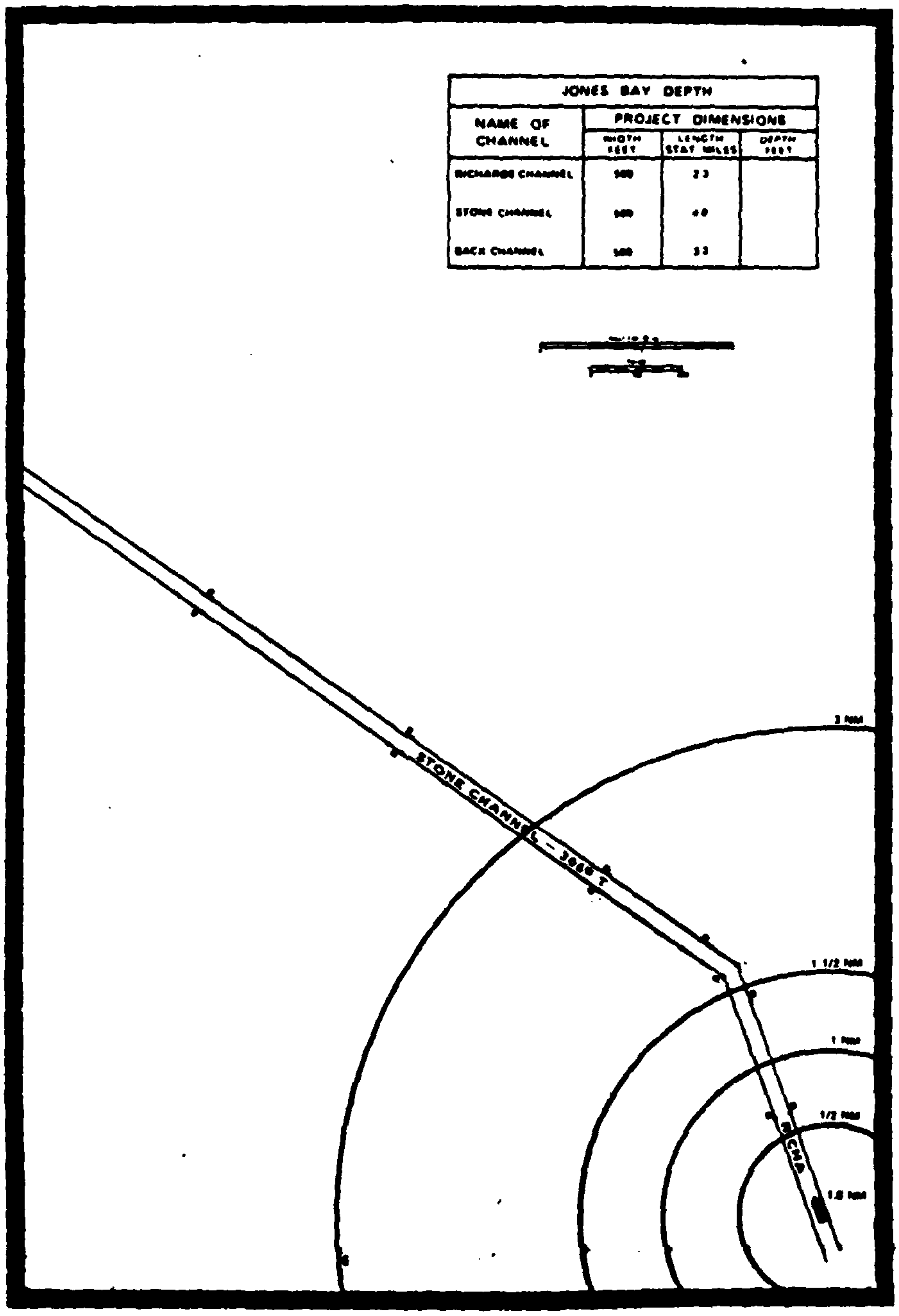
Observation of radar use during the course of the experiment and discussion with the pilots led to the belief that performance differences in ship tracks could be related to individual differences in radar use. Roughly speaking, the pilots could be divided into two groups according to their use of the radar display. In one group, Style A, the pilots made use not only of information about their present crosstrack position, but also incorporated information about future crosstrack position into their

TABLE 7. RADAR RANGE SELECTION FREQUENCY DISTRIBUTION

SCALE

RADAR RANGE SELECTION

SCENARIO	1/2 NM	1.0	1.5	3.0	6	12	24	SCENARIO TOTAL
1		17	40	23	1			81
2	1	18	37	25	1	1		82
3	10	32	48	25	1			115
4	4	14	29	20				67
6	8	30	36	21	1		1	97
7	17	44	45	31				137
8	20	36	48	26	1	1		130
9	17	34	43	28				122
RANGE SCALE CUMULATIVE TOTAL	77	225	326	199	5	2	1	



JONES BAY DEPTH			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH FEET	LENGTH STAT MILES	DEPTH FEET
RICHARDS CHANNEL	500	2.3	
STONE CHANNEL	500	4.0	
BACK CHANNEL	500	3.3	

Figure 21. Appearance of Radar Display at Different Range Scales

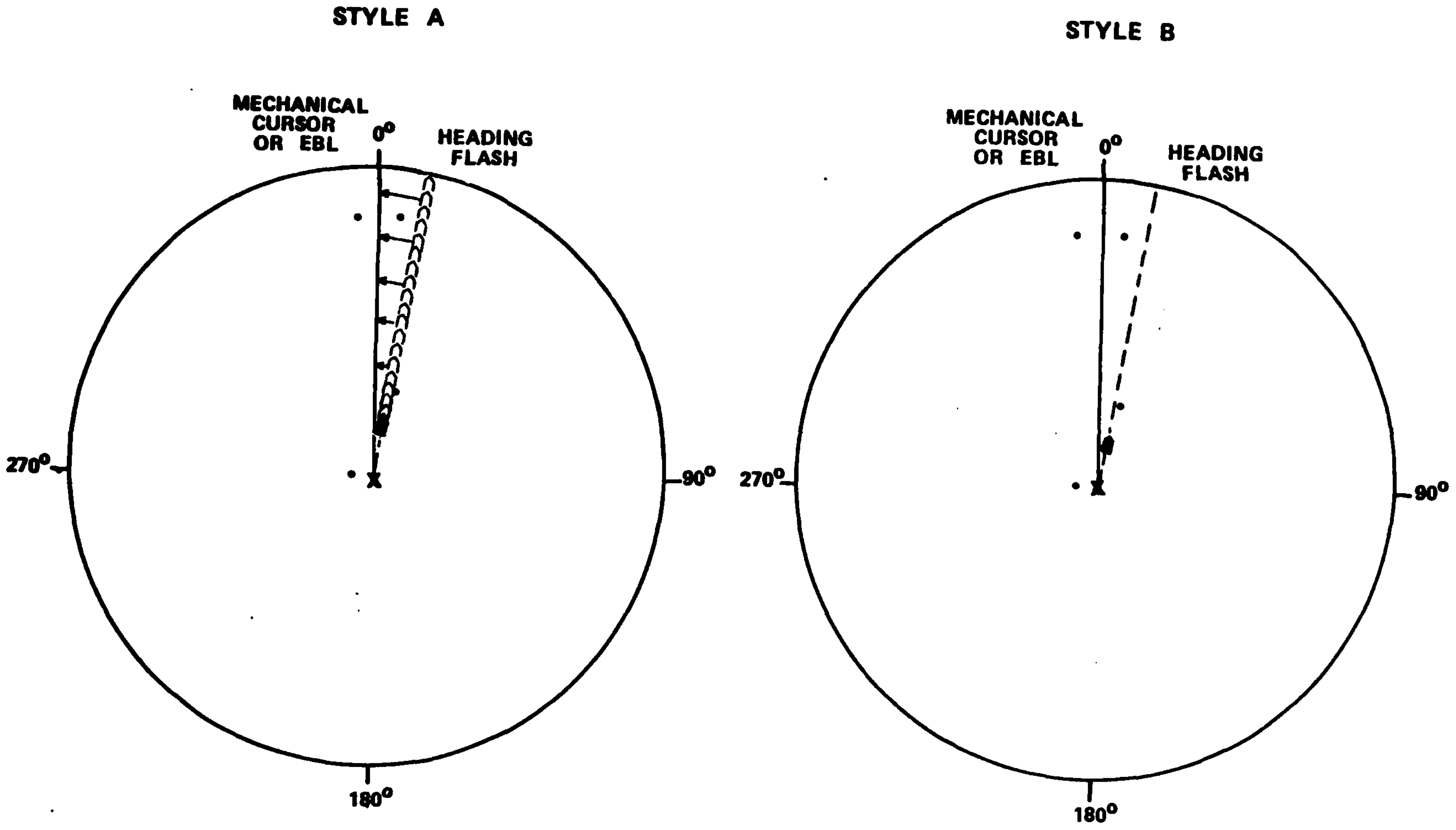
piloting decisions. In the other group, Style B, the pilots use the information about present crosstrack position, but do not use the information available regarding future crosstrack position. It was predicted that these differences in the use of the radar display would lead to a smaller number of large corrections and consequently a smaller track envelope for Style A than for Style B. Evidence for this prediction is discussed shortly.

The distinction made here between style differences in radar piloting should not be viewed as the only factor that distinguishes performances among the pilots or necessarily the most important. The pilots were, in fact, separated in the analysis of the experimental conditions (Sections 2 and 3) using another criterion. To be included in the analysis of the experimental conditions, the pilots had to meet state licensing requirements as well as federal licensing requirements. Only five of the pilots met this criterion. The breakdown here is not by license. The purpose of this particular breakdown by style of radar use is to determine if this factor makes a meaningful contribution to radar piloting performance.

Generally speaking, there are two techniques, course cursor piloting and parallel indexing, that pilots learn to aid them in making use of the radar display during trackkeeping and maneuvering. Course cursor piloting is defined here as the comparison between the heading flash and a reference line, such as the mechanical cursor or EBL, to estimate present and future position in a channel. Parallel indexing is defined as the use of parallel lines of position to establish the intended course and deviation from course. In this experiment, all eight pilots chose course cursor piloting as their preferred method of navigation for all scenarios. (Scope-head plotting was not observed.)

From observation of the pilots' behavior toward the radar display and discussion with the pilots about their use of the display, it became apparent that while all the pilots engaged in course cursor piloting, some pilots were able to gain more information than others. These differences could be divided into two styles according to the use of the radar display. For descriptive purposes, these two groups will be distinguished by the names, Style A and Style B. Figure 22 depicts the information in the radar display for each style used. In Style A, crosstrack position in the channel was estimated not only for the ship's present position, but for future position as well. The heading flash, representing the ship's projected course, could be used to estimate crosstrack position at any point alongtrack from the intended course represented by the mechanical cursor or EBL. In this style the crosstrack position was estimated at multiple points alongtrack to judge the dynamic changes in crosstrack position, not just the distance between a discrete set of points. Thus, the pilot would use not only the closest buoy or gated pair of buoys to estimated position, but would use buoys further down the channel as well. The source of information for position estimation is distributed among the buoys in the channel.

Style B is a subset of Style A. Style B also uses course cursor piloting to obtain information about crosstrack position. However, Style B differs from Style A in being less sophisticated. Pilots exhibiting Style B behavior estimate crosstrack position only between single set of points in the channel. They do not estimate crosstrack position at several different



BOTH PPI DISPLAYS ARE IN HEAD UP MODE WITH 1 1/2 NM RANGE SCALE

Figure 22. Two Styles of Radar Display Use

alongtrack positions. Consequently, they do not obtain information about changes in ship movement as rapidly.

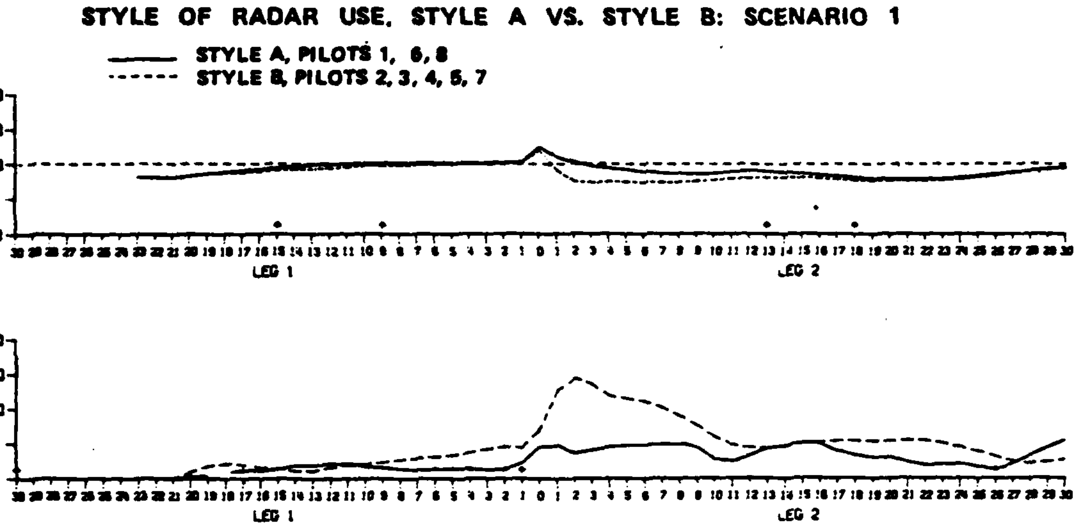
Given these style differences in the use of radar do they result in differences in performance? To answer this question, the eight pilots who participated in the experiment were separated into two groups based upon earlier discussions with pilots about their radar use. Performance was then compared to learn if any differences might emerge as a function of the turn arrangement and buoy spacing in the straight channel segments.

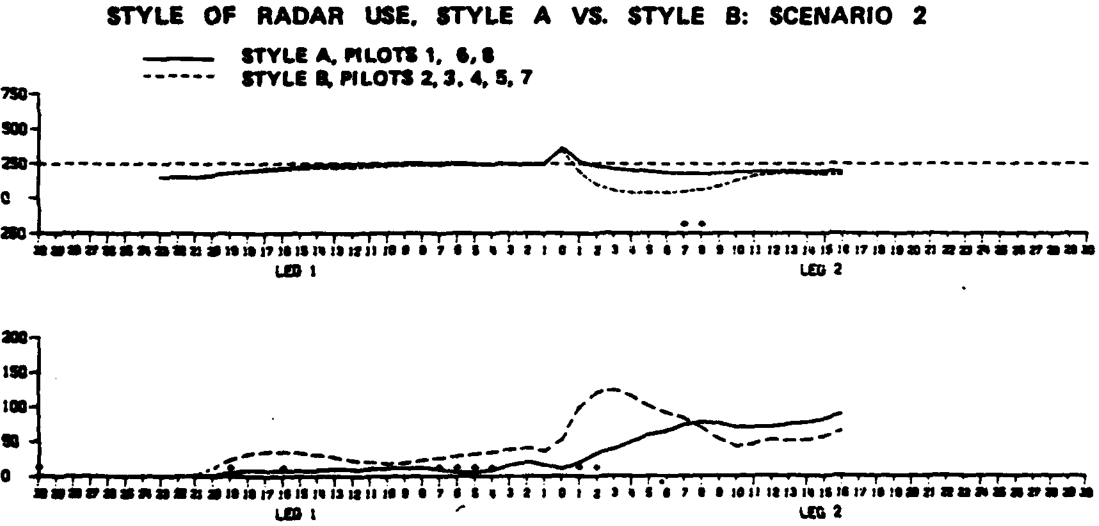
The separation of the pilots into two groups, based upon behavior discussed previously, does result in empirical differences in ship track performance. These differences are evident in the comparison of the turn buoy arrangements in 1/4 nm visibility. Figure 23 shows the effect of style differences in the turn with 1/4 nm visibility. In a three-buoy turn the Style A turn is closer to the centerline than Style B in the pullout from the turn, but not significantly so. In the two-buoy turn the performance difference between the two styles increases. The same is true for the standard deviation measure. In the two-buoy turn the standard deviation is significantly lower for Style A. This effect is illustrated in Figure 23. Thus, while performance deteriorates for both groups, going from a three-buoy turn to a two-buoy turn, performance deteriorates faster for Style B.

These differences are even more pronounced in the zero visibility, buoy density comparison illustrated in Figure 24. Performance deteriorates for both groups in the low buoy density comparison of Scenario 8. However, maneuvering through the turn and trackkeeping performance is consistently worse for Style B throughout Leg 2. It is worth noting that the buoy hopping strategy in Scenario 8 is much more pronounced for Style B, as well. This more pronounced buoy hopping exhibited in Style B supports the assumption that the pilots are responding to single point-to-point estimates of crosstrack position. On the other hand, the pilots in Style A are less likely to depend upon the use of buoys as leading marks. Instead, the pilots use the buoys like ranges to gain more dynamic information about changes in ship movement. Consequently, the pilots are able to respond more gradually and deviations from the intended course are smaller.

Table 8 summarizes the mean and standard deviation for the two styles in the pullout region. For each scenario, the standard deviation is larger and the mean is closer to the right channel edge for the Style B than for Style A. Analysis of both comparisons suggests the following conclusion: Style B is more sensitive to aid arrangements than Style A. As the aid arrangements increase in the risk they pose to safe piloting, the risk is greater for Style B compared to Style A. It is hypothesized that Style A is less sensitive to aid arrangements than the perspective style because they make greater use of the available information for both the turn and straight channel segments.

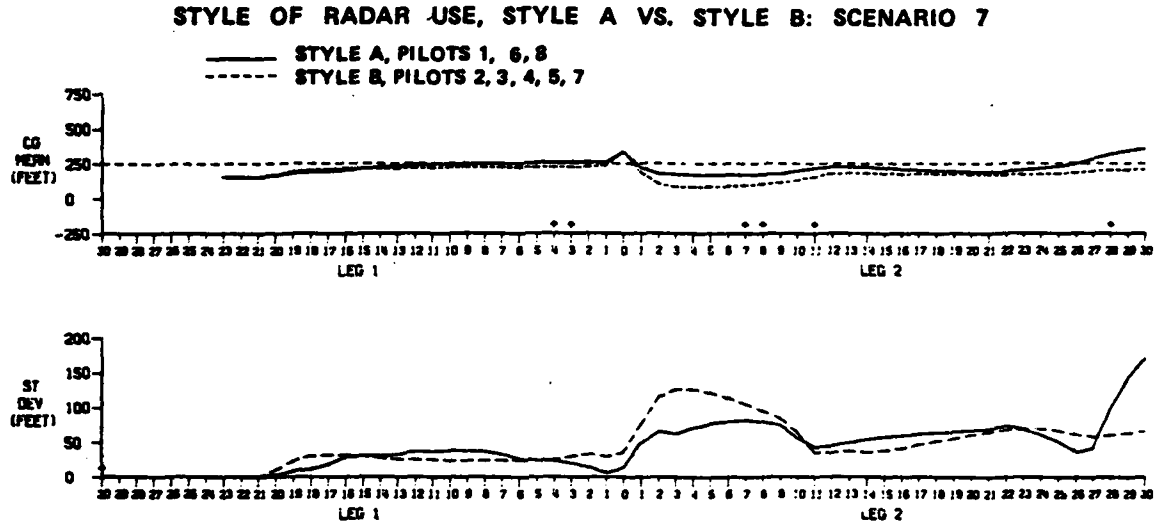
The source of these style differences are probably learned, but the differences appear to be more subtle than academy training versus no academy training. For example, all the pilots in the Style A group received maritime training at the academy level and all but one of the pilots in the



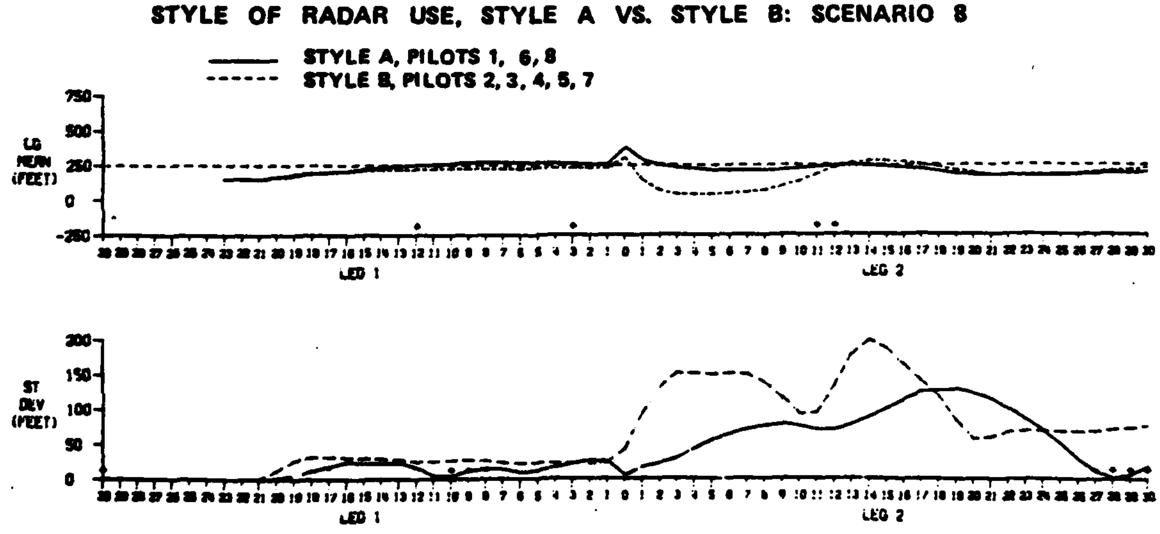


↑ ARROW INDICATES STATISTICAL SIGNIFICANCE AT $P < .10$

Figure 23. Differences in Sensitivity to Turn Buoy Arrangement as a Function of Style of Radar Use



STYLE OF RADAR USE, STYLE A VS. STYLE B: SCENARIO 7



STYLE OF RADAR USE, STYLE A VS. STYLE B: SCENARIO 8

↑ ARROW INDICATES STATISTICAL SIGNIFICANCE AT $P < .10$

Figure 24. Differences in Sensitivity to Buoy Density as a Function of Style of Radar Use

Style B received maritime training at the academy level. The pilots also vary greatly in age and level of experience and these factors may contribute to the style differences. The data regarding the pilot's past experience is insufficient, however, to make any inferences about the origins of these style differences. Nevertheless, the styles are probably learned. If these style differences found in this experiment are indicative of the pilot population at large and one accepts the assumption that these styles can be learned, then the risk associated with specific aid arrangements could be reduced by training pilots to use the appropriate radar style with the appropriate aid arrangements. Before implementing such a procedure, however, more research would be necessary to learn more about the limitations of these styles and how they interact wit the placement of navigational aids.

Finally, the two styles are not wholly unrelated. Rather, the two styles reflect two ends on a continuum of radar piloting behavior. Some pilots placed in one group exhibit responses that are more characteristic of the other style and pilots within a group display different degrees of the behavior associated with the style. However, for analytical purposes, the style of radar use was divided into two discrete groups. It is hoped this separation will increase our understanding of some of the factors that may operate to create individual difference in piloting performance.

4.4 SUMMARY OF RADAR USE

Manipulation of the display features was similar among all pilots. The only feature manipulated with any frequency was range scale which appeared to reflect the difficulty of the scenario.

The division of pilots' performance into two different styles of radar use, Style A and Style B, resulted in meaningful differences in performance. Performance of the pilots exhibiting Style A was consistently better than the other group with a crosstrack mean closer to the center of the channel and a smaller crosstrack standard deviation. Style B was consistently more sensitive to the placement of navigational aids than was Style A.

TABLE 8. CROSSTRACK MEAN AND CROSSTRACK STANDARD DEVIATION (IN FEET) AS A FUNCTION OF STYLE DIFFERENCES IN RADAR USE

Scenario	1		2		7		8	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Style A	21	42	42	40	81	62	22	30
Style B	135	135	196	124	167	126	210	151

Section 5

THE CONTRIBUTION OF THE RADAR I DATA TO THE AN DESIGN MANUAL

5.1 INTRODUCTION

Beyond the experimental analysis of radar use and related factors, the ultimate objective of the present experiment was to provide data to support decisions on aid systems and on operational procedures for low visibility conditions. The following discussion is a summary of the performance data under very low and zero visibility/radar conditions, arranged to facilitate such decision. A secondary purpose of the experiment was to provide data to aid in interpretation of the larger body of AN data: what degree of conservatism is imposed by the difficult shiphandling conditions (wind and current) and by the lack of radar in the adequate-visibility/visual-only conditions?

5.2 PERFORMANCE IN LOW VISIBILITY

The far-greater research investment in the AN project has been in adequate-visibility/visual-only conditions. The user population to which the AN project results apply have been harbor pilots. They depend on and prefer visual methods, with radar serving as a secondary source only, whenever possible. They use radar, or electronic methods, as a primary source only when it is unavoidable. It has been Coast Guard policy to provide aids for visual piloting and it is expected that such a policy will continue. Performance in visual conditions is summarized in the draft manual, the Turn Lights report, and will be summarized again in a final design manual early in 1985.[8,9]

The low-visibility/radar-piloting performance data will have a secondary function in the design process. When there are a number of options possible for visual piloting, low visibility/radar performance can dictate the choice. The variety of visibility conditions in a particular harbor can be considered by proportionally weighing adequate, low, and zero visibility performance. (Such a procedure is discussed in the draft manual.) In special cases, such as ports used by a limited class of radar users, the aids might be designed for radar use, primarily or exclusively.

It is worth a reminder that the pilots' performance recorded during this experiment is that of pilots who have both state and federal licenses and who have recent experience with radar, ships of this size, and channels of this type. Other users will not necessarily perform as well. On the other hand, this level of performance was achieved using radar with no enhancements or special features and with aids having only passive reflectors. Users of more sophisticated radar and/or more sophisticated aids, who have training in their use, might perform better.

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[8] Op. cit. W.R. Bertsche, M.W. Smith, K.L. Marino, and R.B. Cooper.

[9] Op. cit. J. Multer and M.W. Smith.

Performance data from the present experiment is summarized in Tables 9, 10, and 11. The tables follow the draft manual in dividing scenario events into the turn, recovery, and trackkeeping.

The turn is represented by the data line in the pullout at which the crosstrack acceleration of the mean due to the turn falls to zero. This data line has the largest crosstrack displacement and, therefore, the biggest risk that can be attributed to the turn. It has been Data Line 2, 3, or 4 in Leg 2 (very roughly, two to four ship lengths beyond the apex).

Recovery is the pilot's effort to find the desired track (here, the centerline) and bring the ship to it. For recovery without crosscurrent, a data line was selected in Leg 1 to represent the maneuver to the centerline. This data line had a maximum standard deviation and would result in a maximum risk. For recovery with crosscurrent, the data line in Leg 2 with maximum standard deviation and, therefore, maximum risk between Data Line 4 and Data Line 15 (1+ nm beyond the apex) has been chosen to represent the variety of the pilots' efforts.

Trackkeeping is a maintaining of the desired track once it has been achieved. Without crosscurrent a data line in Leg 1 with the mean on the centerline and a minimum standard deviation was selected. With crosscurrent a data line in Leg 2 beyond Data Line 15 (1+ nm beyond the apex) was selected. This second trackkeeping measure is seldom as good as the first, given the remaining crosscurrent and the history of turn and recovery.

What is new in these tables is the relative risk factor (RRF). As an operational definition of this index, a sample calculation for the first cell of the table is presented as Figure 25. The relative risk factor (RRF) is the probability that for a given condition (ship size, visibility, etc.) and for given aid arrangements (three, two, or one buoys in the turn), there will be a "grounding". Because this probability is calculated using a mean and standard deviation from a simulator experiment, there are certain limitations to its use. the RRF is discussed more fully in the draft SRA manual and in the Validation Presimulation report.[10] For the present purposes, it is a way of comparing conditions that takes both the mean and the standard deviation into account.

Each table is laid out by visibility, ship size, and buoy arrangement or density. This layout is a specific instance of the general logic of the project: given a particular set of conditions, what kind of performance will a given aid number or arrangement buy? The conditions and turnmarkings have been described earlier in this report. The 1/4 nm visibility is that used for minimum visibility in the experiment. For application, it can be assumed that it means visibility sufficient to see both buoys of a pair or all the buoys marking a turn. The radar is available for the pilot to use with whatever emphasis he wants. In zero visibility conditions he has no visual option; he is using radar exclusively.

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[10] G.E. Grant and M.W. Smith. "Aids to Navigation Presimulation Report for Validation: Validation for a Simulator-Based Design Project." U.S. Coast Guard, Washington, D.C., September 1982.

TABLE 9. TURN (PULLOUT) PERFORMANCE

	1/4 nm Visibility					Zero Visibility				
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Scenario	Data Line	Mean	Standard Deviation	Relative Risk Factor
30,000 dwt ship										
Three buoys	1	3	49R	61	0.0140	7	3	74R	50	0.0158
Two buoys	2	3	98R	108	0.2224					
One boy						8	3	67R	64	0.0359
80,000 dwt ship										
Three buoys	3	3	202R	32	0.9200	9	3	157R	140	0.5521
Two buoys										
One buoys										

*Means are shown as feet to right or left of channel centerline.
**Standard deviations are in feet.

TABLE 10. RECOVERY PERFORMANCE

		1/4 nm Visibility							
		No Crosscurrent/Wind (Leg 1)				Crosscurrent/Wind (Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
30,000 dwt ship									
Three turn buoy, gates	1	-18	60R	22	0.0000	7	74R	72	0.0447
Two turn buoys, gates	2	-17	36R	32	0.0000	6	112R	96	0.1927
80,000 dwt ship									
Three turn buoys, gates	3	-16	23R	16	0.0000	6	164R	44	0.4364
		Zero Visibility							
		No Crosscurrent/Wind (Leg 1)				Crosscurrent/Wind (Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
30,000 dwt ship									
Three turn buoy, gates	7	-16	37R	21	0.0000	6	69R	46	0.0030
One turn buoy, staggered	8	-17	36R	25	0.0000	6	62R	57	0.0096
80,000 dwt ship									
three turn buoy, gates	9	-17	33R	11	0.0000	10	18R	95	0.0835

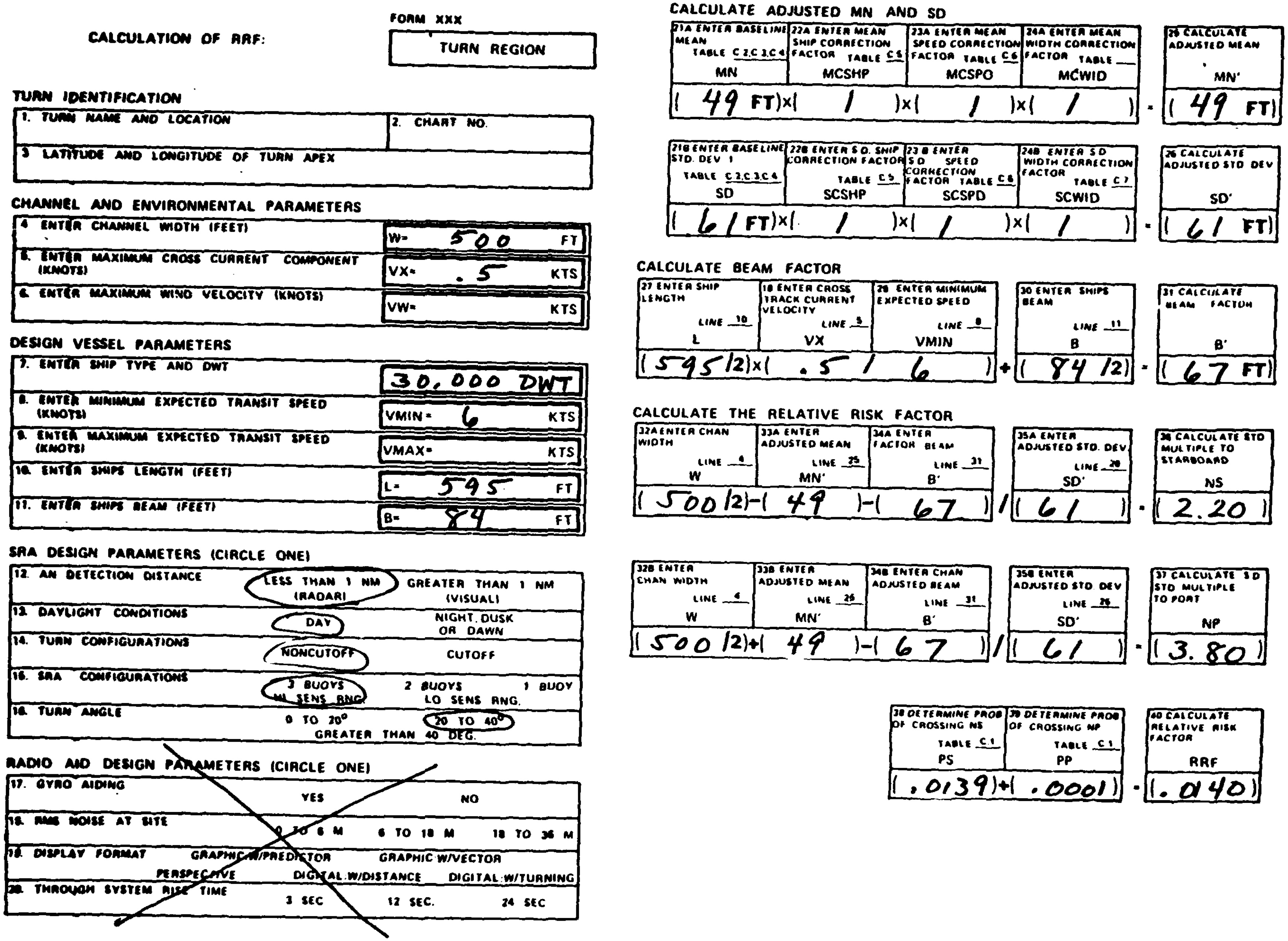
*Mean is in feet to right or left of centerline.
**Standard deviation is in feet.

TABLE 11. TRACKKEEPING PERFORMANCE

	1/4 nm Visibility								
		No Crosscurrent/Wind (Leg 1)				Crosscurrent/Wind (Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
30,000 dwt ship									
Three turn buoys, gates	1	-5	6R	20	0.0000	22	101R	31	0.0016
Two turn buoys, gates	2	-10	6R	19	0.0000	15	62R	67	0.0287
80,000 dwt ship									
three turn buoys, gates	3	-9	1R	28	0.0000	22	59L	69	0.0520

	Zero Visibility								
		No Crosscurrent/Wind (Leg 1)				Crosscurrent/Wind (Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
30,000 dwt ship									
Three turn buoys, gates	7	-10	3R	24	0.0000	15	32R	35	0.0000
One turn buoy, staggered	8	-11	1R	14	0.0000	15	6L	71	0.0073
80,000 dwt ship									
Three turn buoys, gates	9	-8	1L	51	0.0003	24	40L	81	0.0571

*Mean is in feet to right or left of centerline.
**Standard deviation is in feet.



FORM XXX

CALCULATION OF RRF: TURN REGION

TURN IDENTIFICATION

1. TURN NAME AND LOCATION	2. CHART NO.
3. LATITUDE AND LONGITUDE OF TURN APEX	

CHANNEL AND ENVIRONMENTAL PARAMETERS

4. ENTER CHANNEL WIDTH (FEET)	W= 500 FT
5. ENTER MAXIMUM CROSS CURRENT COMPONENT (KNOTS)	VX= .5 KTS
6. ENTER MAXIMUM WIND VELOCITY (KNOTS)	VW= KTS

DESIGN VESSEL PARAMETERS

7. ENTER SHIP TYPE AND DWT	30,000 DWT
8. ENTER MINIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMIN= 6 KTS
9. ENTER MAXIMUM EXPECTED TRANSIT SPEED (KNOTS)	VMAX= KTS
10. ENTER SHIPS LENGTH (FEET)	L= 595 FT
11. ENTER SHIPS BEAM (FEET)	B= 84 FT

SRA DESIGN PARAMETERS (CIRCLE ONE)

12. AN DETECTION DISTANCE	[✓ LESS THAN 1 NM (RADAR)]	GREATER THAN 1 NM (VISUAL)	
13. DAYLIGHT CONDITIONS	[✓ DAY]	NIGHT, DUSK OR DAWN	
14. TURN CONFIGURATIONS	[✓ NONCUTOFF]	CUTOFF	
15. SRA CONFIGURATIONS	[✓ 3 BUOYS HI SENS RNG]	2 BUOYS LO SENS RNG.	1 BUOY
16. TURN ANGLE	0 TO 20°	[✓ 20 TO 40°]	GREATER THAN 40 DEG.

~~RADIO AID DESIGN PARAMETERS (CIRCLE ONE)~~

~~17. GYRO AIDING~~	~~YES~~	~~NO~~	
~~18. RMS NOISE AT SITE~~	~~0 TO 6 M~~	~~6 TO 18 M~~	~~18 TO 36 M~~
~~19. DISPLAY FORMAT~~	~~GRAPHIC W/PREDICTOR~~ ~~PERSPECTIVE~~	~~GRAPHIC W/VECTOR~~ ~~DIGITAL W/DISTANCE~~	~~DIGITAL W/TURNING~~
~~20. THROUGH SYSTEM RISE TIME~~	~~3 SEC~~	~~12 SEC.~~	~~24 SEC~~

CALCULATE ADJUSTED MN AND SD

21A ENTER BASELINE MEAN TABLE C2,C3,C4 MN		22A ENTER MEAN SHIP CORRECTION FACTOR TABLE C5 MCSHP		23A ENTER MEAN SPEED CORRECTION FACTOR TABLE C6 MCSPD		24A ENTER MEAN WIDTH CORRECTION FACTOR TABLE ___ MCWID		25 CALCULATE ADJUSTED MEAN MN'
(49 FT)	×	(1)	×	(1)	×	(1)	=	(49 FT)

21B ENTER BASELINE STD. DEV 1 TABLE C2,C3,C4 SD		22B ENTER S.D. SHIP CORRECTION FACTOR TABLE C5 SCSHP		23B ENTER S.D. SPEED CORRECTION FACTOR TABLE C6 SCSPD		24B ENTER S.D. WIDTH CORRECTION FACTOR TABLE C7 SCWID		26 CALCULATE ADJUSTED STD DEV SD'
(61 FT)	×	(1)	×	(1)	×	(1)	=	(61 FT)

CALCULATE BEAM FACTOR

27 ENTER SHIP LENGTH LINE 10 L		18 ENTER CROSS TRACK CURRENT VELOCITY LINE 5 VX		28 ENTER MINIMUM EXPECTED SPEED LINE 8 VMIN		30 ENTER SHIPS BEAM LINE 11 B		31 CALCULATE BEAM FACTOR B'
(595 /2)	×	(.5	/	6)	+	(84 /2)	=	(67 FT)

CALCULATE THE RELATIVE RISK FACTOR

32A ENTER CHAN WIDTH LINE 4 W		33A ENTER ADJUSTED MEAN LINE 25 MN'		34A ENTER FACTOR BEAM LINE 31 B'		35A ENTER ADJUSTED STD. DEV LINE 26 SD'		36 CALCULATE STD MULTIPLE TO STARBOARD NS
(500 /2)	−	(49)	−	(67)	/	(61)	=	(2.20)

32B ENTER CHAN WIDTH LINE 4 W		33B ENTER ADJUSTED MEAN LINE 25 MN'		34B ENTER CHAN ADJUSTED BEAM LINE 31 B'		35B ENTER ADJUSTED STD DEV LINE 26 SD'		37 CALCULATE SD STD MULTIPLE TO PORT NP
(500 /2)	+	(49)	−	(67)	/	(61)	=	(3.80)

38 DETERMINE PROB OF CROSSING NS TABLE C1 PS		39 DETERMINE PROB OF CROSSING NP TABLE C1 PP		40 CALCULATE RELATIVE RISK FACTOR RRF
(.0139)	+	(.0001)	=	(.040)

Figure 25. Calculation of the Relative Risk Factor

Turn performance as summarized in Table 9 is the most critical in a transit. Inspection of the table shows that ship size is a variable of major magnitude, as was the case with adequate-visibility/visual-only conditions summarized in the Turn Lights report. Relative risk values for the 80,000 dwt ship are larger than all the values with the 30,000 dwt ship: the options are greater for aid arrangements and for operational decisions with the smaller ship. Even assuming that "risk" here is relative and conservative, it appears that large ships and very low visibility are not a "safe" combination. As was the case with adequate-visibility/visual-only piloting, risk goes up as the number of buoys goes down. The lower risk for zero visibility conditions is either the result of the pilots concentration on radar methods or the result of practice with the ship type. In either case, the 1/4 nm visibility conditions are most comparable to past visual conditions and appropriate for extending the generality of the manual. The zero visibility conditions represent the best that can be achieved with traditional radar and passive aids for comparison to other all-weather methods yet to be evaluated.

Performance during recovery from the turn is summarized in Table 10. This table is divided into recovery with no crosscurrent/wind (Leg 1) and recovery with crosscurrent/wind (Leg 2). Notice that the crosscurrent and wind combination is a major variable. Without crosscurrent and wind, relative risk values are all 0.0000 (carried out to four places). This value is doubtlessly closer to real world risks but does not differentiate among conditions. In applying these data, it may be useful to assume crosscurrent in order to choose among conditions. In the draft design manual it was suggested that straight segments with traffic be considered "recovery," in that the pilot is changing the intended track. Such a use results in risks of grounding higher than those for trackkeeping, but does not include the risk of hitting the traffic ship.

Performance during trackkeeping is summarized in Table 11. Again the table is divided into trackkeeping with and without crosscurrent. Again, this is a major variable without which there is no differentiation among conditions. In addition to differentiating among conditions, the more conservative values for trackkeeping with crosscurrent could be used for straight segments with a history of turns and traffic behind them. Only under the best conditions does trackkeeping in the second leg get back to the values of the first leg.

5.3 DESIGN CONDITIONS AND DEGREE OF CONSERVATISM

The project performance data and the RRF values derived from them suggest more difficulty or "risk" to aid arrangements than would be expected in the real world. How much more difficulty or risk? Early in the project it was assumed that easy shiphandling conditions would not differentiate among aid arrangements, while difficult shiphandling conditions -- crosscurrent and wind and a slower speed than the pilots preferred -- would differentiate, and would build a degree of conservatism into the data and its recommendations. Inspection of Tables 9, 10, and 11 supports the assumption that easy shiphandling conditions do not discriminate. An additional comparison is available to evaluate, at least for one combination of conditions, the degree of conservatism.

Scenarios were included in this experiment to evaluate the effects of crosscurrent and wind in Leg 2. Scenario 1 with these conditions and Scenario 4 without were compared in Section 2 as an evaluation of current and wind. They can also be discussed as an evaluation of "design conditions." For very low visibility, the design ship speed of 6 knots was considered "realistic" and was not changed for Scenario 4. Performance is summarized in Table 12. In Scenario 1 without the crosscurrent and wind the minimal risk continues throughout the transit. There are substantial differences between the two scenarios in the turn pullout and recovery. Possibly the following current and wind as the ship goes into the turn has some effect on the turn pullout. Certainly, the crosscurrent, which has its greatest velocity in the pullout and recovery region, is responsible for the difference there. There has been a question of the relative contribution of the turn and crosscurrent/wind to the poorer performance in Leg 2. The good pullout and recovery in Scenario 4 suggests it is primarily the result of the crosscurrent/wind. At least for the 30,000 dwt ship, a well-marked 35-degree turn is not a major problem even with very limited visibility (1/4 nm). The design conditions do build a degree of conservatism into the data. (The Validation II experiment[11] included a design condition evaluation in the Narragansett Bay simulation. The SRA supplemental experiment[12] being run during this writing included a comparison in the experimental channel in adequate-visibility/visual-only conditions.)

The adequate-visibility/visual-only conditions that make up the bulk of the project were run without radar available to the pilot. It has been hypothesized that this lack of radar lends a degree of conservatism to those conditions, especially to those with a low density of buoys. The suggestion was that the radar features would compensate for such low-density, less-effective arrangements as a one-buoy turn and long-spaced, staggered buoys. Scenario 6 with a 1-1/2 nm visibility and radar available is comparable to the earlier Ship Variables experiment, Scenario 2. These two scenarios have been discussed in Section 3. Performance is summarized in Table 13. This turn is better than any seen with visual alone or with radar alone. There is a degree of conservatism in the turn data. Minimally-marked turns could be better than evaluated. However, it is likely that if radar had been available in the adequate-visibility/visual-only conditions and if the pilots had used it as they did in this experiment with its emphasis on radar use, there would have been no differentiation among turn arrangements. The same degree of conservatism does not seem to exist for the rest of the transit.

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[11] G. Grant and J. Moynehan. "Aids to Navigation II/Implementation: Preliminary Observations and Data Analysis." U.S. Coast Guard, Washington, D.C., May 1983.

[12] K.L. Marino and M.W. Smith. "Aids to Navigation SRA Supplemental Experiment Presimulation Report." U.S. Coast Guard, Washington, D.C., March 1983.

TABLE 12. DESIGN CONDITIONS: CURRENT AND WIND

		TURN (PULLOUT) PERFORMANCE							
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor				
Design Conditions	1	3	49	61	0.0140				
Realistic Conditions	4	3	6	43	0.0000				
		RECOVERY PERFORMANCE							
		(Leg 1)				(Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
Design Conditions	1	-18	60R	22	0.0000	7	74R	72	0.0447
Realistic Conditions	4	-11	13R	48	0.0000	9	14R	12	0.0000
		TRACKKEEPING PERFORMANCE							
		(Leg 1)				(Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
Design Conditions	1	-5	6R	20	0.0000	15	65R	39	0.0004
Realistic Conditions	4	-7	9R	29	0.0000	15	10R	10	0.0000

*Mean is in feet to right or left of centerline.
**Standard deviation is in feet.

TABLE 13. DESIGN CONDITIONS: VISUAL CONDITIONS WITHOUT RADAR AVAILABLE

TURN (PULLOUT) PERFORMANCE

	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
Visual Only Ship Variables	2	3	72	45	0.0068
Visual and Radar Radar II	6	3	28	26	0.0000

RECOVERY PERFORMANCE

		(Leg 1)				(Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
Visual Only Ship Variables	2	-***	-	-	-	6	88R	60	0.0359
Visual and Radar Radar I	6	-17	36R	30	0.0000	14	144R	88	0.2811

TRACKKEEPING PERFORMANCE

		(Leg 1)				(Leg 2)			
	Scenario	Data Line	Mean*	Standard Deviation**	Relative Risk Factor	Data Line	Mean*	Standard Deviation**	Relative Risk Factor
Visual Only Ship Variables	2	-	-	-	-	15	76R	58	0.0202
Visual and Radar Radar II	6	-13	25R	26	0.0000	15	141R	90	0.2744

*Mean is in feet to right or left of centerline.
**Standard deviation is in feet.
***The data is not directly comparable because of entrance from outside the channel.

To conclude the discussion on design conditions, the variety of artificial, or design conditions, introduced into the experimentation do allow for discrimination among conditions and do add a degree of conservatism, especially in the regions of the transit expected to have the highest risk, the turn and the recovery. The available comparisons suggest that the wind and current have their effect in the turn pullout and recovery and that the lack of radar in the adequate-visibility/visual-only conditions has its effect only in the turn pullout.

APPENDIX A

CHARACTERISTICS OF THE USCG/SA SIMULATOR

The simulator used for this experiment is at Ship Analytics, Inc. in North Stonington, Connecticut. Its visual capability was developed for the U.S. Coast Guard for the Performance of Aids to Navigation Project. The components of the simulator are illustrated in Figure A-1 and consist of the following:

1. The ship's bridge
2. Standard ship's controls
3. Ship's indicators
4. An advanced "radio aided" navigation display unit
5. Computer generated visual system
6. Host computer with requisite interface equipment
7. Postexercise data reduction facility

A.1 THE SHIP'S BRIDGE

The bridge is 15 feet 9 inches wide and 15 feet 6 inches deep with windows for viewing the visual scene. Additional facilities include a chart table with a ten drawer chart storage. The lighting on the bridge can be controlled, and total darkness can be achieved.

A.2 SHIP'S CONTROLS

The control mechanisms found in the bridge simulator are tied directly to the host computer, providing the proper inputs for ship's controls with resultant ship's motion incorporated in the visual image. These control mechanisms include the following:

1. A ship's wheel and helm unit
2. An engine order telegraph which provides control of the ship's engines both ahead and astern. Propeller rpm and ship acceleration are determined by ownship's dynamics programmed for the computer for each specific ship size.

A.3 SHIP'S INDICATORS

The indicators are also tied to the host computer to provide information to the pilot. They include the following:

1. Two gyro repeaters, one on the steering stand and one mounted with an azimuth circle
2. A shaft rpm indicator
3. A rudder angle indicator
4. An ordered course indicator
5. A ship's clock which has been modified to show scenario time

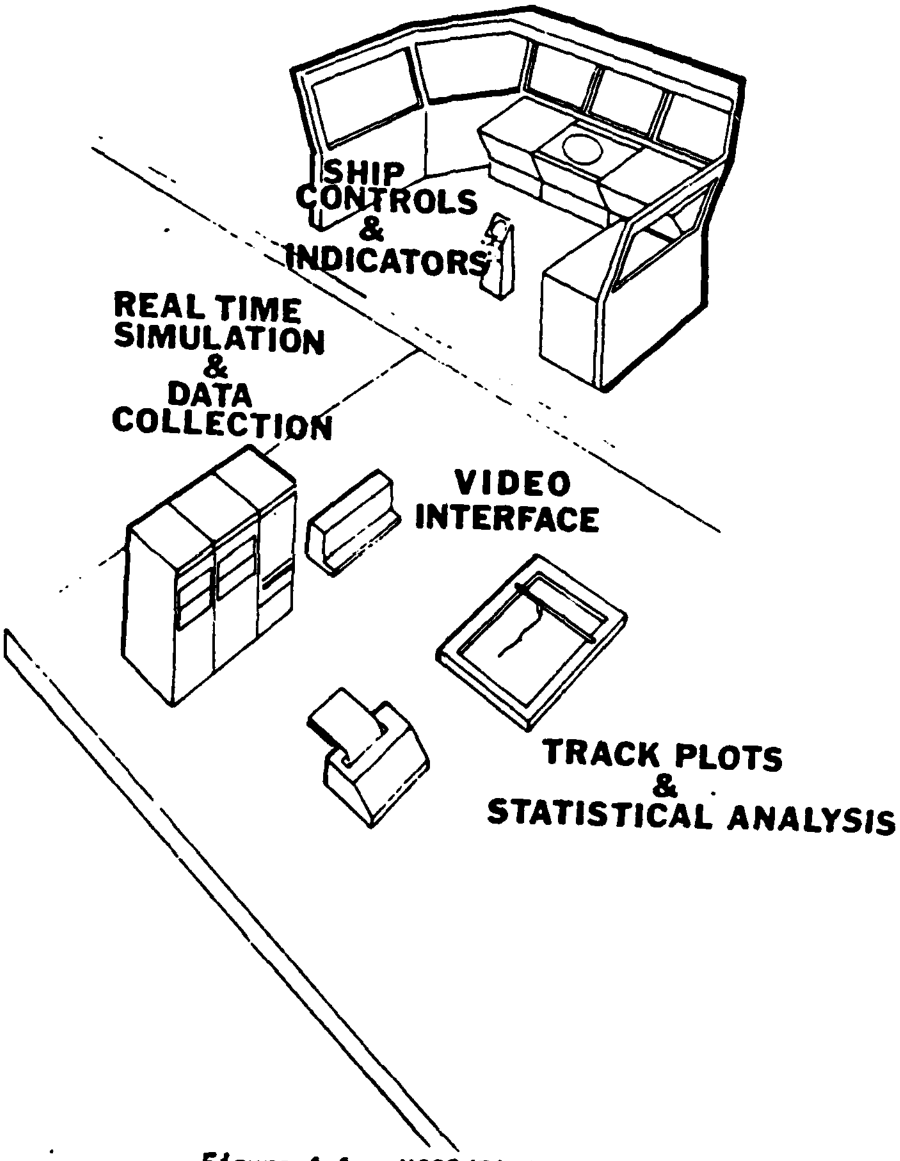


Figure A-1. USCG/EA Simulator

A.4 NAVIGATION DISPLAY UNIT

The navigation display unit presents a variety of information displays to the pilot. It simulates a generic 3 cm radar presentation on a 16-inch PPI.

A.5 VISUAL SYSTEM

The visual system provides a 182-degree horizontal and a 20-degree vertical field of view. The dynamic scene for daytime conditions includes ownship's bow, the sky, water, and visible aids. The nighttime scene translates the aids into appropriate lights.

A.6 THE HOST COMPUTER

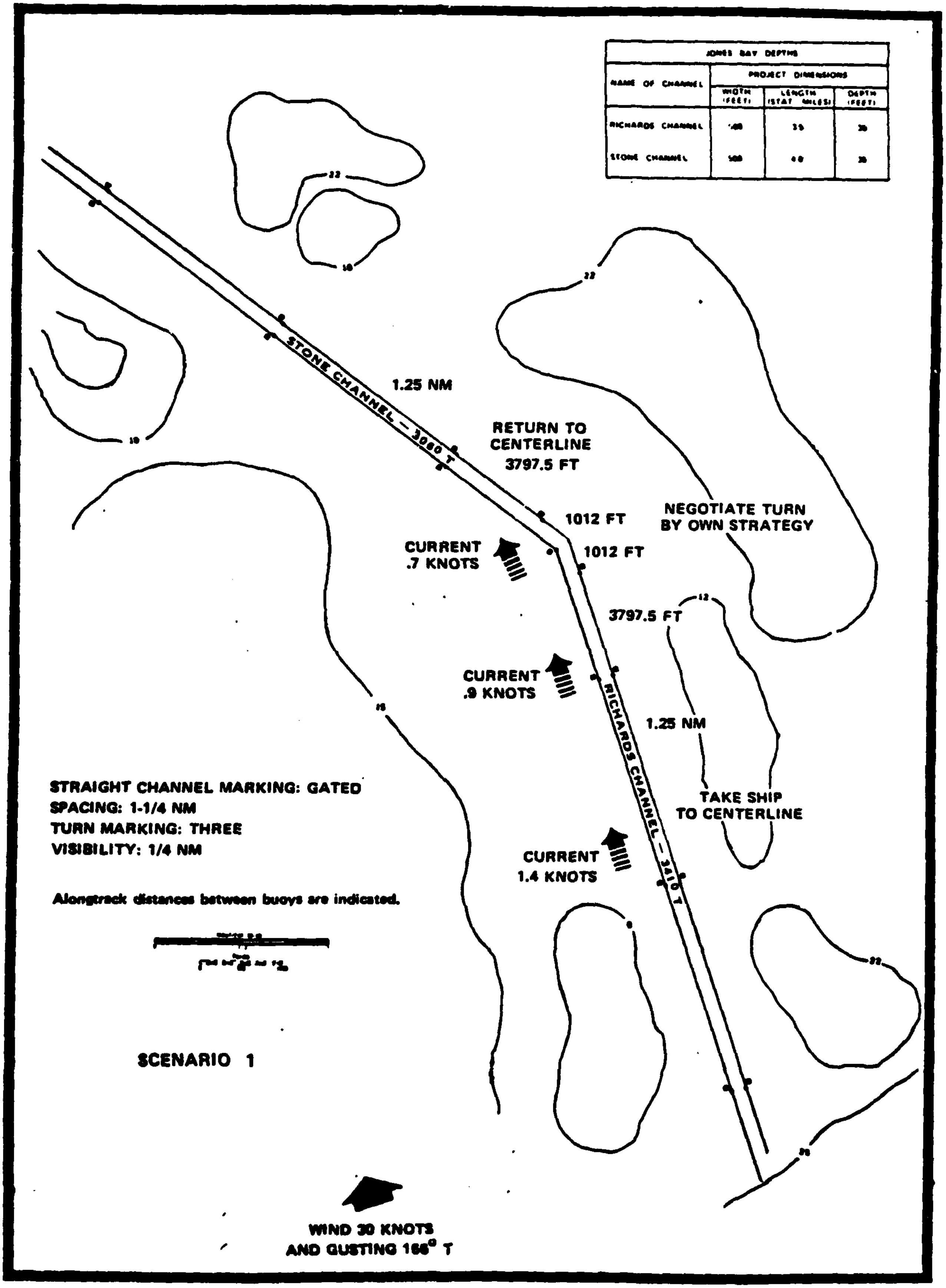
The host computer provides processing for the visual system consistent with ownship's characteristics, including maneuverability. The visibility conditions, the hydrodynamic model, and individual scenario topographical conditions are part of the initial conditions.

A.7 THE DATA REDUCTION CAPABILITY

Computer facilities are available to provide postexercise data reduction, analysis, and hard copy for individual scenarios or groups of scenarios.

APPENDIX B

THE EXPERIMENTAL SCENARIOS

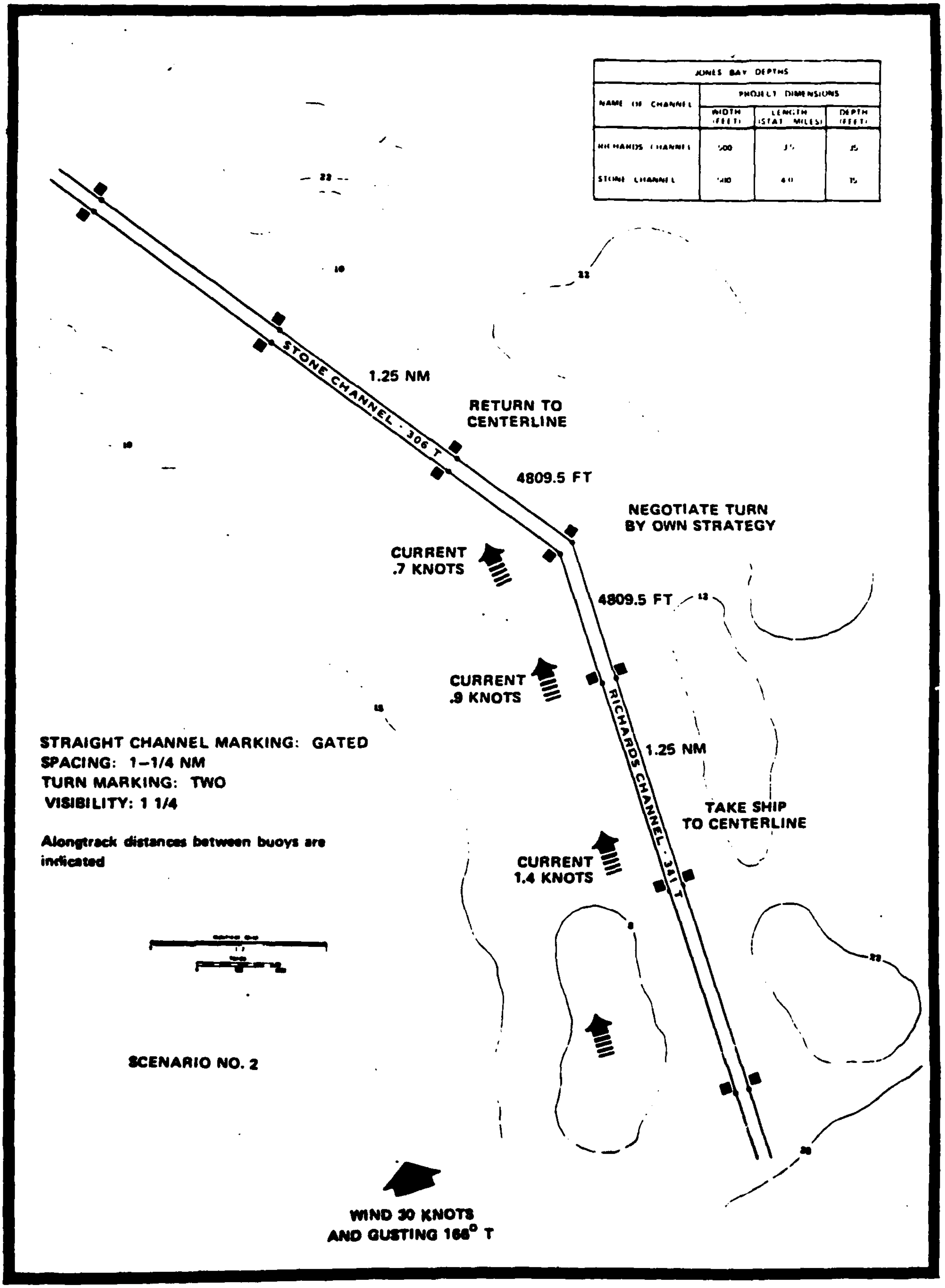


JONES BAY DEPTHS			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (STAT MILES)	DEPTH (FEET)
RICHARDS CHANNEL	400	3.5	35
STONE CHANNEL	500	4.0	35

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 1/4 NM

Alongtrack distances between buoys are indicated.

SCENARIO 1

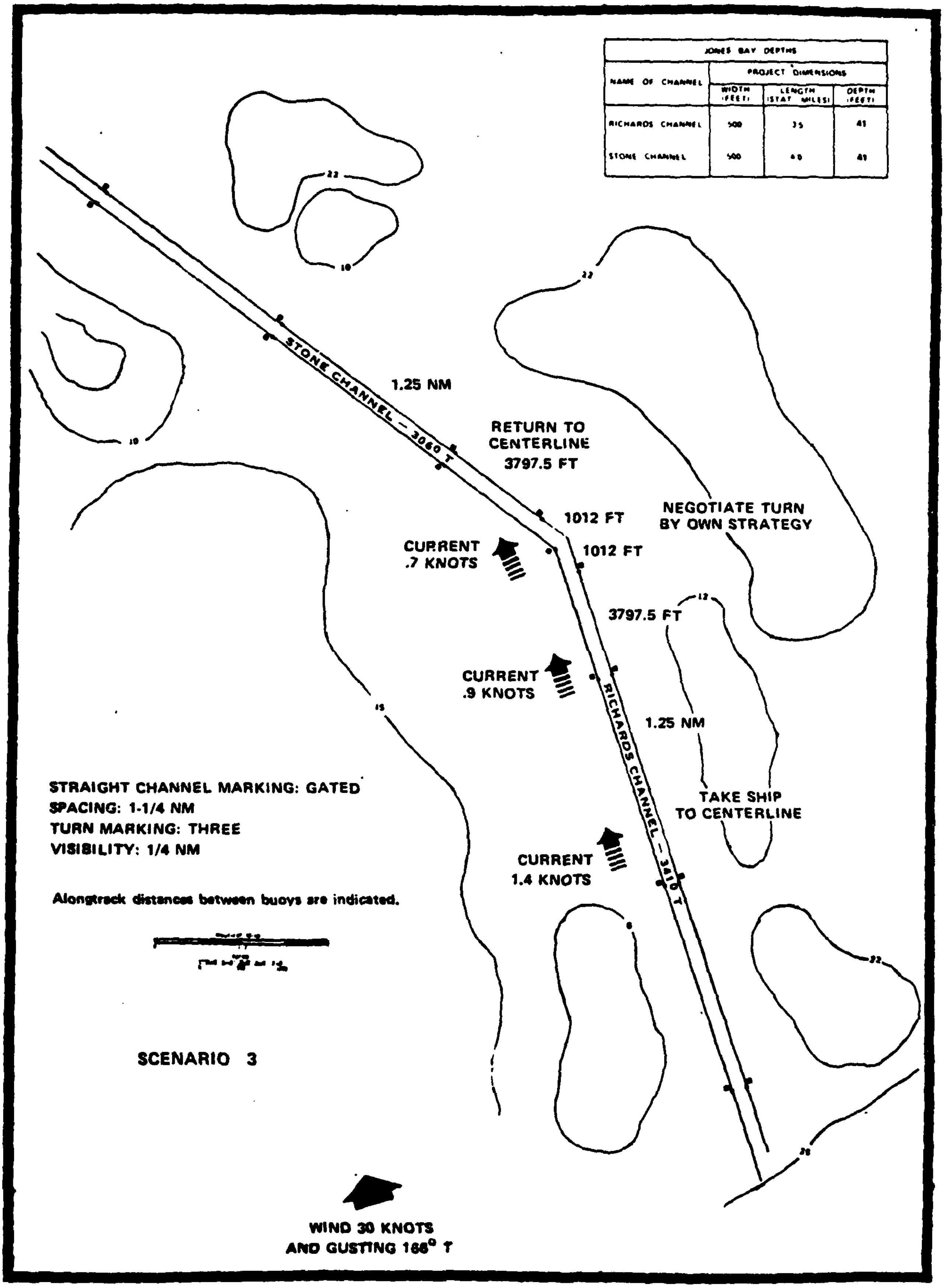


JONES BAY DEPTHS			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (STAT. MILES)	DEPTH (FEET)
RICHARDS CHANNEL	500	3.5	35
STONE CHANNEL	400	4.0	35

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1–1/4 NM
TURN MARKING: TWO
VISIBILITY: 1 1/4

Alongtrack distances between buoys are indicated

SCENARIO NO. 2

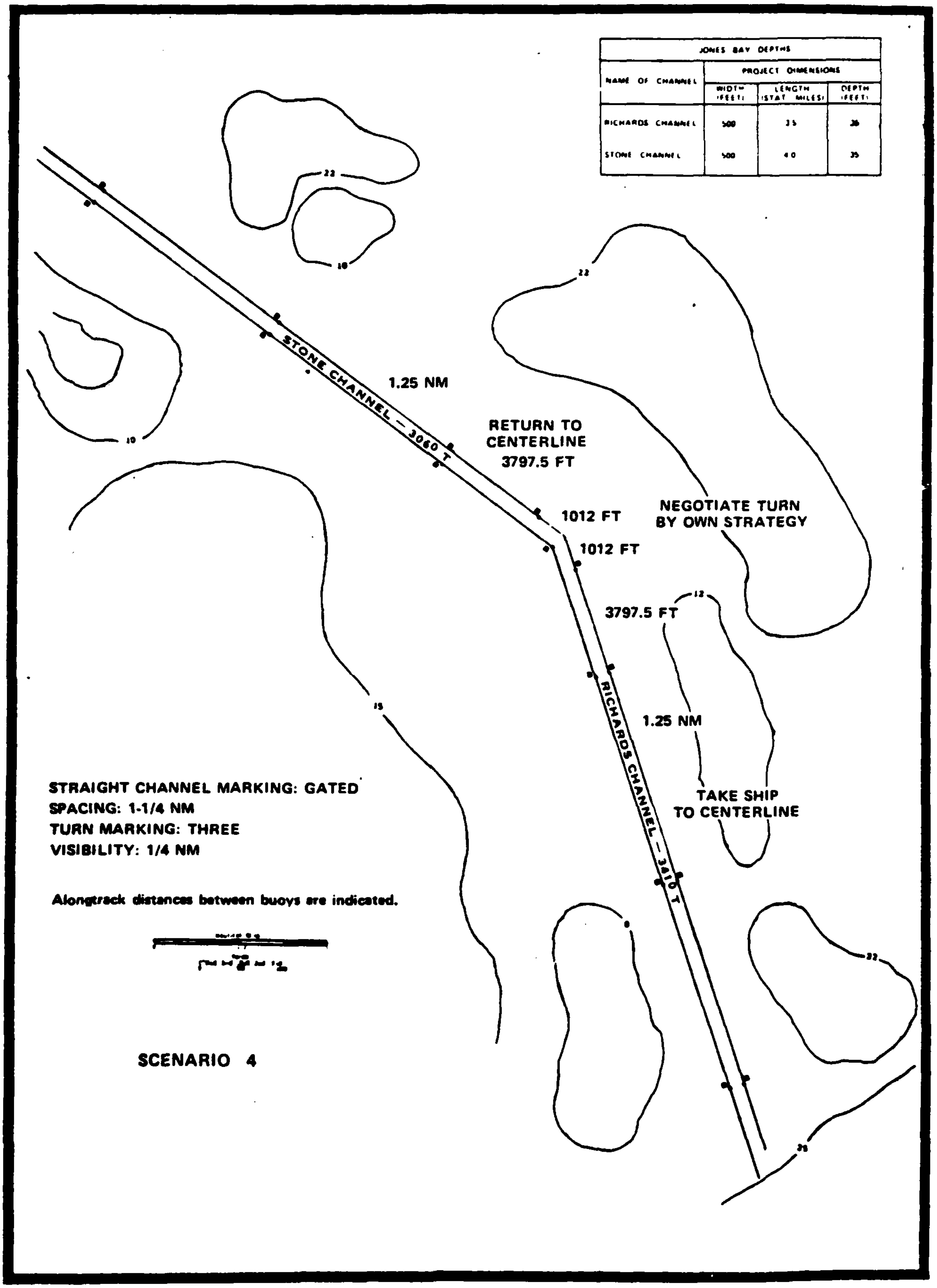


JONES BAY DEPTHS			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (STAT MILES)	DEPTH (FEET)
RICHARDS CHANNEL	500	3.5	41
STONE CHANNEL	500	4.0	41

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 1/4 NM

Alongtrack distances between buoys are indicated.

SCENARIO 3

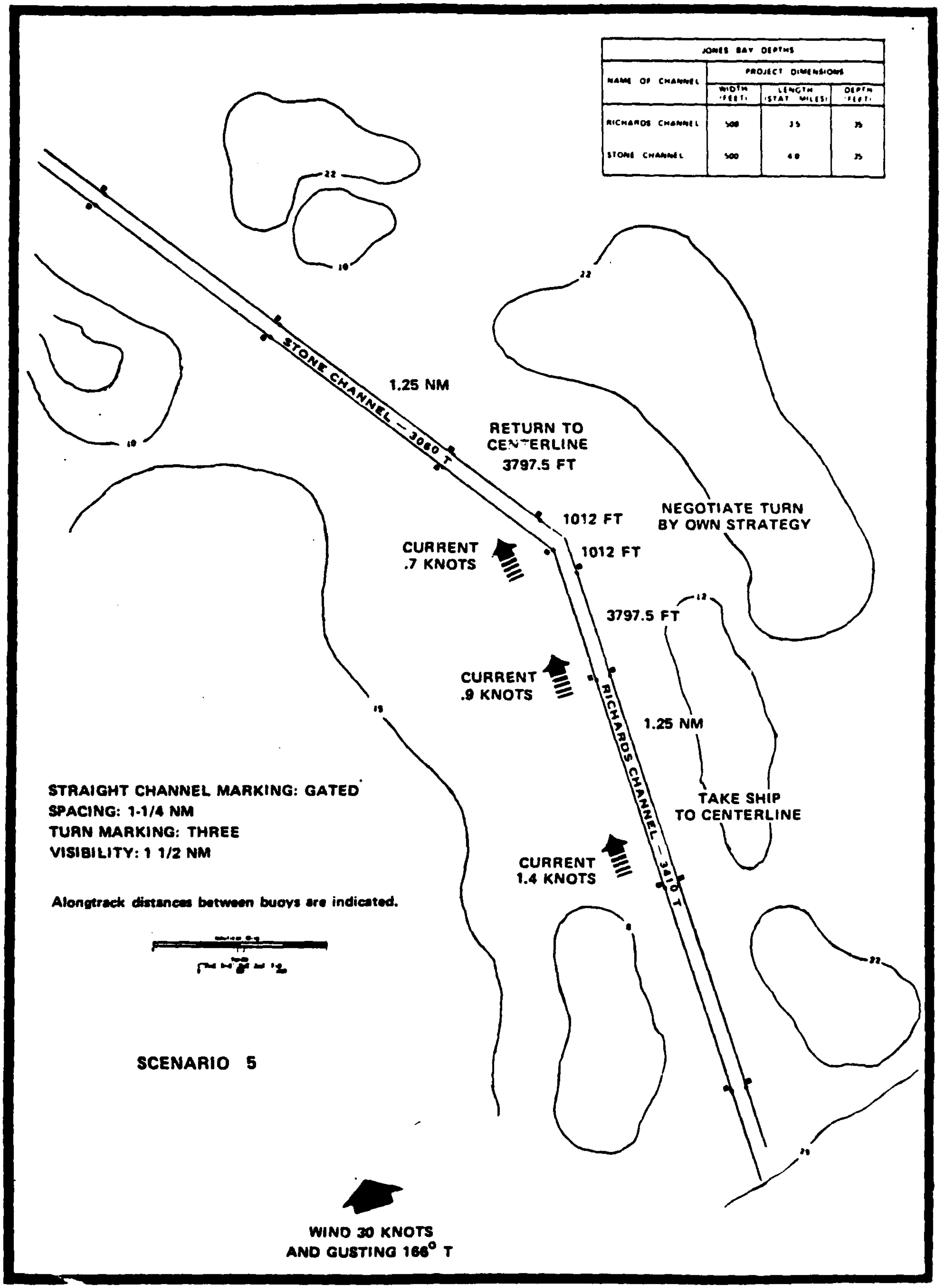


JONES BAY DEPTHS			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (STAT. MILES)	DEPTH (FEET)
RICHARDS CHANNEL	500	3.5	36
STONE CHANNEL	500	4.0	35

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 1/4 NM

Alongtrack distances between buoys are indicated.

SCENARIO 4



JONES BAY DEPTHS			
NAME OF CHANNEL	PROJECT DIMENSIONS		
	WIDTH (FEET)	LENGTH (STAT MILES)	DEPTH (FEET)
RICHARDS CHANNEL	500	3.5	35
STONE CHANNEL	500	4.0	35

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 1 1/2 NM

Alongtrack distances between buoys are indicated.

SCENARIO 5

AD-A137 596   AIDS TO NAVIGATION RADAR I PRINCIPAL FINDINGS:
PERFORMANCE IN LIMITED VIS..(U) ECLECTECH ASSOCIATES
INC NORTH STONINGTON CT J MULTER ET AL. DEC 83
UNCLASSIFIED   EA-83-U-143 USCG-D-79-83 DOT-DG-885285-A   F/G 17/7   NL

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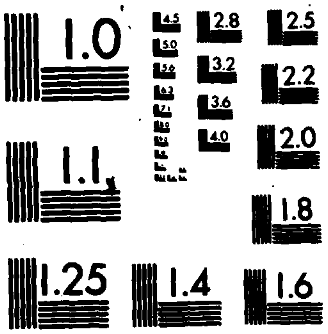
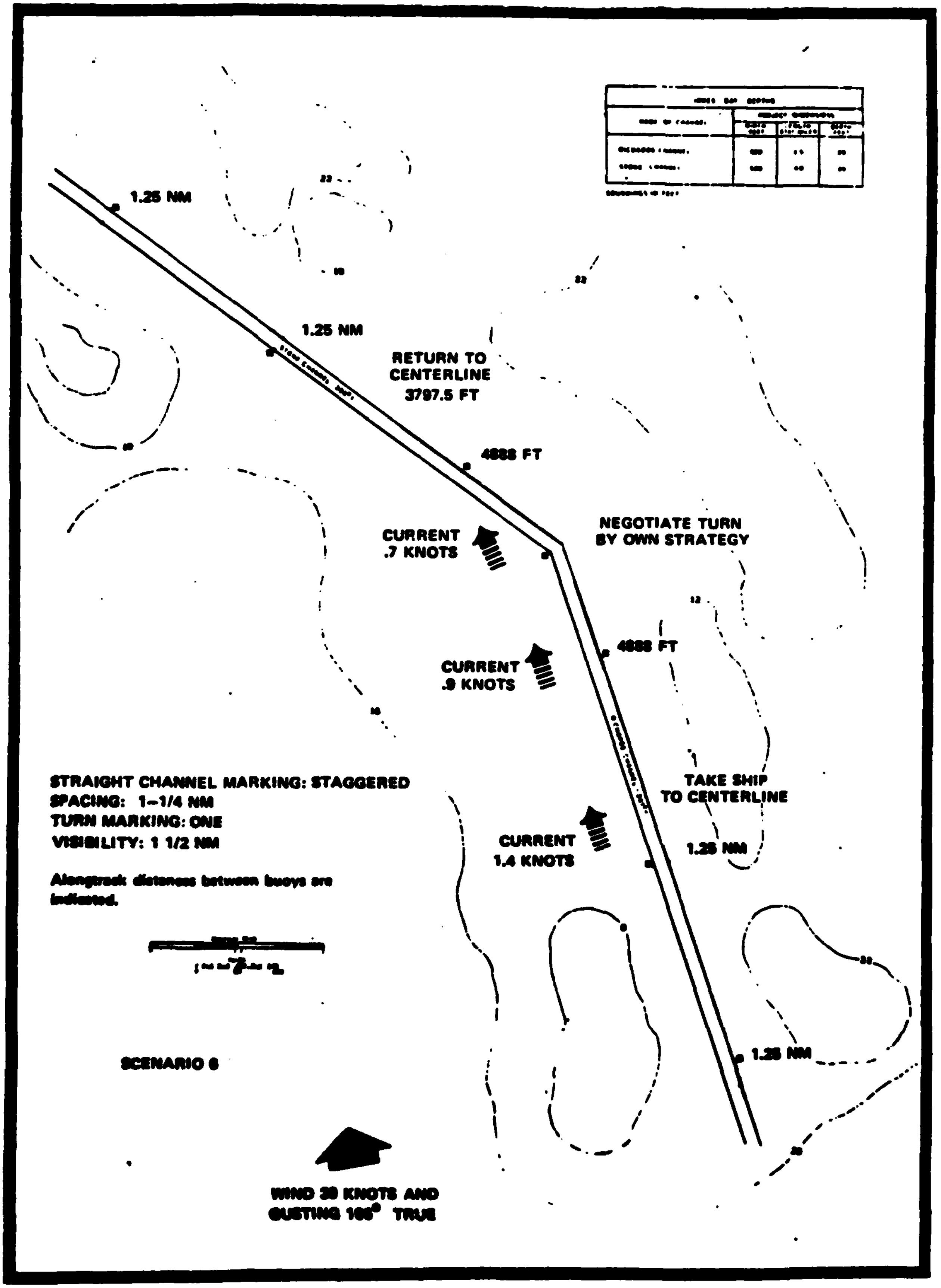


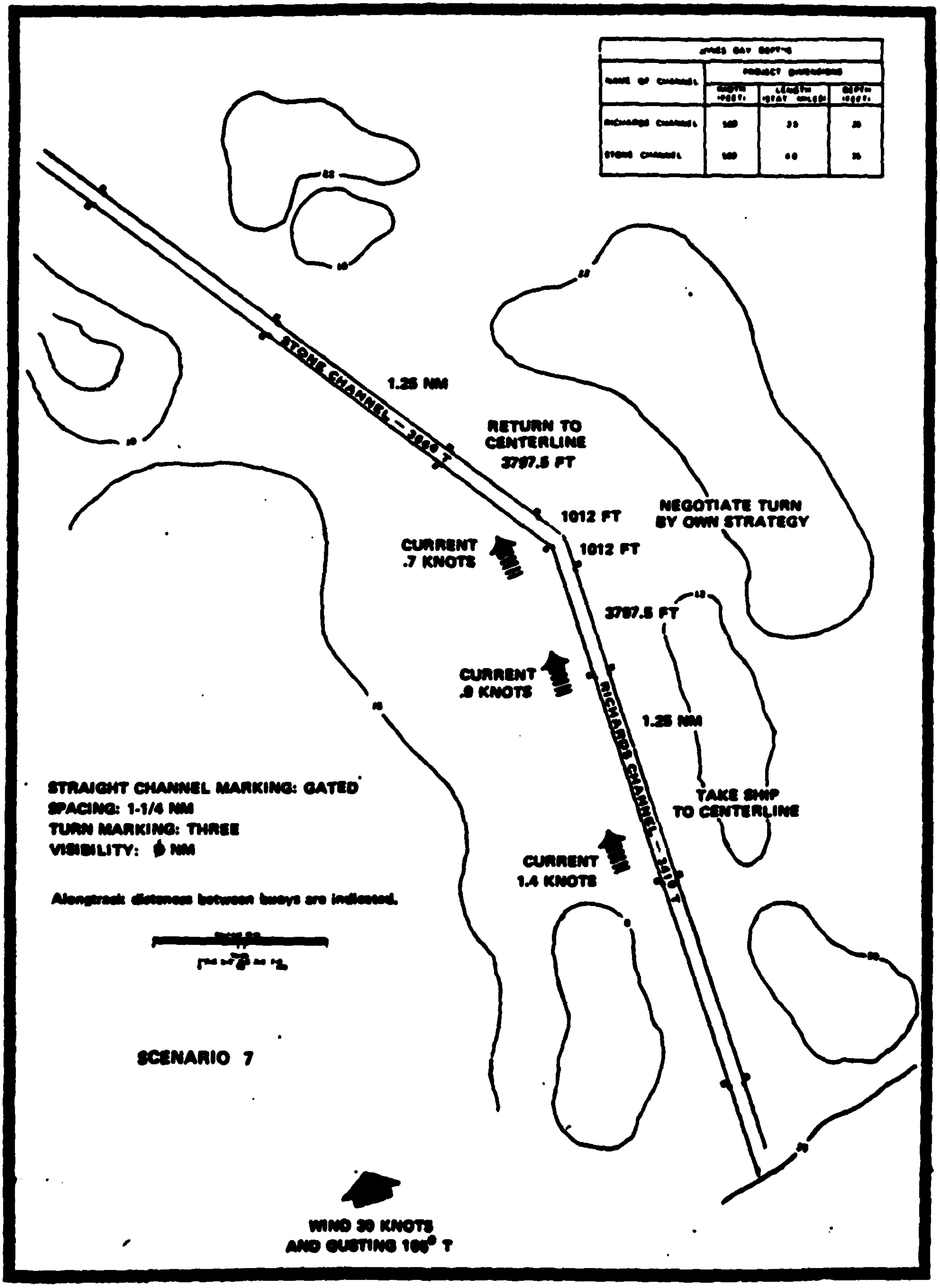
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A



STRAIGHT CHANNEL MARKING: STAGGERED
SPACING: 1–1/4 NM
TURN MARKING: ONE
VISIBILITY: 1 1/2 NM

Alongtrack distances between buoys are indicated.

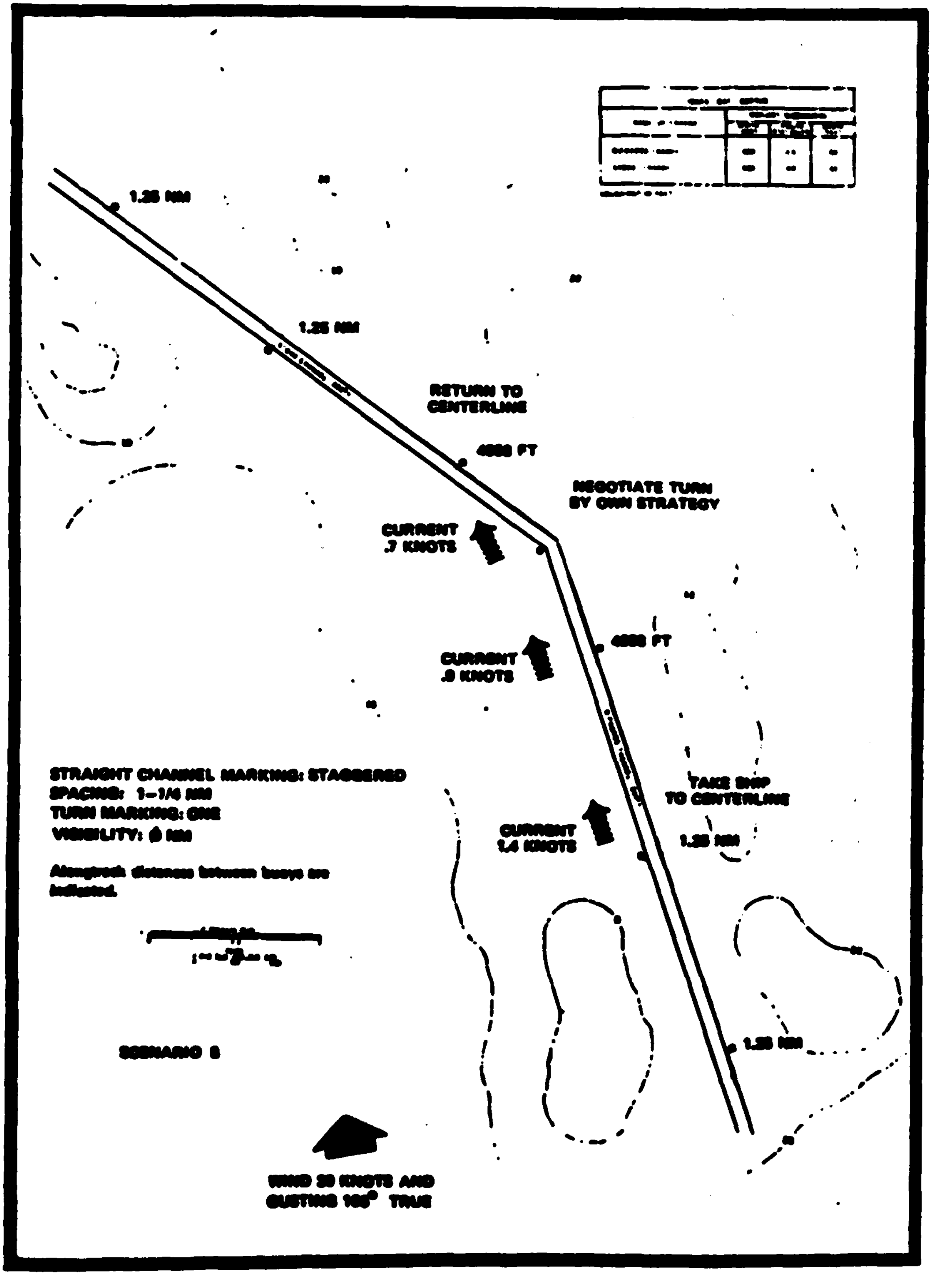
SCENARIO 6



STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 0 NM

Alongtrack distances between buoys are indicated.

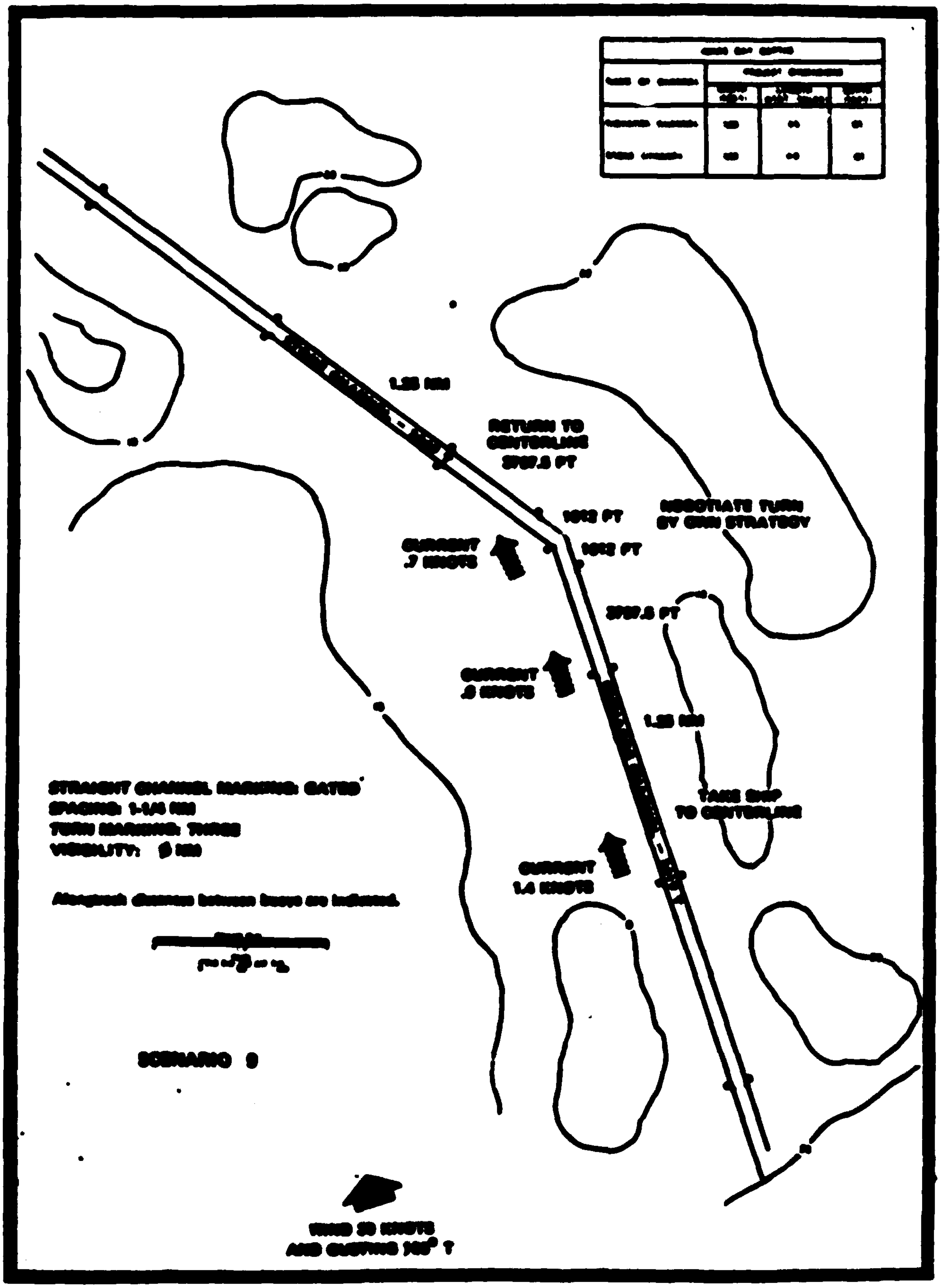
SCENARIO 7



STRAIGHT CHANNEL MARKING: STAGGERED
SPACING: 1–1/4 NM
TURN MARKING: ONE
VISIBILITY: 0 NM

Alongtrack distances between buoys are indicated.

SCENARIO 8

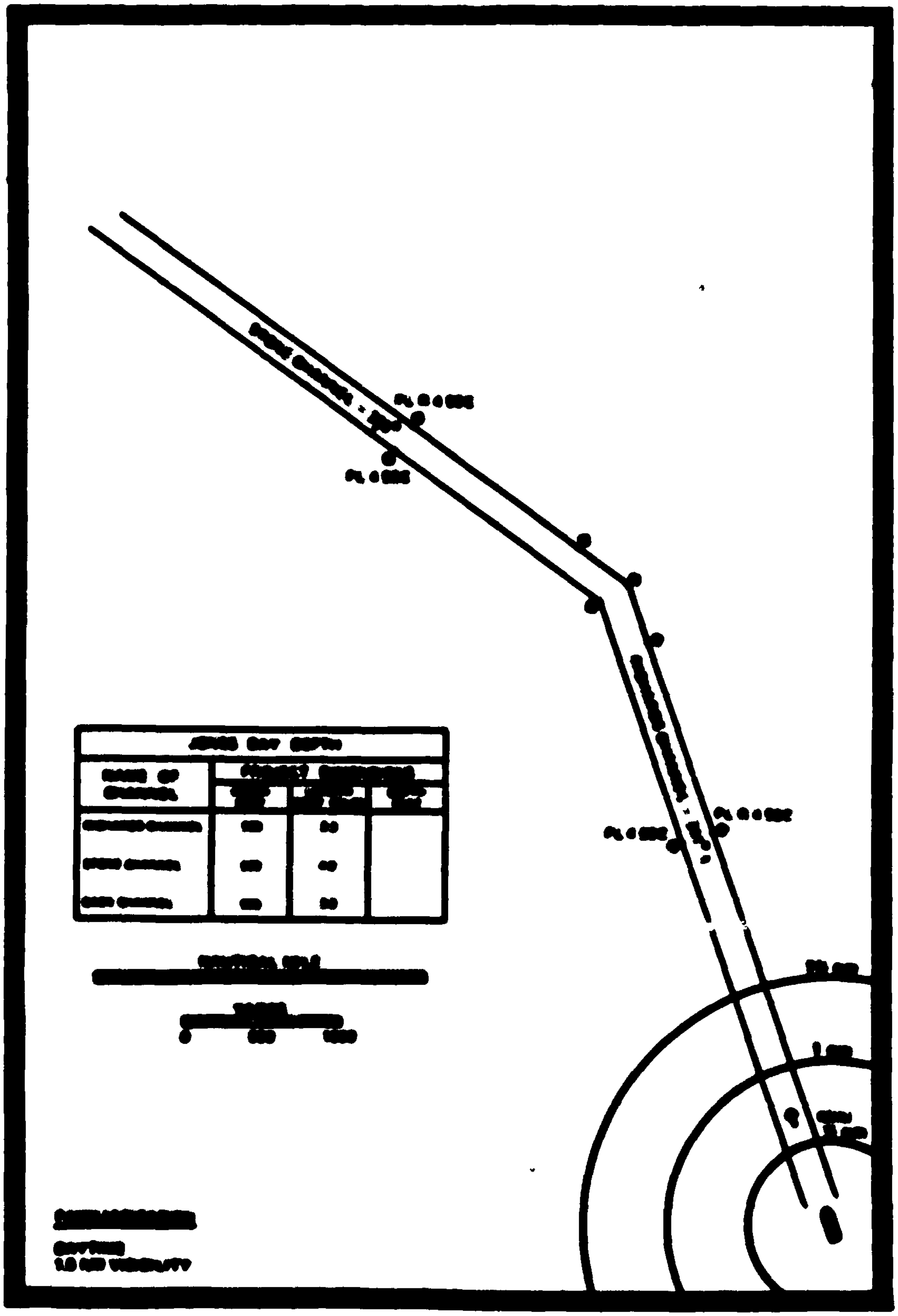


[illegible]	[illegible]		
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]

STRAIGHT CHANNEL MARKING: GATED
SPACING: 1-1/4 NM
TURN MARKING: THREE
VISIBILITY: 5 NM

Alongtrack distance between buoys are indicated.

SCENARIO 9


1 nm
0

Appendix C

INSTRUCTIONS TO THE PILOT

C.1 INTRODUCTION

The primary purpose of this experiment is to evaluate the use of radar and passive reflecting floating aids to navigation for piloting in the low visibility environment. You will have available a 16-inch PPI display with a number of selectable features which you may manipulate to obtain the display most suited to your piloting needs.

Depending upon the visibility allowed by the scenario, there will be buoys visible to supplement the available radar information. In viewing the buoys, it is important to stand in the center of the bridge as it is only there that the buoys appear in their proper location and perspective.

There will be a total of 10 scenarios today. They will consist of the following:

- A familiarization scenario to acquaint you with the wind, current, channel, turn, and the 30,000 dwt ship.
- Six 21-minute (approximately) scenarios with the 30,000 dwt tanker through the turn under different visibility and floating aids to navigation configurations.
- A familiarization scenario to acquaint you with the wind, current, channel, turn, and the 80,000 dwt ship.
- Two 24-minute scenarios with the 80,000 dwt tanker under different visibility conditions.

The day will end with a questionnaire to include your comments on the findings of the study. Please ask questions or make comments at any time.

C.2 GENERAL INFORMATION

The 30,000 dwt tanker. The ship is 595 feet long with an 84-foot beam and a [illegible]-foot draft. It has a split house with a midship bridge that puts the eyepoint 228 feet back from the bow, 75 feet behind the center of gravity, and 46 feet above the water. There is a card describing the ship's characteristics on the bridge.

The 80,000 dwt tanker. The ship is 763 feet long with a 125-foot beam and [illegible]-foot draft. It has a rear house that puts the eyepoint 732 feet back from the bow, 300 feet back from the center of gravity, and 80 feet from the water. There is a card describing the ship's characteristics on the bridge.

Maneuvering instructions. When you take control, please move the ship to the centerline as quickly as you think prudent. Stay as close to a strictly defined "centerline" as you think practical. You may leave the centerline when you decide it is necessary for the approach to a turn. Use your own strategy to negotiate the turn. You may increase the speed in the turn if you think it is necessary. Please return to the original speed as soon as possible.

C.3 THE CHANNEL AND THE ENVIRONMENTAL CONDITIONS

The attached figures illustrate the general channel layouts for the various scenarios as well as pertinent environmental conditions and maneuvering instructions. These charts will be available to you on the bridge.

The channel s 500 feet wide with a minimal depth for each ship. The scenarios include shallow water effects but no bank effects.

The current at the beginning of the run has a set of 341 degrees T and a drift of 1.4 knots. It moves up the first leg of the channel, decreasing to 0.7 knots at the completion of turn. The current is broad on the port quarter at the turn pullout, the gradually turns to follow the second leg of the channel. The current continues to decrease until the end of the run.

There is a gusting wind averaging 30 knots throughout the scenario. Its direction averages 166 degrees T during the turn.

The visibility for the scenarios will vary from 1-1/2 nm to 0 nm according to the requirements of the scenario.

Appendix B

RADAR 1: POSTSIMULATION QUESTIONNAIRE

1. Realism of the Radar

1.1 Was the radar sufficiently realistic to function as radar should? If not, what would you like to see changed?

2. The 1-1/2 nm Visibility/Radar Scenarios (Scenarios 5 and 6)

2.1 Did you make use of the radar? For what purpose?

2.2 What features of the radar did you use? What influenced your choice?

2.3 Did its use affect the ship tracks compared to visual-only piloting?

2.4 How did your use here compare to at-sea use?

3. The 1/4 nm Visibility/Radar Scenarios (Scenarios 1, 2, 3, 4)

3.1 What features of the radar did you use? How did you use them? What influenced your choice?

3.2 Would you expect the ship track to look different than it would in longer visibility? Would this be true for both two- and three-buoy turn arrangements? For both size ships?

3.3 Would you have conducted transits like these at sea? What would you have done? Would ship size matter?

4. The Zero Visibility/Radar Scenarios (Scenarios 7, 8, 9)

4.1 What features of the radar did you use? How did you use them? What influenced your choice?

4.2 Would you expect the ship track to look different than it would with some visibility? Would this be true with both high- and the low-buoy density? Would this be true for the larger and the smaller ship?

4.3 Would you have conducted transits like these at sea? What would you have done? Would ship size matter?

5. Radar Use At Sea

5.1 When and why do you typically use radar at sea? What factors influence your use? What techniques do you use?

5.2 Do you ever use a course cursor? When and why?

5.3 Do you ever use parallel plotting? When and why?

5.4 Do you have much experience with racons? What kind? How do you use them?

5.5 How would you like to see the Coast Guard use racons?

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