CAORF TECHNICAL REPORT

THIMBLE SHOAL STUDY
FINAL REPORT

- Draft -

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EXECUTIVE SUMMARY

INTRODUCTION

The Virginia Port Authority has initiated a large multi-phase program to improve facilities in the greater-Norfolk Harbor, including the ports of Hampton Roads, Newport News, Norfolk, and Portsmouth. The expansion plans address a variety of landside facilities and waterways, to improve the capacity and efficiency of moving cargo through the port. One major focus is to improve the facilities and infrastructure to effectively accommodate the modern large deep-draft container vessels.

One element of the port improvement program is the incremental deepening of the Thimble Shoal Channel (TSC) in Chesapeake Bay, which is being managed by the U.S. Army Corps of Engineers, Norfolk District (ACOE-ND). Initial plans are for the inbound lane of this channel to be dredged to a depth of 50’, matching the existing depth of the outbound lane. This would accommodate the needs of deep draft containerships calling on the port.

The purpose of this study was to evaluate the configuration of the TSC dredged to a 50’ depth, when used by a large fully loaded inbound containership. This report describes the methodology, findings, conclusions and recommendations of a man-in-the-loop simulation study, which was sponsored by the ACOE-ND. The study was conducted by the Computer Aided Operations Research Facility (CAORF), U.S. Merchant Marine Academy (USMMA), Kings Point, NY.

METHODOLOGY

The evaluation was performed using data collected during simulated transits in both the existing and deepened Thimble Shoal Channels. The evaluation was based on comparing the simulated transits of the fully loaded S-Class ship (i.e., new design vessel) in the proposed deepened channel, with those of the largest containership that currently visits the port (i.e., a partially loaded S-Class ship, the baseline vessel). Transits in the baseline vessel provided the standard of acceptable performance, against which the new design was compared.

One senior Virginia Pilot controlled the inbound ships from the bridge of the CAORF simulator, in all of the simulated transits. Questionnaire data were collected from the pilot before, during and after the series of simulated transits, to augment the simulator generated data.

A series of 29 simulated transits were conducted, 8 in the baseline vessel (partially loaded S-Class ship), 20 in the new design vessel (fully loaded S-Class ship), and one in a smaller auxiliary oiler. A total of 25 out of these 29 runs were used for descriptive statistical analysis. The primary test conditions consisted of worst credible wind (50 knots) and current (1.5 knots) from the starboard beam, and abaft of the beam; calm conditions were also simulated in some baseline transits. The baseline TSC was a simulation of the existing channel, with a minimum depth of 45’ in the inbound lane, and 50’ in the outbound lane. The new design channel consisted of the existing channel uniformly deepened to 52’

The data analyzed included objective data from each simulated transit, and pilot judgments. The findings and conclusions of this study are based on the judgments of the Norfolk pilot in collaboration with the CAORF staff, and as interpreted by the CAORF staff.

FINDINGS

The evaluation was performed in three parts: 1) channel navigation, 2) meeting and passing, and 3) channel depth.

Channel Navigation. The fully loaded S-Class ship (new design vessel) was found to handle better than the partially loaded S-Class ship (baseline vessel) under the severe wind and current conditions. However, the two ships were judged to be approximately equivalent from a pilotage standpoint, since the partially loaded ship was able to transit at a higher speed and thus attain equivalence in controllability.

Meeting and Passing. The pilot was able to adequately control the fully loaded S-Class ship, under the severe wind and current conditions, to successfully meet and pass the large outbound ship in multiple transits. Although some differences were noted between the fully loaded and partially loaded S-Class vessels, on balance the performances with both vessels were approximately equivalent. On this basis, the evidence suggests that the safety of meeting and passing a large outbound ship is equivalent for fully loaded and partially loaded S-Class ships under severe wind and current conditions.

Although this investigation was not designed to address the width of the TSC, but rather to investigate the comparative performances of the fully loaded and partially loaded S-Class ships, some evidence was found to suggest that passing distances achievable between large ships in the TSC are less than the lower acceptable safety margin identified by pilots (Note, only a single pilot participated in this investigation). This finding pertains to the current situation with large ships transiting the TSC under severe wind and current conditions, as well as after the proposed TSC modifications.

Channel Depth. Channel depth was not originally an issue of investigation for the evaluation. However, during validation and screening runs it became apparent that the fully loaded S-Class ship would not be able to transit at the higher speeds desired by the pilot, due to a potential for grounding in the channel. In fact, calculations showed the amount of squat attained by the fully loaded S-Class ship (i.e., with a draft of 47’) would cause the ship to ground in a 52’ deep channel before it reached a speed of 14 knots. Furthermore, the slim under the keel clearance (UKC) at 12 knots would often cause this large ship to ground on the simulator, due to roll and pitch associated with the severe wind and current conditions, as well as the large rudder control activities. Even at 10 knots, the speed at which many of the test transits were made, the ship grounded after passing the traffic ship due to the roll associated with the ship-to-ship interaction. Note, however, that subsequent analysis revealed that the ship model produced greater roll from the passing interaction than should occur at sea.

The high propensity to ground that was experienced in the simulated transits was likely exaggerated, due to insufficient roll damping. Furthermore, limitations in the hydrodynamic ship simulation models at the very shallow water conditions investigated by this study, may overstate the propensity to ground at sea. Nevertheless, the very limited UKC presents a real risk of grounding in conditions that may cause substantial rolling or pitching.

CONCLUSIONS

The inbound transit of the fully loaded S-Class ship is concluded to be safe, since its control was equivalent to that of the partially loaded ship, meeting the criteria of relative safety (i.e., New design compared with the baseline of safety).

The criterion of safety traditionally accepted in simulation studies is the comparative performance of the new design (i.e., new ship and waterway characteristics) with the baseline design (i.e., existing ship and waterway characteristics). The baseline design is considered safe, by default, since it has performed acceptably in the past and continues without question today. This relative measure of safety, which is considered the most valid typically available, enables data to be collected for comparative evaluation of safety. On this basis, it is concluded that transits of the fully loaded S-Class ship in the 52' deep TSC should be acceptably safe, with regard to channel navigation. The safety associated with the potential of this vessel grounding is an important, but separate, issue.

The results of this study suggest that the proposed TSC modification will be safe for bringing fully loaded S-Class ships into Norfolk Harbor under wind conditions up to 30 knots. At severe wind conditions (i.e., above 30 knots) the safety of an inbound transit in the fully loaded S-Class ship should be considered marginal, with caution exercised in making the decision to bring the ship in. This is due to a potential for grounding in a 52' deep channel, resulting from the very limited UKC and the potential for the ship to roll and/or pitch, particularly when meeting/passing another large ship.

The results further suggest that transits of large ships of the S-Class size are marginal today, when meeting/passing a large traffic ship under severe cross wind and current conditions (i.e., winds above 30 knots). The width of the existing TSC is concluded to be adequate under most circumstances, but marginal for very large ships meeting and passing under cross winds above 30 knots.

RECOMMENDATIONS

1. The ACOE should proceed with the current plans for dredging the TSC to a depth of 50 feet.

2. If funding is available, the TSC should be dredged to a depth greater than 50 feet (e.g., 52 feet), to provide a greater margin of safety from in-channel grounding by very large ships, such as the fully loaded S-Class ship.

3. With additional funding availability, the channel should be made wider (e.g., 1,200 feet) to provide a better margin of safety for piloting large ships under severe wind and current conditions.

4. The potential for the fully loaded S-Class ship to ground in the proposed TSC should be thoroughly investigated, to definitively determine the likelihood of grounding as a function of the following factors: a) wind, current and wave conditions; b) own ship speeds; c) meeting/passing conditions; and d) channel depths.

5. Information should be compiled and disseminated to appropriate organizations and persons (e.g., pilots, ship operators), providing guidance regarding the hazards associated with bringing large deep draft ships into the harbor under severe wind and current conditions. This should address a) the potential for grounding and its causal factors; and b) ship control issues under severe wind and current conditions.

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A. INTRODUCTION

The Virginia Port Authority has initiated a large multi-phase program to improve facilities in the greater-Norfolk Harbor, including the ports of Hampton Roads, Newport News, Norfolk, and Portsmouth. The expansion plans address a variety of landside facilities and waterways, to improve the capacity and efficiency of moving cargo through the port. One major focus is to improve the facilities and infrastructure to effectively accommodate the modern large deep-draft container vessels. This includes modification to port waterways to enable deep draft cargo vessels to safely enter and transit (O'Brien, 2000).

One element of the port improvement program is the incremental deepening of the TSC, which is being managed by the U.S. Army Corps of Engineers, Norfolk District (ACOE-ND). The deepening is required to allow inbound deep draft vessels to fully serve the ports. The current work effort is to support deepening the navigation system inbound lane to 50 feet. Ship simulation is required to evaluate existing channel operability for future vessels.

The purpose of this study was to evaluate the configuration of the TSC dredged to a 50' depth, when used by a large fully loaded inbound containership. This report describes the methodology, findings, conclusions and recommendations of a man-in-the-loop simulation study, which was sponsored by the ACOE-ND. The study was performed by the Computer Aided Operations Research Center (CAORF), U.S. Merchant Marine Academy (USMMA), Kings Point, NY. The data were generated by an experienced Virginia Pilot making simulated transits in the existing and deepened Thimble Shoal Channels, conducted on a ship bridge simulator, and from questionnaire responses associated with those transits. This work is the first of several simulation studies planned to assist with the Norfolk Harbor expansion program.

B. BACKGROUND

B.1 NORFOLK HARBOR DEEPENING PROJECT

The Norfolk Harbor Deepening Project has brought together organizations with common interests in local harbor improvements, representing a closely coordinated effort. The involved organizations include:

Independent Docking Pilots
McAllister Towing
Moffatt & Nichol Engineers
Paradigm Associates
U.S. Army Corps of Engineers, Norfolk District
U.S. Army Corps of Engineers, Engineer Research and Development Center Hydraulics Lab
U.S. Coast Guard, Fifth District – ATON
U.S. Coast Guard, Marine Safety Office, Hampton Roads
U.S. Naval Station Docking Pilots
U.S. Navy
U.S. Merchant Marine Academy, Computer Aided Operations Research Facility
U.S. National Oceanographic and Atmospheric Administration
Virginia Pilot Association
Virginia Port Authority

The overall project includes plans for deepening portions of the Atlantic Ocean channel, Chesapeake Bay, and the Norfolk Inner Harbor. It also includes plans for extensive modification of terminal, highway and rail facilities affecting several ports in the Norfolk area, and the eastward expansion of Craney Island to accommodate a new port facility. The Norfolk Navy Base has plans, in parallel, to upgrade and extend piers. The overall Norfolk Harbor Deepening Project has many elements, several of which will be addressed with simulation.

This report addresses the first of the simulation-based studies to be performed at CAORF, USMMA, Kings Point, NY. It addresses plans to deepen the inbound side of the TSC, in the Chesapeake Bay.

B.2 THIMBLE SHOALS CHANNEL DEEPENING

The TSC is a 1,000' wide waterway in Chesapeake Bay, stretching 11.7 miles from a point 4 miles east of Old Point Comfort toward the entrance of Chesapeake Bay at Cape Henry, Virginia. The outbound lane of the channel was deepened to 50', to accommodate a new class of coal colliers, in the aftermath of the early-mid 70's oil crises. This resulted in an asymmetrical channel design: the outbound lane being 50' deep, and the inbound lane with a minimum depth of 45'. This design, which was deemed feasible as a result of simulation studies, was a cost-effective approach to meet the port's needs at that time. Where-as the fully loaded outbound colliers required 50' of depth, the ballasted inbound coal colliers drew less water and did not require additional channel depth.

Recent years have witnessed the growth in size of containerships. The Maersk Lines Suez-Class (S-Class) containerships, for example, have an overall length of 1,138 ft, a beam of 141', and a draft of 47' when fully loaded. At the present time, large containerships visiting Norfolk have been restricted to a draft of about 38', which requires the large deep draft containerships to be only partially loaded when entering and leaving Norfolk Harbor. A major factor underlying the port improvement program is the need to fully accommodate the new large deep draft classes of containerships. Large containerships have been brought into Norfolk Harbor, occasionally in the past, but not on a regular basis. And, they have not been brought in fully loaded.

The TSC deepening project under investigation proposes to increase the channel depth to 50’ (with 2 feet of additional margin), with no change in channel width. The simulation study is required to evaluate the configuration of the existing channel when used by the design vessel.

C. PROBLEM

The objective was to evaluate the configuration of the TSC for bringing fully loaded S-Class vessels into Norfolk Harbor, after the inbound side of the channel is deepened to 50'. More specifically, the objective was to verify the safety of a fully loaded S-Class vessel making an inbound transit under exceptionally difficult conditions. Discussions with the Virginia Pilot Association (VPA) indicated that the proposed TSC design was adequate for inbound transits of fully loaded S-Class vessels. Hence, the emphasis was on verifying the proposed TSC design, rather than determining the channel parameters.

Discussions between the ACOE, VPA and other port representatives, and CAORF staff, identified the focus of the simulator study. This was to examine the ability to control a fully loaded inbound S-Class vessel under extreme environmental conditions, with regard to maintaining its track in the TSC, and passing a large outbound vessel. The issues concerned the ability to control the vessel (e.g., rudder and rpm), to achieve an adequate safety margin with the channel boundary and with the meeting vessel while passing.

D. METHODOLOGY

D.1 APPROACH OVERVIEW

Discussions with the ACOE-ND and Engineer Research and Development Center (ACOE-ERDC) Hydraulics Lab, and the VPA indicated that the TSC, after deepening to the proposed 50', was expected to be adequate for bringing fully loaded S-Class vessels into Norfolk Harbor. The level of safety was expected to be equivalent to that experienced today when transiting the TSC. Hence, an approach was devised to enable a Norfolk pilot to verify the expected safety of the TSC passage, by making real-time simulated transits in a deepened TSC on the CAORF ship bridge simulator. The following points summarize this approach:

- The analysis approach was based on having a single Norfolk pilot making simulated inbound transits under the worst credible conditions. Using a single senior pilot was considered a cost-efficient method for verification of a proposed channel modification that was generally believed as adequately safe for bringing large vessels into Norfolk Harbor.

- Verification of the TSC safety would be based on the judgments of the pilot, after completing the simulated transits. The pilot's judgments of TSC safety would, therefore, be based on his at-sea experience piloting vessels in the Norfolk Harbor area, and his experience piloting the S-Class vessels in the modified TSC on the CAORF simulator.

- Previous research has suggested that the safety of a channel design can be evaluated by comparing the transit performance under design conditions (i.e., inbound transit of a fully loaded S-Class ship in the proposed deepened TSC), with performance of familiar ships in the existing channel (i.e. inbound transit of the most difficult vessel currently entering Norfolk Harbor, using the existing TSC). Transit performance in the partially loaded S-Class ship in the TSC, therefore, represents a criterion of acceptable safety. Comparison of transit performance between the fully loaded and partially loaded S-Class ships, together with pilot judgments, formed the basis of the study conclusions.

- The worst credible conditions to be investigated were determined during meetings with the ACOE-ND and pilots. These conditions were modified during the data collection, in accordance with experiences during the simulated transits. This enabled focusing on issues of importance.

- The worst credible conditions investigated consisted of strong cross-wind (40, 50 and 60 knots), strong cross-currents (up to 1.5 knots), and the situation of meeting and passing a large outbound vessel. The Norfolk pilot was constrained to transit at one of several pre-determined own ship speeds.

- A 52' deep TSC was used in the simulated transits, to represent the deepened channel design. This includes the nominal 50' channel depth, plus an additional 2' in accordance with the expected contract dredging requirements (e.g., advanced maintenance).

- Data were collected during each simulator transit. A debriefing session was conducted immediately after each transit, during which the pilot and CAORF staff investigated/discussed the own ship performance and related factors of the transit. The pilot filled out a questionnaire after each transit, documenting his judgments regarding that transit. The pilot filled out a summary questionnaire after completing all of the transits; this questionnaire is the primary information source for conclusions regarding the planned TSC deepening.

- The findings and conclusions of this study are based on the judgments of the Norfolk pilot in collaboration with the CAORF staff, and as interpreted by the CAORF staff.

The remaining parts of this section provide details of the methodology.

D.2 ANALYSIS APPROACH

D.2.1 Test Plan

The TSC test plan, which resulted from discussions with the ACOE and VPA, was designed to run one Norfolk pilot in multiple inbound transits, under worst credible conditions. This plan would allow the pilot to experience transiting the TSC in the fully loaded S-Class ship, under extremely difficult conditions. His experiences during the transits, together with descriptive information generated by the simulator and CAORF staff during each transit, would allow the pilot to render valid judgments about the proposed TSC design.

The test plan included the following elements:

- The conditions to be investigated were determined during discussions with the ACOE, pilots and other port representatives. These were later modified as a function of discussions with the test pilot, and experiences during simulated transits. The test conditions are addressed later in this section.

- A series of pre-planned data collection runs were made, after which additional data collection runs were conducted in accordance with the findings from preceding runs. The additional runs comprised approximately 2/3 of all runs. The methodology integrated the data collection and analysis functions, such that findings were developed after each run, leading to specification of subsequent run conditions, and so on. Hence, the data collection and analysis was largely a real-time process, based on the judgments of the pilot and CAORF staff following each scenario run.

- The planned procedure was to conduct and evaluate the test transits (i.e., fully loaded S-Class ship transiting the proposed TSC deepened to 50') on the basis of safety criteria. The safety criteria include minimum distance to the channel boundary, and minimum distance to the meeting vessel while passing (i.e., closest point of approach [CPA]). In addition, the relative performance of the test transits was compared with similar baseline transits (i.e., current large vessel transiting the existing TSC, which is at least 45' deep on the inbound side).

- A series of simulator runs were planned, as follows, each of which is addressed further in Sec. D.2.4:

    - Validation runs
    - Familiarization runs
    - Screening runs
    - Test runs: Baseline transits
Design transits

- The evaluation of the safety of the proposed TSC modification was to rely primarily on the pilot's judgment, based on his experiences during the simulated transits, and augmented with the simulator-collected data. CAORF staff, including experienced US Merchant Marine Academy faculty, met with the pilot immediately following each transit to discuss the transit results.

- Pilot judgments were captured in questionnaires, administered prior to simulator involvement, after each simulator run, and after all simulator runs were completed. These questionnaires are a major source of test data.

- Objective data were generated by the simulator during each transit, at 5-second intervals. These consisted of a wide range of ship and waterway parameters. Examples are: own ship speed, heading, course, rudder angle, engine rpm, position, and depth under the keel; data on other vessels, such as position, course, and speed; and environmental conditions, such as wind direction and velocity. Selected data were analyzed to identify potential performance trends, including calculation of descriptive statistics. It should be noted, that one transit was made under each combination of conditions, and one pilot participated in all transits. Hence, inferential statistical analysis was not performed.

The following sections provide details of the test plan elements.

D.2.2 Test Conditions

In accordance with the objectives of the study (i.e., evaluation of inbound S-Class ship in the proposed TSC), the test conditions were selected to provide most difficult situation for the pilot. The worst credible conditions were determined on the basis of: 1) worst credible environmental conditions under which the S-Class may transit the TSC (e.g., highest wind speed); 2) the most difficult configuration of those environmental conditions (e.g., wind direction); 3) the most difficult traffic situation that would likely be encountered during the TSC transit (i.e., passing a large outbound vessel which is crabbing and crowding toward channel center line); and 4) the most difficult own ship configuration (e.g., speeds).

Simulated transits conducted with the fully loaded S-Class inbound in the proposed TSC channel (i.e., channel depth of 52') were designated as *design* scenarios. Simulated transits conducted with a partially loaded S-Class inbound in the present TSC configuration (i.e., minimum of 45' depth at Mean Lower Low Water [MLLW] level) were designated as *baseline* scenarios.

The Norfolk Harbor pilot made 29 inbound test transits in the TSC, in addition to validation, familiarization and screening runs. Three transits were made under unique conditions (e.g., no traffic ship, T-AO own ship) that were not readily comparable with the other test transits, and therefore were not included in the analysis. The data were lost for a fourth test transit, which also was not included in the analysis. Table 1 presents a summary of the initial conditions for each of the 25 baseline and test scenarios that were analyzed in this report.

In all scenarios the inbound vessel was an S-Class, at a draft of either 38' (baseline) or 47' (design). The own ship transited at several speeds, as indicated in the table. The channel depth corresponded to the ship draft: 1) Baseline scenarios had the current TSC depth, which was 45' or greater; and 2) Design scenarios had a TSC depth of 52', with three scenarios run at depths greater than 52'. In all scenarios, a large outbound vessel (Collier or S-Class) was met and passed in the TSC. The outbound S-Class was fully loaded (47' draft), as was the Collier (50' draft). Several outbound vessel speeds were investigated. Several wind conditions were investigated, including velocity and direction, with corresponding current conditions. Four baseline transits were made under current conditions specified in TSC data collected by ACOE-ERDC; these were conducted under calm wind conditions.

Table 1. Scenario Initial Conditions.

Scenario Number	Scenario Type	Channel Depth [ft]	Environment		Own Ship (Inbound)			Traffic Ship (Outbound)		
			Wind from (Spd / Dir) [kts/deg]	Current to (Spd / Dir) [kts/deg]	Vessel	Draft [ft]	Speed [kts]	Vessel	Draft [ft]	Speed [kts]
1	Baseline	45+	50 / 045	1.5 / 225	S-Class	38	12	Collier	50	8
2	Design	52	50 / 045	1.5 / 225	S-Class	47	10	Collier	50	8
3	Design	52	50 / 045	1.5 / 225	S-Class	47	10	S-Class	47	10
4	Baseline	45+	50 / 045	1.5 / 225	S-Class	38	12	Collier	50	10.5
5	Design	52	50 / 045	1.5 / 225	S-Class	47	10	Collier	50	10.5
6	Design	52	50 / 045	1.5 / 225	S-Class	47	10	S-Class	47	8
7	Baseline	45+	50 / 017	1.5 / 198	S-Class	38	12	Collier	50	8
8	Design	52	50 / 017	1.5 / 198	S-Class	47	10	S-Class	47	8
9	Design	52	50 / 017	1.5 / 198	S-Class	47	10	Collier	50	10.5
10	Design	52	50 / 017	1.5 / 198	S-Class	47	10	S-Class	47	10
11	Design	52	50 / 017	1.5 / 198	S-Class	47	9	S-Class	47	10
12	Design	52	50 / 017	1.5 / 198	S-Class	47	8	S-Class	47	10
13	Design	52	50 / 017	1.5 / 198	S-Class	47	8	Collier	50	10.5
14	Design	54	50 / 017	1.5 / 198	S-Class	47	10	S-Class	47	10.5
15	Design	54	50 / 017	1.5 / 198	S-Class	47	8	S-Class	47	10.5
16	Design	56	50 / 017	1.5 / 198	S-Class	47	8	S-Class	47	10.5
17	Design	52	40 / 045	1.2 / 225	S-Class	47	8	S-Class	47	10
18	Design	52	40 / 045	1.2 / 225	S-Class	47	8	S-Class	47	10
19	Design	52	40 / 045	1.2 / 225	S-Class	47	8	S-Class	47	8
20	Design	52	40 / 045	1.2 / 225	S-Class	47	8	Collier	50	8
21	Design	52	40 / 045	1.2 / 225	S-Class	47	8	Collier	50	10.5
22	Baseline	45+	Calm	ERDC DB	S-Class	38	16	Collier	50	10.5
23	Baseline	45+	Calm	ERDC DB	S-Class	38	16	Collier	50	10.5
24	Baseline	45+	Calm	ERDC DB	S-Class	38	14	Collier	50	10.5
25	Baseline	45+	Calm	ERDC DB	S-Class	38	14	Collier	50	10.5

Table Key:

DB	Data base	ft	Feet
deg	Degrees	kts	Knots
Dir	Direction	Spd	Speed
ERDC	Engineer Research and Development Center		

The first 6 scenarios in Table 1 were the pre-planned data collection runs, with the original conditions modified as a result of the screening runs and discussions with the Norfolk pilot. The order of the first 6 scenarios was randomized, to minimize learning effects (i.e., ship, scenario conditions, simulator). The remaining 19 scenarios were conducted to investigate aspects of interest stemming from preceding scenario transits. The test conditions are explained further in the following subsections:

Scenario Situation
S-Class Own Ship
Outbound Traffic Ship
Thimble Shoal Channel
Wind and Current

It should be recognized that the difference between the proposed TSC channel depth simulated (i.e., 52') and the draft of the fully loaded S-Class ship (i.e., 47') is extremely small. This under the keel clearance of 5' is further reduced in proportion to the own ship speed. At 12 knots, for example, bow squat is greater than 3', reducing the UKC to less than 2'. This UKC severely strains the ability of simulation models to accurately predict the ship's behavior in six degrees of freedom. Furthermore, calculations show that a roll angle of only 1.6 degrees will result in the shoulder of a 140' beam flat-bottomed hull to touch ground when the UKC is 2'. The conditions of the scenarios were extreme, including own ship heeling due to the strong wind and the necessary application of large rudder angles; and own ship rolling due to the interaction between the two large vessels when passing close by. The squat was an issue of "theoretical" concern prior to the start of simulator runs. However, the severity of the squat and rolling were not fully appreciated until real-time transits were made with the pilot on the simulator. This early finding affected the conditions to be investigated (as explained throughout this section), and was an important result of the study (The potential of grounding is addressed in Section E, Findings).

Scenario Situation. The test scenario was designed with own ship as a fully loaded S-Class vessel; inbound in the TSC under the worst credible wind and current conditions; meeting head-on, and passing, a large outbound traffic ship in the area between buoy pair #9 and #10, and buoy pair #13 and #14. This location was selected by the VPA because of relatively shallow water outside the channel, thus locating the test situations in a less-forgiving area of the TSC. The transits occurred during daylight hours, with good visibility. The focus of the scenario was to maintain own ship course in the channel while approaching the outbound traffic ship, and to successfully pass the outbound ship.

It was decided during the screening runs that the two ships should be positioned about 3 miles apart at the start of each scenario, which would allow sufficient time for the pilot to establish a stable course in the TSC, and position own ship for the passing situation. The passing situation occurred between about 6 and 11 minutes into the scenario, depending on the speeds of both ships.

S-Class Own Ship. The own ship, which was brought inbound in the TSC by the Norfolk pilot, was an S-Class vessel. Two configurations were run:

- S-Class partially loaded, with a 38' draft.
  This ship was used in the baseline transits (see D.2.4 Simulator Runs, Baseline Transits).

- S-Class fully loaded, with a 47' draft.
  This ship was used in the design transits (see D.2.4 Simulator Runs, Design Transits).

Two own ship speeds were planned to be investigated in the test transits, 8 and 12 knots. These speeds were selected to represent the likely minimum and maximums that the fully loaded S-Class vessel would use under the scenario conditions. The screening runs showed that the originally-planned 8-knot speed was not feasible (i.e., the fully loaded S-Class ship was not adequately controllable at 8 knots under the 60 knot wind condition), hence the minimum own ship speed was raised to 10 knots. In addition, the pilot would have preferred transiting at a higher speed (e.g., 16 knots) to achieve better controllability.

However, the screening runs showed that the squat of the fully loaded S-Class in the proposed 52' depth TSC, under the very strong wind and current conditions to be investigated, would preclude a speed of even 12 knots (i.e., the ship would hit bottom on the simulator due to heel and roll). Hence, the initial design condition test transits were made at a speed of 10 knots. The pilot was requested to transit close to this initial speed, although he could modify the speed if he wanted. The pilot usually maintained the initial speed, with small variations up or down.

Note, some later transits were made at an 8-knot speed under 40 knot and 50 knot wind conditions.

Outbound Traffic Ship. The scenarios were conducted with two types of outbound ships, meeting own ship head-on in the TSC:

- Collier (coal carrier) fully loaded, with a 50' draft, and speed of either 8 or 10.5 knots. This ship was used in both the baseline and design transits.

- S-Class fully loaded, with a 47' draft, and speed of either 10 or 12 knots. This ship was used in the design transits only.

The speeds of the outbound ships were determined in discussions with the ACOE and VPA, and with the test pilot during validation and screening runs on the simulator. These speeds were selected to represent the likely minimum and maximums that the outbound vessel would use under the scenario conditions, in accordance with creating worst credible situations for the inbound ship. The outbound side of the TSC is currently dredged to 50'; however, grounding was not an issue of investigation for the scripted outbound traffic ship.

The track of the outbound traffic ship was scripted (predetermined), such that it often crabbed with its bow near the channel centerline until shortly before meeting own ship. Immediately prior to the passing situation, the traffic ship moved closer to the channel boundary to facilitate the passing of the two vessels, as would typically occur at sea.

Thimble Shoal Channel. The Thimble Shoal Channel is illustrated in Figure 1, showing the straight channel with an inbound alignment of 288°. The North Auxiliary and South Auxiliary channels are shown in the figure alongside the TSC. Relevant aids to navigation are indicated by dots and squares, in their respective colors. The primary gaming area of the scenario is outlined, with each buoy identified by number. The approximate own ship starting position in all scenarios was on the inbound side of the TS channel, inside the gaming area boundary to the right of buoy pairs #9 and #10. The corresponding starting position of the traffic ship was on the outbound side of the TS channel, inside the gaming area boundary to the left of buoy pairs #13 and #14. The Chesapeake Bay Bridge-Tunnel is shown to the right of the gaming area, extending to near the channel. The coast of Virginia, including the area around the Little Creek inlet, is shown in the lower area of Figure 1. The two meeting ships passed near buoy pair #11 and #12.

The scenarios were conducted in two TSC configurations, with only the channel depths differing for each. The baseline transits were conducted using the existing TSC configuration, which had varying depths in the relevant channel areas (i.e., a minimum depth of 45', and often deeper). The design transits were conducted using the proposed TSC configuration, with a constant depth of 52'. The proposed TSC is expected to be designated as a 50' deep channel, with advanced maintenance and dredging margins that will yield a 52' channel depth (USACOE, 1995). The use of the additional 2' of depth (i.e., 52' depth, rather than 50' depth) was critical to the study, since the fully loaded S-Class would have otherwise grounded on the simulator. As noted previously, the UKC for the design vessel (fully loaded S-Class with a 47' draft) is very small, especially when moving, due to squat effects.

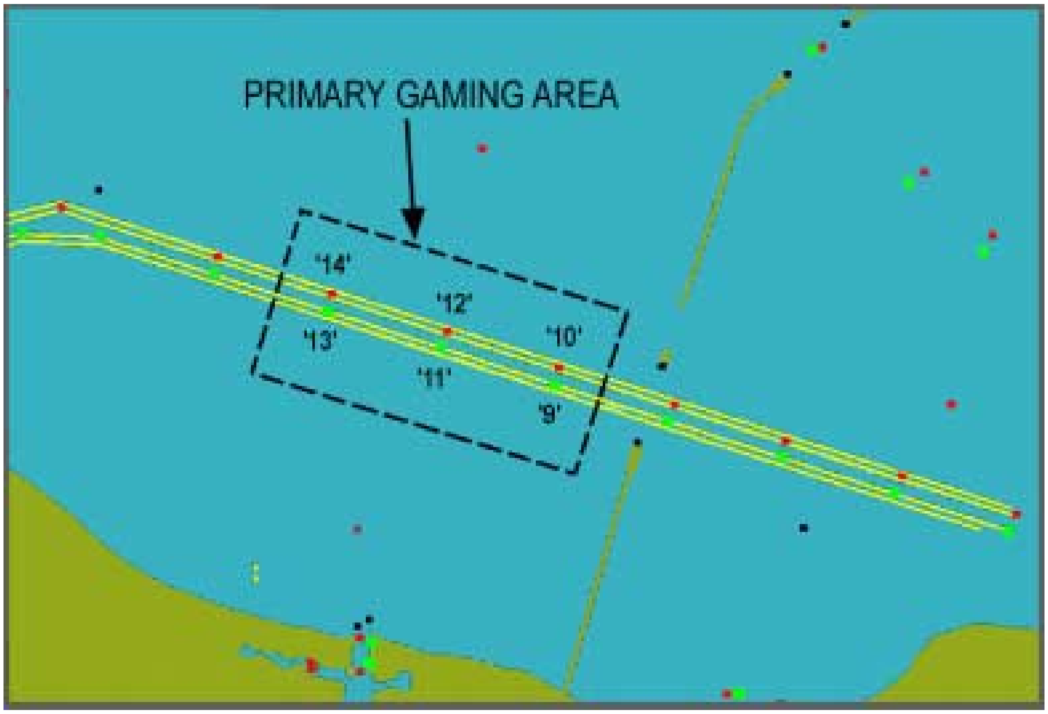

Figure 1. Thimble Shoal Channel

Wind And Current. The original test plan called for a wind velocity of 60 knots, from the north, as the worst credible condition. This velocity was later reduced to 50 knots after discussion with the Norfolk test pilot, the ACOE-ND representative, and experience with the S-Class ship in screening runs. The wind direction was also modified, to originate from the northeast (i.e., 045°). Later transits were made under several different wind conditions, such as strong winds from approximately the north-northeast (017° exactly), placing the wind perpendicular to the axis of the TSC (See Table 1).

A wind-driven current was simulated in each scenario representing the most credible adverse environmental conditions. The current's direction was in parallel with the wind; current speed was calculated to be in proportion to the wind speed (Wiegel, 1964). A current velocity of 1.5 knots was used with the 50 knot wind during baseline and design transits, with correspondingly less current under other wind conditions. Actual TSC current data were collected by ACOE-ERDC, and used during baseline transits under calm wind conditions. Table 1 lists the current directions and velocities for each run/transit.

D.2.3 Norfolk Pilot

All simulator runs were made by an experienced senior Norfolk pilot (i.e., holding an unlimited qualification for 10 years). Although this pilot did not have experience with a S-Class ship, he has had extensive experience with piloting many types and sizes of vessels into and out of Norfolk Harbor. He has piloted fully loaded coal colliers (50' draft) outbound through the TSC, numerous times. Importantly, his experience has included piloting large containerships under the worst credible conditions to be investigated in this study (e.g., under 55 knot winds, requiring extreme crabbing angles). The Norfolk pilot demonstrated a high level of piloting skill during the runs, as evidenced by his ability to control the vessel under the extreme conditions; and he provided substantial guidance in interpreting performance, and reaching conclusions about the proposed TSC design.

D.2.4 Simulator Runs

A large series of simulator runs were conducted with the Norfolk pilot. These were divided into five categories, as noted earlier. Each category of runs is explained below.

Validation Runs. The initial activity with the Norfolk pilot was validating the simulation: visual and radar data base, wind and current conditions, and the S-Class handling characteristics. Over a dozen validation runs were conducted to assure the simulation characteristics were appropriate for the study objectives. Refinements were made to improve various elements of the simulation, based on pilot expertise. Validation of the simulated S-Class characteristics was performed, focusing on:

- Open sea handling
- Effects of wind
- Effects of current
- Handling in a channel: Bank
Shallow water
Meeting/passing

For example, the S-Class vessel was initially operated in an open-sea deep water data base to evaluate the ship's response to rudder and throttle commands; wind and current effects were then evaluated; and, finally, the ship was operated in shallow water conditions, including meeting/passing large vessels. Refinements were made, as a result of the validation work, to the S-Class model and environmental conditions (i.e., wind and current). The visual scene and radar data bases were adequate as designed. The validation was performed with the assistance of the Norfolk pilot who participated in the subsequent test transits.

Familiarization Runs. The test pilot is usually familiarized with the simulator (e.g., bridge equipment, general simulator environment) prior to participating in the test runs. In this study, the familiarization and validation functions were accomplished together, since the pilot assisting with the validation work was also the pilot who made the test transits.

Screening Runs. A series of six screening runs were originally planned, to finalize the conditions to be investigated during the test transits. The screening runs took place in the TSC, investigating various conditions and their effects on the transit scenario. Over a dozen screening runs were actually required to finalize the test conditions. This was due to issues that arose concerning the wind and current conditions, squat and grounding in the extreme shallow water condition of the proposed TSC, own ship crab angle required to transit the TSC, and own ship speed with regard to S-Class controllability. For example, the initial conditions specified a wind velocity of 60 knots from the north. This wind velocity, during the screening runs, was determined to be beyond the reasonable maximum for bringing an S-Class into Norfolk Harbor. The controllability of the ship was not acceptable under this wind condition. Hence, a worst credible wind velocity of 50 knots was selected.

Modifications to scenario conditions were made, as a result of the screening runs, including: wind velocity and direction; current velocity and direct; and own ship speeds. The test conditions are presented in Section D.2.2 Test Conditions.

Baseline Transits. Previous research has suggested that the safety of a channel design can be evaluated by comparing the transit performance under design conditions (i.e., inbound transit of a fully loaded S-Class ship in the proposed deepened TSC), with performance of familiar ships in the existing channel (i.e., inbound transit of the most difficult vessel currently entering Norfolk Harbor, using the existing TSC). Vessels entering Norfolk Harbor today, using the existing TSC, represent the baseline of acceptable safety. Performance differences between baseline transits and design transits would indicate potential safety differences.

The screening runs modified the baseline conditions such that only two baseline transits were subsequently planned (i.e., one inbound own ship speed, and two outbound collier speeds). The order of the planned baseline and design transits was randomized, to reduce the learning effects that would likely occur as the pilot gains experience when making transits on the simulator. After the 6 planned transits were completed, additional baseline and design transits were conducted to investigate issues stemming from the preceding transits. These included one baseline transit with a smaller Navy Fleet Oiler (This scenario is not listed in Table 1). The baseline transit conditions are presented in Section D.2.2 Test Conditions.

Design Transits. The design transits provided the information about the proposed TSC design. They were conducted with the pilot controlling a fully loaded S-Class ship, inbound in the deepened TSC (52' depth).

Four design transits were planned as a result of the validation and screening runs, modifying the initial test plan. These included the four combinations of traffic ship type (two types) and outbound speeds (two speeds for each ship). The specific conditions were explained earlier in this section. As noted above, the order of the initial baseline and design transits was randomized, to reduce the potential learning effect that would be expected as pilot gains experience on the simulator. After these planned transits were completed, additional baseline and design transits were conducted to investigate additional conditions. The design transit conditions are detailed in Section D.2.2 Test Conditions.

D.2.5 Performance Data and Analysis

The investigation relied on two primary sources of information: 1) simulator data generated by the pilot's transits; and 2) questionnaire data, reflecting pilot judgments. The simulator data were provided in summary form immediately after each scenario run, for discussion during the debriefing that followed each run. Pilot judgments were obtained, in questionnaire form, prior to any simulator involvement, after each scenario run on the simulator, and after all scenario runs were finished. Since the methodology used an *analysis approach*, rather than a *balanced experiment*, multiple runs under identical conditions were not made. Hence, descriptive statistical analysis of simulator-generated parameters is of limited value; furthermore, inferential statistical analysis is not appropriate. Conclusions were reached as a result of discussions with the Norfolk pilot, resulting from his experiences in the transits, simulator data, and discussions between the pilot and CAORF staff. This was a dynamic process, that evolved as scenario runs and findings were made. The available simulator data and questionnaire data are summarized in the following subsections.

Simulator Data. The simulator generated a wide range of data during each scenario run. Many parameters were monitored at the control station by CAORF staff during the run, and were the subjects during post-run discussions. A subset of relevant parameters were printed out immediately following each run, and served as aids during each post-run discussion with the pilot. They included:

- **Snap Shots** – of the control station display at critical times. Each snap shot presented:

- Geographic situation display picture (in color), showing the TSC, buoys, own ship and traffic ship positions, their course and heading vectors, and their history tracks.

- A wide variety of current-time status information, depending on the particular information selected for display. The potentially displayed information included detailed own ship parameters (e.g., ground speed, speed through the water, rudder angle, rpm, heading, UKC); detailed traffic ship parameters (similar to those of own ship); graphic and alphanumeric displays of bow and stern movements; and detailed environmental parameters.

- A historical time-line list (or graphs) of selected scenario parameters (e.g., own ship rudder angle, speed, list, UKC at bow, rate of turn) for a designated period of time prior to the time of the snapshot.

▪ **Time-Line Listing** – of selected scenario parameters, over the duration of the scenario. Examples of parameters in the list include own ship heading, speed, draft, rate of turn, rudder angle, course through the water, list angle, and UKCs at the bow and stern.

▪ **Track Plot** – of the meeting encounter in the TSC. This plot presented hull outlines of each ship at designated time intervals (20-second intervals) leading up to, and following, the passing. Each vessel's course and rudder angle, channel boundaries, and buoys were also displayed on these track plots.

▪ **Time History Diagram** – Multiple parameters plot (5 parameters) over time, showing graphically how the parameters changed during the scenario. The parameter curves were superimposed on a single plot, illustrating the relationships between parameters (e.g., heading, rate of turn, rudder angle).

Several additional parameters were generated during each run for discussion and analysis purposes. These included:

- CPA range between own ship and the traffic ship (hull to hull)
- Area of the respective hulls at which the CPA occurred
- Distance to the channel boundary at the time of CPA
- Area of the own ship hull at which the minimum distance to the channel boundary occurred
- Location at which grounding occurred

<u>Questionnaire Data</u>. Three questionnaires were developed, to provide a means of documenting pilot judgments regarding issues and experiences pertinent to the study objectives. A fourth questionnaire was developed to collect pilot background information. The questionnaires were:

▪ **Safety Criteria Questionnaire** (Appendix B.1) – designed to capture pilot judgments regarding TSC issues (e.g., wind conditions) and safety criteria (e.g., minimum safety margin [clearance] to the channel boundary), prior to his having any involvement with the simulator. These pilot judgments were intended to provide criteria against which his later performance could be compared.

▪ **Post-Run Questionnaire** – designed to capture pilot judgments regarding each scenario run. It was administered immediately after each scenario run was completed. The questionnaire addressed a range of issues, including own ship characteristics (e.g., speed, controllability), safety and performance (e.g., clearance between ships), and TSC characteristics.

- **Run Summary Questionnaire** (Appendix B.2) – designed to capture the pilot's conclusive judgments regarding the proposed TSC design, resulting from his experiences during the scenario runs and discussions with CAORF staff. In essence, this questionnaire was designed to capture the pilot's bottom-line conclusions. The questionnaire addressed issues similar to those of the Post-Run Questionnaire, but in an overall context based on his accumulated run experiences.

- **Background Questionnaire** – designed to collect basic information about the previous experience of the pilot.

D.2.6 Data Collection Procedures

The data collection was integrated with the analysis, as discussed previously. This process resulted in a pre-planned series of 6 scenario runs (i.e., 2 baseline and 4 design scenarios), in accordance with initial plans and the screening run results. Subsequently, a series of 19 additional scenario runs was conducted, with conditions of each determined from results of preceding runs during the data collection and analysis process. The procedures followed during each run were the same, and are summarized below:

- The individuals present during each run, and who participated in the post-run analysis discussions, included:
  - Norfolk Harbor pilot
  - CAORF staff, including:
    - Expert mariner (USMMA Master Mariner instructor)
    - Control Station Operator (CSO), and an assistant
    - Human Factors Experimental Psychology expert
    - Analyst, project engineer
    - Helmsman
  - ACOE-ND representative

- The Norfolk pilot and the helmsman were on the bridge during each scenario run. With several exceptions that occurred only in the later runs, all members of the CAORF staff were in the control room during each run. The human-ship-waterway performance during each run was monitored by the CAORF staff from the control room, which had visual scene monitors, detailed graphical and alphanumeric monitoring information on multiple screens, and remote TV monitors of the bridge area. Virtually all details of the scenario, and pilot and helmsman actions, were readily observable from the control station area.

- The initial conditions for each scenario were set up prior to the start of the scenario. This included placing own ship in the TSC at the initial speed, and usually at a heading (crab angle) requested by the pilot. The scenario was started when the pilot indicated he was ready on the bridge.

- The scenario continued until the traffic vessel was passed in the TSC, or until own ship grounded. Please note, as a result of the screening runs and selected own ship speed, grounding usually did not occur until the passing situation was basically over (i.e., own ship was either past the traffic ship, or nearly so). Grounding, when it occurred, was usually the result of the roll due to interaction with the traffic ship. The scenario lasted for approximately 7 to 13 minutes, depending on conditions.

- Immediately following completion of each scenario run, the pilot, helmsman and CAORF staff convened for the post-run analysis and discussion. Printouts were made of relevant information (see D.2.5 Performance Data And Analysis), and used for group discussion. The CAORF expert mariner generally led the discussion, although all persons actively participated. The format of the post-run sessions was:

  - Norfolk pilot filled out the Post-Run Questionnaire, with the assistance of the CAORF mariner (and other persons, as appropriate).
  - The track charts and other printed data were reviewed and discussed, as appropriate.
  - Findings and conclusions were identified, as regards the environmental conditions, own ship, and the TSC. These focused on the most relevant aspects of each scenario, such as a close CPA or grounding condition.
  - Conditions for later/subsequent scenario runs were identified. After the pre-planned runs were completed, the subsequent scenarios were configured to investigate other conditions stemming from the discussions. Often, a consensus was reached on the conditions for the next scenario.
  - Occasionally, a scenario was replayed at the control station, which provided fast-time and real-time playback, to more-closely investigate some aspect.
  - The subsequent run was set up, and the pilot and helmsman proceeded to the bridge. This process was repeated for the next scenario run and post-run session.

- After the final scenario run was completed, including the post-run discussion, the pilot completed the Summary Questionnaire.

D.3 DATABASE CHARACTERISTICS

D.3.1 Visual

The database for the visual scene was a three-dimensional mathematical model of the study area. This model represented all relevant visual information that was seen from ownship (the ship represented by the bridge simulator) as it traversed the area. The primary sources for the database construction were National Oceanic and Atmospheric Administration (NOAA) Charts #12222 and #12245, harbor photographs, and discussions with representatives of the ACOE-ND, the VPA and master mariners from the USMMA Department of Marine Transportation.

The *Visual Database* for this portion of the project included the navigational channels Norfolk Harbor Entrance Reach and Thimble Shoal, and landmasses including Old Point Comfort, Cape Henry and Sewells Point to the west, and the coastline of Virginia Beach to the south. It also incorporated the deep-water area to the east of the TS channel. All buoys and navigational lights in the study area were presented in the visual scene as represented on the NOAA charts. Important structures such as the Chesapeake Bay Bridge-Tunnel and Thimble Shoal Light were also portrayed in sufficient detail to facilitate recognition and familiarity with the visual scene. Enough detail of landmarks (including buildings, towers and tanks) was included to insure realistic shiphandling performance. The test pilot's observations during the validation runs concurred that adequate visual information was present.

The *ownship bow* was superimposed over the visual scene during real-time simulation, with both scenes being presented in correct perspective consistent with 108-foot and 117-foot heights of eye at the center of the wheelhouse (corresponding to the 38-foot and 47-foot draft vessels). As a result, there was a slight discrepancy in the perspective view as seen from each bridge wing. However, the pelorus on each wing was calibrated to compensate for this.

D.3.2 Radar

The *Radar Database* was structurally isomorphic to the visual database. Visual database features such as buoys, landmasses, towers and terminals were also represented in the Radar Database. The radar presentation utilized functional real-world radar equipment that was stimulated by a simulated radar signal. This display also incorporated shadow, fading, and clutter effects.

D.3.3 Hydrographic

A *Bathymetric (Depth Contour) Database* was constructed to model the various underwater structures, such that the ownship experienced realistic hydrodynamic interaction effects (e.g. shallow water and bank effects) during simulated transits.

A three-dimensional mesh that closely replicated the shape and contour of the waterway floor was modeled according to depth information provided by NOAA Charts #12222 and #12245, and detailed bathymetric data supplied by the ACOE-ERDC. The only modifications to real-world data, as currently maintained by the ACOE, were those necessary to achieve a simulated 52-foot project depth in the TSC, in accordance with the new design under investigation. The TSC waterway floor for the 52-foot new design depth was modeled with a flat bottom.

Two *Water Current Databases* (representing both existing and projected designs) were also constructed. Current modeling was accomplished with a collection of discrete points each containing individual water speed and direction values stored via fixed vector structures. Source material for the current database was obtained from:

- Tidal Current Tables for the Atlantic Coast of North America (published by NOAA)
- Detailed current data supplied by the ACOE-ERDC
- ACOE-ND
- Subjective evaluations by members of the VPA

The tidal current data provided by ACOE-ERDC were used in the scenarios of calm weather conditions. These tidal current data were already depth-averaged by ERDC. Locations between data points were assigned current values by means of mathematical interpolation.

A wind-driven current was simulated in each scenario representing the most credible adverse environmental conditions. The current's direction was in parallel with the wind; current speed was calculated to be in proportion to the wind speed (Wiegel, 1964). A current velocity of 1.5 knots was used with the 50 knots wind during baseline and design transits, with correspondingly less current under other wind conditions.

D.3.4 Situation Display

The *Situation Display* (also referred to as the *Instructor's Station Display*) *Database* depicted low-fidelity aerial perspectives of the harbor area with coastal outlines, aids to navigation, channel markings and numerical depth soundings (See Figure 2). The display was used at the control station to monitor the progress of ownship and traffic ships during simulation. Utilizing this as an underlay, ships' trajectories were displayed on the screen as they traveled through the database. Throughout the experiment, the Test Observer (TO) and the CSO had the ability of producing hard copy snapshots via color laser printer for the purposes of subject debriefing and data analysis.

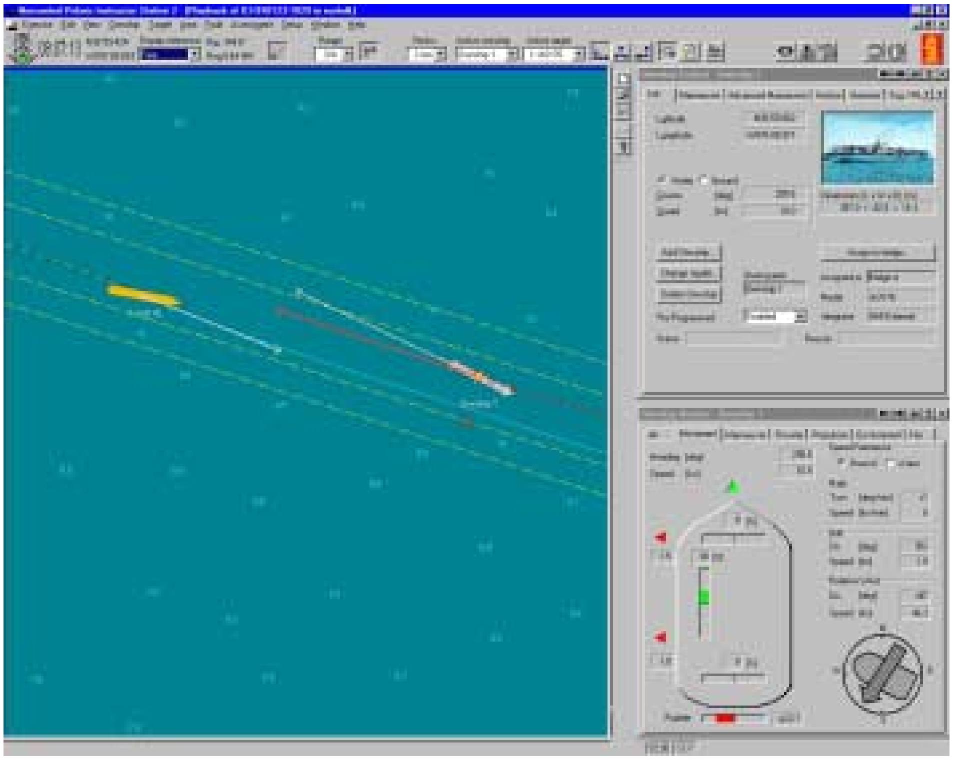

Figure 2. Sample Situation Display

D.4 VESSEL MODELS

Two ship models were used as ownship models: The 1,139' 6,600 TEU containership Susan Maersk at 38' draft was selected as the baseline ownship model, while the same vessel at 47' draft was selected as the design ownship model. Susan Maersk represents the largest class of containerships currently calling upon the ports of Hampton Roads. At present, this vessel operates around 38' draft when transiting through the TSC. The 47' draft represents the fully loaded condition that was tested in the evenly dredged 52' TSC. The ownship particulars are summarized in Table 2. The Handle Position/Propeller Revolution/Speed relations for 38' draft Susan Maersk in deep and 1.2 x draft shallow water are summarized in Table 3. The Handle Position/Propeller Revolution/Speed relations for 47' draft Susan Maersk in deep and 1.2 x draft shallow water are summarized in Table 4.

These ship models were developed by Danish Maritime Institute (DMI). The hydrodynamic coefficients of these models were based on neural network scheme and empirical formula. The math model simulation results have been compared with predictions from free running zigzag model tests and subsequent system identification. The comparison showed reasonable agreement. These models have been used extensively at DMI for training and application research in the areas of casualty prevention, harbor engineering, etc. The detailed maneuvering performances of Susan Maersk are reported in the ship model documents prepared for each draft (DMI, 2000).

Table 2 Ownship Particulars at Two Study Drafts

Particulars of Susan Maersk		38' Draft vs. 47' Draft
Displacement	m^3	109,476 vs. 136,132
Length between perpendiculars	m	331.54
Length overall	m	347.00
Breadth molded	m	42.90
Draught fore/aft	m	11.6/11.6 vs. 14.3/14.3
Wetted Surface	m^2	16,374 vs. 21,417
Frontal area	m^2	1,781 vs. 1,445
Side area	m^2	10,334 vs. 8,381
Block coefficient		0.6635 vs. 0.6635
Trim by the stern	%	0
Metacentric Height	m	2.45 vs. 1.87
LCB, % of LPP forward of LPP/2		-1.65
Radius of inertia, % of LPP		25.0
Type of Engine		Diesel
Number of propellers		1
Type of propellers		Fixed Pitch
Direction of rotation		Clockwise
No. of blades		6
Propeller diameter	m	9.00
Pitch ratio at 0.7R		0.94
Area ratio		0.892
Shaft Power (Ahead)	MW	50.00
Number of rudders		1
Type of rudders		Semi Spade
Position		in CL
Area of rudder	m^2	104.16
Turning velocity of rudder	°/sec.	2.5
Max rudder angle	°	35
Number of bow thrusters		1
Nominal bow-thruster thrust	kN	294
Numbers of stern thrusters		2
Nominal stern-thruster thrust	kN	2 x 147

Table 3 Handle/Propeller Revolution/Speed Table at 2 Water Depths for 38' Susan Maersk.

Handle	Propeller		Water Depth	
	RPM	Pitch Ratio P/D	1000 m Speed (Knots)	1.2 Tm = 13.9 m Speed (Knots)
1.0	94	0.940	24.7	-
0.8	65	"	17.8	15.8
0.5	50	"	13.7	12.1
0.25	35	"	9.5	8.1
0.125	25	"	6.7	5.5
-0.125	-25	"	-4.4	-2.8
-0.25	-35	"	-6.9	-4.3
-0.5	-50	"	-9.7	-7.0
-0.8	-59	"	-11.6	-8.6
-1.0	-65	"	-12.7	-9.5

Handle 1.0 = Full Ahead (Sea Mode)

Table 4 Handle/Propeller Revolution/Speed Table at 2 Water Depths for 47' Susan Maersk.

Handle	Propeller		Water Depth	
	Revolutions	Pitch Ratio P/D	1000 m Speed (Knots)	1.2 Tm = 17.2 m Speed (Knots)
1.0	94	0.940	24.6	-
0.8	65	"	17.7	-
0.5	50	"	13.6	13.5
0.25	35	"	9.5	9.5
0.125	25	"	6.6	6.4
-0.125	-25	"	-5.0	-3.4
-0.25	-35	"	-7.5	-5.2
-0.5	-50	"	-10.8	-8.4
-0.8	-59	"	-12.5	-9.7
-1.0	-65	"	-14.1	-11.2

Handle 1.0 = Full Ahead (Sea Mode)

There were two models used as the traffic ship models: a 950' long x 145' beam 150K DWT collier at 50' draft, and the Susan Maersk at 47' draft. The collier was used as a traffic ship for both baseline and design scenarios, while the Susan Maersk was used as traffic ship only for the design scenarios. The collier was used in the previous TSC navigation study conducted at CAORF (Schryver 1986). The 150K DWT collier represents the largest class of bulk carriers currently calling upon the ports of Hampton Roads.

While the motion of the ownship model was governed by extensive 6 Degree-of-Freedom (6-DOF) math model calculations, the movement of the traffic ship was based on simplified modeling, and scripted to follow predetermined track lines. The traffic ship models do react to wind and current with a dynamically calculated crab angle. Therefore, the visual presentation of the traffic ship did provide cues to the test pilot for making navigation judgments.

D.5 OWNSHIP BRIDGE EQUIPMENT

The ownship bridge was equipped with functional hardware including all instrumentation which is standard aboard large merchant vessels. These items included:

- Steering
  - Gyro steering, hand steering, NFU steering, and steering failure alarms
  - Gyro repeater
  - Rudder order indicator and rudder angle indicator
  - Bow/stern thrusters with respective indicators and status lights
- Propulsion
  - Engine telegraph, throttle control, and combinatory control
  - RPM and start air indicators
  - Engine failure alarms
- Ship motion Indicators and voyage log
  - Doppler log
  - Rate of turn indicator
  - Log/distance/time
- Navigation
  - Magnetic compass, ceiling-mounted periscope-type
  - Collision avoidance system
  - ARPA radar
  - Electronic Chart Display Information System (ECDIS)
  - Bridge wing gyro repeater with pelorus mounted
  - Wind speed, direction, and air temperature
  - GPS and Loran-C
  - Depth echo sounder
- Communication
  - VHF and VHF DSC
  - NavTex
  - Sound powered phone
  - Ship whistle
  - Navigation lights and signal lights
  - Fire indicator and distress alert

Refer to Appendix 1 for more information of CAORF Visual Bridge Ship-handling Simulator (VBSS).

E. FINDINGS

The evaluation of the safety of the proposed TSC modification is addressed in terms of

1. Relative comparison of the new design (i.e., Fully loaded S-Class ship in the 52' deep TSC) with the baseline (i.e., Partially loaded S-Class ship which has safely transited the existing TSC);
2. Comparison of pilot-ship performance with safety criteria expressed by the pilot prior to making simulated transits; and
3. Judgments made by the pilot as a result of his experiences in the simulated transits, which were captured in questionnaires.

It should be noted that differences may exist between at sea conditions and those created on the simulator. Although the simulated environment provides much information, including all information deemed essential to effective piloting, it does not perfectly replicate the at sea environment. This is a primary reason for using a relative standard of safety, in this case, the performance of piloting the baseline ship. Hence, whereas a 200' to 300' minimum safety margin may be achievable at sea, the simulated situation may preclude identical performance.

The expected primary concern in the investigation was the performance of own ship when meeting and passing the traffic ship in the TSC. Figure 3 shows a typical track plot generated during the scenario transit, focused at the time and place where the two ships met and passed in the TSC. The plot is oriented as north-up. It shows the TSC outer boundaries, and auxiliary channels, as dashed lines. Own ship is always transiting from right to left along the channel axis, with the traffic ship going in the opposite direction. This plot is comprised of a series of situation snap-shots, at fixed time intervals, presenting the multiple corresponding positions of own ship and the traffic ship over a period of time. The plot effectively elucidates the track and swept area of the respective ship hulls as they pass along the channel, and by each other. The rudder angle of own ship is graphically presented at each snapshot time increment, to further assist the analysis.

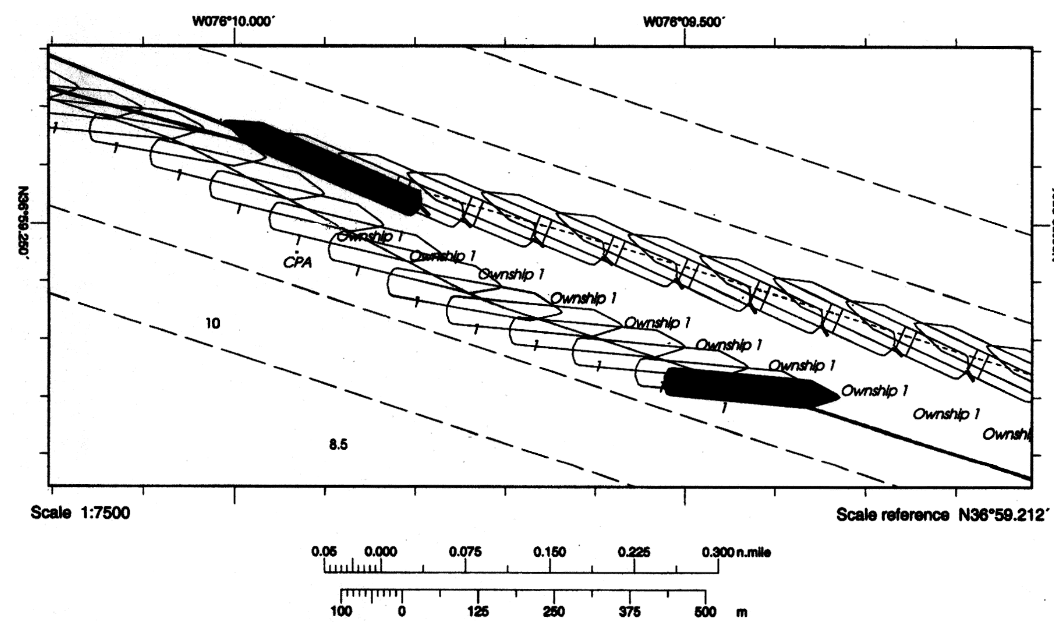

Figure 3: Representative Track Plot

This example track plot shows the final positions of the ownship and traffic ship (i.e., black hull outlines) at the termination of the scenario transit, having just passed in the TSC. The plot also shows the positions of both ships every 5 seconds leading up to the termination time. Further inspection shows that own ship was carrying large left rudders as the two ships approached and passed each other. The CPA range between the ships is apparent, as are the distances to the respective channel boundaries. As can be seen, the large crab angles of the two ships, due to the strong wind and current conditions, severely reduces the available channel cross sectional area for passing.

The track plot was a major tool for post-run discussions between the research staff and the pilot, since it provided an effective graphical history of the encounter over time. The track plots for all the analyzed transits are presented in Appendix C.

The findings are addressed in this section in regard to the elements of performance indicative of safe operation of the fully loaded S-Class ship in the 52' deep TSC. The elements are:

Channel Navigation:	Partially loaded S-Class Ship Fully loaded S-Class Ship Comparison of Fully- and Partially loaded Ships
Meeting & Passing:	Range at the Closest Point of Approach Distance to Channel Boundary Combined: Distances to Traffic Ship and Channel Boundary Effects of Wind and Current Direction Effects of Traffic Ship Type Pilot Judgments About Meeting & Passing Performance
Channel Depth:	Grounding Problem on the Simulator Pilot Judgments About Channel Depth

E.1 CHANNEL NAVIGATION

One of the two central issues in this study was the controllability of the fully loaded S-Class ship under severe crosswind and current conditions. That is, did the pilot have sufficient control to maintain the desired course along the TSC, and how did this degree of control compare with that of the partially loaded S-Class ship. The pilot judged this transit as difficult, requiring a high degree of skill and experience.

With respect to the severe wind and current conditions, the pilot judged the S-Class vessels to handle well, in both laden conditions. He was able to effectively control the ship to achieve the desired track, as long as sufficient speed was maintained. Neither ship exceeded the channel boundary during their transits. Both ships remained beyond a safe distance to the channel boundary during all transits, until the passing situation (See Section E.2 Passing). Consequently, the pilot judged the overall safety of the inbound transit of the fully loaded ship in the 52' deep TSC as average.

The following subsections address the controllability of each ship.

<u>E.1.1 Partially loaded S-Class Ship (Baseline Vessel)</u>

The screening runs showed that the partially loaded ship, in 60 knot cross-wind (and 2 knot cross current) conditions, had steerage limitations at inbound speeds under 16 knots. That is, maximum rudder was not sufficient to hold the ship's course along the TSC under these conditions. This ship also had steerage limitations in 50 knot cross-wind conditions at a speed of 8 knots. The pilot noted that the partially loaded ship would normally transit the TSC inbound at a minimum speed of 12 knots, especially when strong cross wind and current would be present. Consequently, a 12-knot speed was considered as the minimum for the baseline vessel (partially loaded S-Class ship) during the test runs.

The partially loaded ship was able to transit the existing TSC, and the proposed TSC, at whatever speed the pilot chose. This is in contrast to the fully loaded ship, which was found to have an upper speed restriction during the simulator transits due to insufficient UKC in the 52' deep TSC. As a result of the baseline transits, the pilot judged he was able to adequately control the partially loaded ship at 12 knots speed or higher, to achieve the desired course in the TSC.

The pilot had to maintain a large crab angle (i.e., generally 7^o to 12^o from the base course, depending on conditions), at a speed of 12 knots, to achieve the desired track in the TSC. This required large rudder angles (generally, 20^o – 35^o) to be carried throughout the transit, reducing the rudder safety margin (i.e., amount of rudder remaining that could be used). The large rudder angle illustrates the ship control difficulty faced by the pilot. The most rudder the pilot would typically use under normal conditions transiting the TSC, would be 5^o – 10^o. Despite the control difficulty, the pilot generally did not manipulate the engine RPM to assist with control, providing an additional control source and safety margin during the transits. As noted earlier in this report, performance of the partially loaded ship is considered the baseline of acceptable safety, against which the fully loaded ship was to be compared.

E.1.2 Fully loaded S-Class Ship (Design Vessel)

The screening runs showed that the fully loaded ship was likely to ground in the 52' deep TSC at speeds of 11 knots and above (See Section E.3 Channel Depth). This resulted in an upper speed constraint of 10 knots in the scenarios.

The pilot judged he was able to adequately control the fully loaded ship to achieve the requisite course in the TSC, during all of its transits under the severe wind and current conditions (up to 50 knot winds), including at a speed of 8 knots. As with the partially loaded ship, the fully loaded ship had to maintain a large crab angle (i.e., 7^o to 12^o from the base course), to achieve the desired track along the TSC. This required the pilot to carry large rudder angles (generally, 20^o – 35^o) through the transit, reducing the rudder safety margin similarly to that experienced with the partially loaded ship. As with the partially loaded ship, the pilot generally did not manipulate the engine RPM to assist with control, providing an additional control source and safety margin.

E.1.3 Comparison of Fully- and Partially loaded Ships

The fully loaded ship was judged to handle better than the partially loaded ship in the strong cross wind and current conditions, at similar speeds. Controllability of the fully loaded ship at 8 knots compared favorably with the partially loaded baseline ship at up to 12 knots, under the severe conditions. At these speeds both ships were required to carry very large rudder angles through the transits (i.e., Both ships often carried rudder angles of 20^o – 35^o for much of the transit).

The pilot judged the bottom-line controllability of both ships to be equivalent. Whereas the partially loaded ship was less controllable at slow speeds, it could proceed through the 52' deep TSC at 12 knots or more to achieve a reasonable level of controllability. The fully loaded ship had an upper speed limitation in the simulator transits (i.e., 10 knots), due to a potential for grounding at higher speeds, especially when passing a large vessel in the TSC (See Section E.3 Channel Depth). On the other hand, the pilot was able to maintain control under the severe wind and current conditions at a speed as low as 8 knots.

E.1.4 Summary of Channel Navigation

The findings indicate that the pilot was able to adequately control the fully loaded S-Class ship transiting the 52' deep TSC. Furthermore, he judged the fully loaded S-Class ship as equivalent to the partially loaded S-Class ship, for transiting the TSC under the severe wind and current conditions. The major points of this finding are:

- Control of the partially loaded S-Class ship (baseline vessel) was not adequate when transiting the existing TSC at speeds below 12 knots, under the severe wind and current conditions investigated.

- Control of the fully loaded S-Class ship was adequate when transiting the 52' deep TSC at speeds as low as 8 knots, under the severe wind and current conditions investigated.

- Both vessels required about the same degree of crab angle to transit the TSC, which was large.

- Both vessels were required to carry large rudder angles (generally, 20^o – 35^o for each ship) to maintain course in the TSC, at their respective speeds. This limited the amount of rudder reserve available to each ship during their transits.

- Engine RPM was generally not manipulated during the transits by either ship, providing an additional margin of control for each ship, if needed.

- The fully loaded ship was found to handle better than the partially loaded ship under the severe wind and current conditions, as judged by the pilot. The partially loaded ship was required to maintain a higher speed to achieve the same level of controllability as the fully loaded ship. However, the bottom-line controllability of both ships was judged as equivalent. The fully loaded ship was constrained to an upper speed limit of 10 knots due to a potential for grounding in the 52' deep TSC, whereas the partially loaded ship could transit at a higher speed and thus achieve equivalent controllability.

Piloting the fully loaded ship was judged to be approximately equivalent to that of piloting the partially loaded S-Class ship under the same conditions. On a relative basis, therefore, the safety of piloting the fully loaded ship was equivalent to that of the partially loaded ship, which is considered the standard of acceptable safety.

It is important to note that the results were obtained under severe wind and current conditions. As such, they represent the most extreme credible conditions under which the ships would be brought into the TSC. It should be cautioned, however, that these findings result from transits made by a single, highly experienced, pilot on the simulator. Although he was able to satisfactorily control the fully loaded ship, the conditions did require using a large amount of control force (i.e., rudder angle) to transit the TSC. Piloting the fully loaded S-Class ship under the severe cross wind and current was judged to be a very difficult task, with relatively small margins for error, and small reserve forces available.

E.2 MEETING & PASSING

The second major issue investigated was the safety of the fully loaded inbound S-Class meeting head-on, and passing, a large ship in the TSC, under the severe cross wind and current conditions. This passing situation, which is described in Section D Methodology, occurred in all of the 25 baseline and design runs analyzed. The inbound S-Class ship met an outbound collier or another S-Class ship. Both the own ship and traffic ship transited the TSC with large crab angles, due to the wind and current, making the passing situation very difficult.

The pilot judged both the partially loaded and fully loaded S-Class ships to handle well, as noted earlier. Despite the difficult conditions and the large channel cross-section areas occupied by the two ships, no collisions occurred during the simulated transits; and, own ship never strayed outside of the channel. There were, however, several transits in which the CPA range was small, and when own ship encroached into the outbound lane while passing. Also, own ship transited close to the outer channel boundary during several transits. It must be remembered that the meeting/passing situation involving two very large vessels, and under severe wind and current conditions, would be considered unusual, and expected to occur infrequently.

The transits were combined into four groups for analysis purposes. The groups were established in accordance with the wind/current conditions (i.e., 50 knot wind, 40 knot wind, or calm wind); and baseline and design vessels (i.e., partially- or fully loaded S-Class own ship). The groups are:

- **Baseline Transits in 50 Knot Wind (Baseline-50)** – This group was comprised of 3 transits with the 38' draft S-Class own ship, in the existing TSC, with 50 knot wind from 045^o or 017^o.

- **Baseline Transits Under Calm Wind (Baseline-Calm)** – This group was comprised of 4 transits with the 38' draft S-Class own ship, in the existing TSC, with calm wind and current conditions.

- **Design Transits in 50 Knot Wind (Design-50)** – This group was comprised of 13 transits with the 47' draft S-Class own ship, in the 52' TSC, with 50 knot wind from 045^o or 017^o.

- **Design Transits in 40 Knot Wind (Design-40)** – This group was comprised of 5 transits with the 47' draft S-Class own ship, in the 52' TSC, with 40 knot wind from 045^o.

The two primary indices of performance during the meeting/passing situation were the CPA range between the two ships, and the distance to the channel boundary at the time of CPA. Please note, each transit had unique conditions, such that no two transits in any of the groups were made under identical conditions. Hence, each group represents a compromise, such that other factors may account for the pilot-ship performance in any given transit. Nonetheless, these groupings enabled meaningful comparison of the two ships with regard to attained CPA range and distance to the channel boundary. The following subsections address the findings.

E.2.1 Range at the Closest Point of Approach (CPA)

Prior to involvement with the simulated transits, the pilot was asked for his estimate of the minimum acceptable safety margin (clearance) with the outbound vessel when meeting in the TSC. He stated 200'~300' as the safety margin, although noting that it could vary depending on conditions. This estimate provided information to consider together with the relative performances of the two ship configurations.

The average CPA range achieved by each group is presented in Figure 4. The standard error of the mean for each group is shown by the brackets around the respective means, indicating the 95% confidence range for each mean. As can be seen, the two design groups (fully loaded S-Class inbound in the 52' deep TSC, with 40 knot and 50 knot wind conditions) resulted in approximately equivalent CPA ranges. The overlap of their standard error brackets supports this finding. The Baseline-50 group (partially loaded S-Class ship inbound in the existing TSC, with the 50 knot wind condition) achieved a smaller average CPA range than the two design groups, but with a relatively large standard error, overlapping the means of the two design groups. These three groups should be considered as having achieved approximately equal average CPA ranges, since the analysis methodology employed does not permit performing inferential statistical calculations to determine if a significant difference exists. Hence, on the average, the CPA range achieved by the fully loaded S-Class ship was no different than that achieved by the baseline ship under similar conditions; the data certainly show that the fully loaded ship's CPA range was no worse. This finding provides relative evidence of acceptable safety in TSC transits with the fully loaded S-Class ship (i.e., The fully loaded S-Class ship is similar to the standard of acceptable safety, the partially loaded S-Class ship).

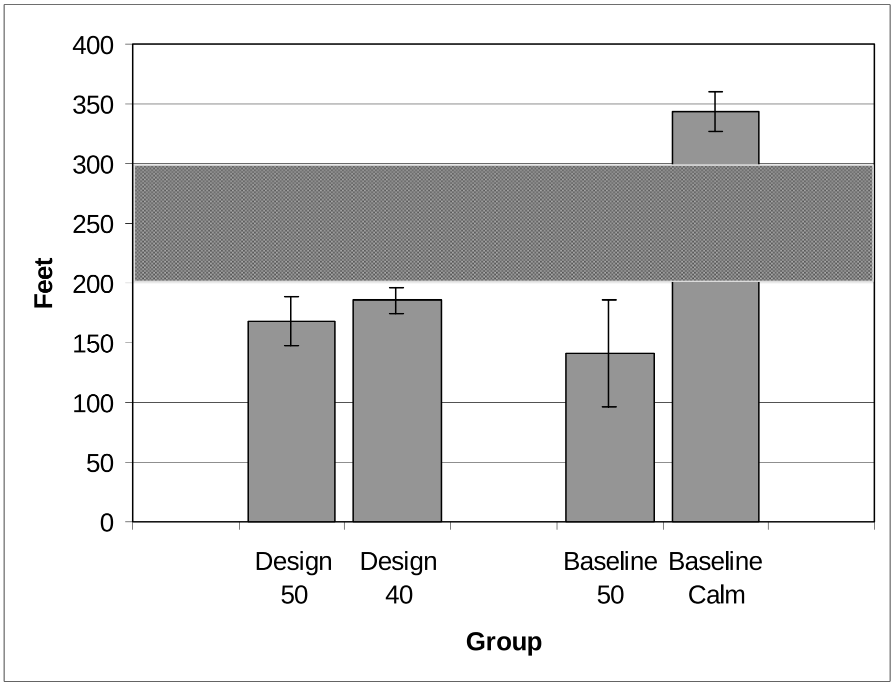

Figure 4. Average CPA Range of Each Group.

As can be seen in Figure 4, the Baseline-Calm group achieved a substantially larger average CPA range than the other groups, and a standard error far removed from the other groups. Although a part of this CPA difference may be attributed to the greater level of ship control associated with the calm wind and current condition, a substantial part of this difference is also likely attributable to the large crab angles that were required during transits under the severe wind and current conditions. The crab angles resulted in the ship footprints spanning a considerable portion of the channel's cross section, reducing the available space between the ships, and also between each ship and the respective channel boundaries.

The minimum acceptable safety margin between ships identified by the pilot (200-300') is presented as a horizontal band across the chart. This band denotes the lower boundary of the safe passing distance, which would be somewhere between 200' and 300'. Typically, when under calm conditions, one may expect a smaller margin would suffice, since the ship is easier to control. On the other hand, since the desired safety margin is also easier to achieve under calm conditions, a larger margin of safety may be appropriate. Under the severe wind conditions, the large crab angle reduced the potentially available margin; and the amount of rudder needed to maintain course reduced the level of reserve control available. Although a larger margin of safety may be desirable under more severe conditions, the conditions act to reduce the potential margin that is achievable. Hence, care must be exercised when interpreting the desired safety margin.

As can be seen in Figure 4, the average CPA ranges achieved by the three severe wind groups were all below the lowest safety margin boundary expressed by the pilot, before he participated in the simulated transits. The risk associated with bringing a large containership in under the severe wind and current conditions investigated, would be increased in comparison with that during calm conditions. It is, perhaps, this difference in risk that is reflected in the low average CPA ranges. The CPA ranges are less than desired for both the baseline and design groups, but nevertheless are similar for these groups.

The specific CPA ranges achieved during each transit are plotted in Figure 5, for each group. The horizontal band representing the minimum acceptable safety margin is also provided in this figure. Each curve plots the CPA ranges as a series, in the order the scenarios were run in that group. The Baseline-Calm group included 4 scenarios, with the run-order as plotted; the Design-50 group had 13 scenarios; the Design-40 group had 5 scenarios; and the Baseline-50 group had 3 scenarios. Please note, the scenario run order is only relative to the other scenarios in that group; the absolute scenario run order is represented by the list of scenarios in Table 1.

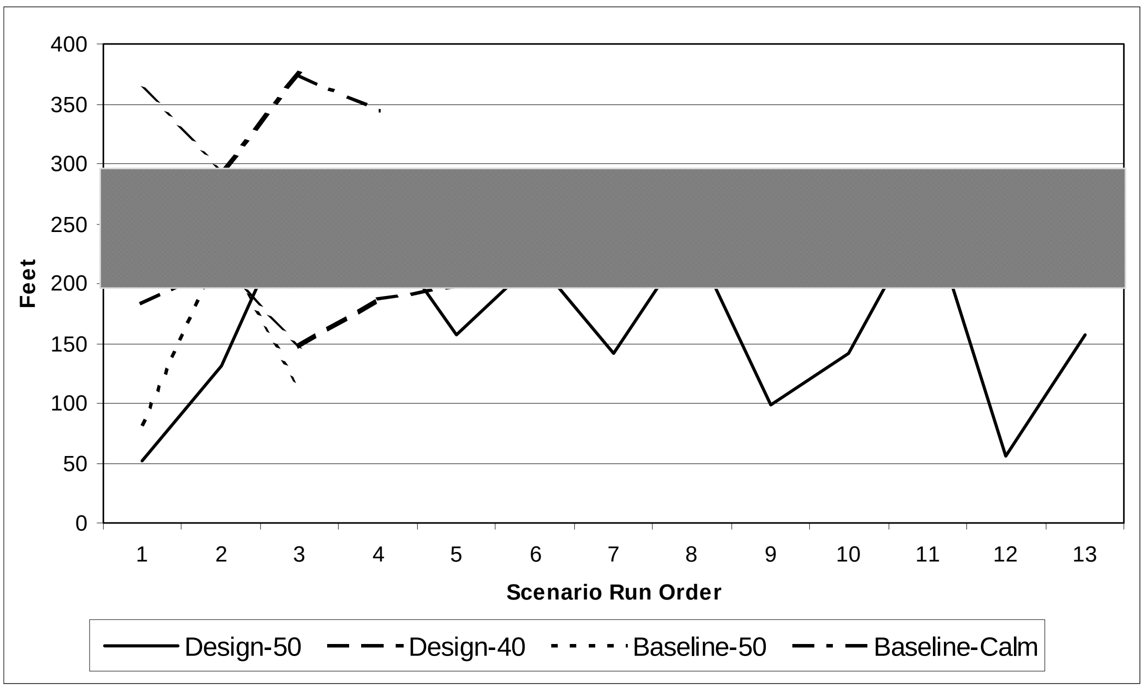

Figure 5. CPA Range Achieved During Each Transit.

CPA ranges at or above the highest safety margin (300') were consistently achieved only in the Baseline-Calm group of transits (see Figure 5). Some transits in each of the other three groups (i.e., severe wind and current condition groups) resulted in CPA ranges above the lower safety margin of 200', but not above the higher margin. In addition, most transits in these groups resulted in CPA ranges below the lower safety margin. Several transits resulted in CPA ranges of less than 100 ft: two in the Design-50 group, and one in the Baseline-50 group. As noted earlier, although the criteria of absolute safety is a concern (i.e., pilot-identified minimum acceptable safety margin), the more germane issue to the study is the relative safety of the fully loaded ship in comparison with the partially loaded ship (i.e., design versus baseline). The ranges of CPA distances in these two groups (i.e., Design-50 and Baseline-50) are somewhat similar, as evidenced by the curves in Figure 5. Their standard deviations are also similar, at 75.7' and 78.1' for the Design-50 and Baseline-50 groups, respectively. These findings compliment those pertaining to the CPA range averages addressed above.

The performance in the Design-40 group of transits appears somewhat more consistent than in either the Design-50 or Baseline-50 transit groups, as evidenced by their much smaller standard deviation of 24.2'. This result, of course, would be expected due to the somewhat less severe wind and current conditions. And, it is consistent with a trend toward the performance in the Baseline-Calm group.

The data in Figure 5 suggest equivalence between the transits made with the fully loaded ship and the partially loaded ship. These findings, together with those pertaining to the average CPA ranges addressed above, suggest equivalent safety between the design and baseline conditions (i.e., fully loaded S-Class ship in the 52' TSC, in comparison with the partially loaded S-Class ship in the existing TSC) with regard to meeting and passing in the TSC.

E.2.2 Distance to Channel Boundary

The pilot was able to maintain a safe distance to the channel boundary during all transits, prior to meeting and passing the traffic vessel (see Section E.1 Channel Navigation). He was also able to achieve equivalent CPA ranges with the fully loaded and partially loaded ships (Section E.2.1 Range at the Closest Point of Approach). The other factor related to passing performance is the distance to the channel boundary. When meeting an outbound ship in the TSC the pilot expressed the judgment that the best strategy would be achieve greater clearance with the meeting vessel than with the channel boundary, particularly when cross wind and current conditions set own ship toward the center of the channel. An alternative strategy, especially when in calm conditions, would be to split the available space between the oncoming ship and the channel boundary, such that the CPA range would equal the distance to the channel boundary. The pilot noted that the ratio of these distances may vary depending on situation factors, such as amount of set due to wind and current.

Figure 6 presents the average channel safety margin (i.e., distance to the channel boundary) for each analysis group of transits, at the time of CPA (With brackets denoting the standard error of the mean, at the 95% confidence level). The minimum safety margin expressed by the pilot prior to participating in simulator runs, is presented as the horizontal band of shading in the figure, ranging from 50' to 100'. The average channel boundary margins achieved by all groups are above the minimum safety margins expressed by the pilot, as are their lower standard error limits (i.e., excepting that of the Baseline-Calm group). The highest average was in the Baseline-50 group, while the lowest average was in the Baseline-Calm group. The averages of the two design groups are in between. Although the average of the Design-50 group is smaller than that of the Baseline-50 group, it is higher than the other groups, and substantially above the upper safety margin expressed by the pilot. Furthermore, the standard error of the means overlaps for the Design-50 and Baseline-50 groups, suggesting no meaningful difference in performance between these two groups. These results suggest that the performance of the fully loaded S-Class ship is adequate with regard to this factor.

Figure 7 shows the safety margin (i.e., distance to the channel boundary) at CPA, for each transit, in each group. The distances are plotted for all transits in the order they occurred, within the respective groups. The horizontal band shows the upper and lower channel safety margins expressed by the pilot. With the exception of three transits, all distances to the channel boundary at the time of CPA were above the upper channel safety margin expressed by the pilot. One transit in each group, excepting the Baseline-50 group, resulted in a distance between the two safety margins.

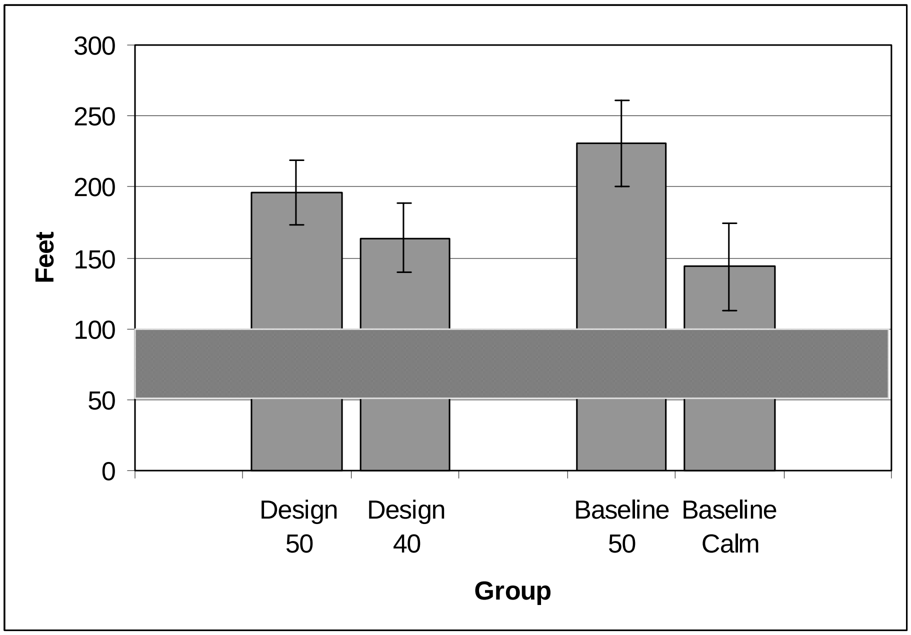

Figure 6. Average Channel Safety Margin at CPA.

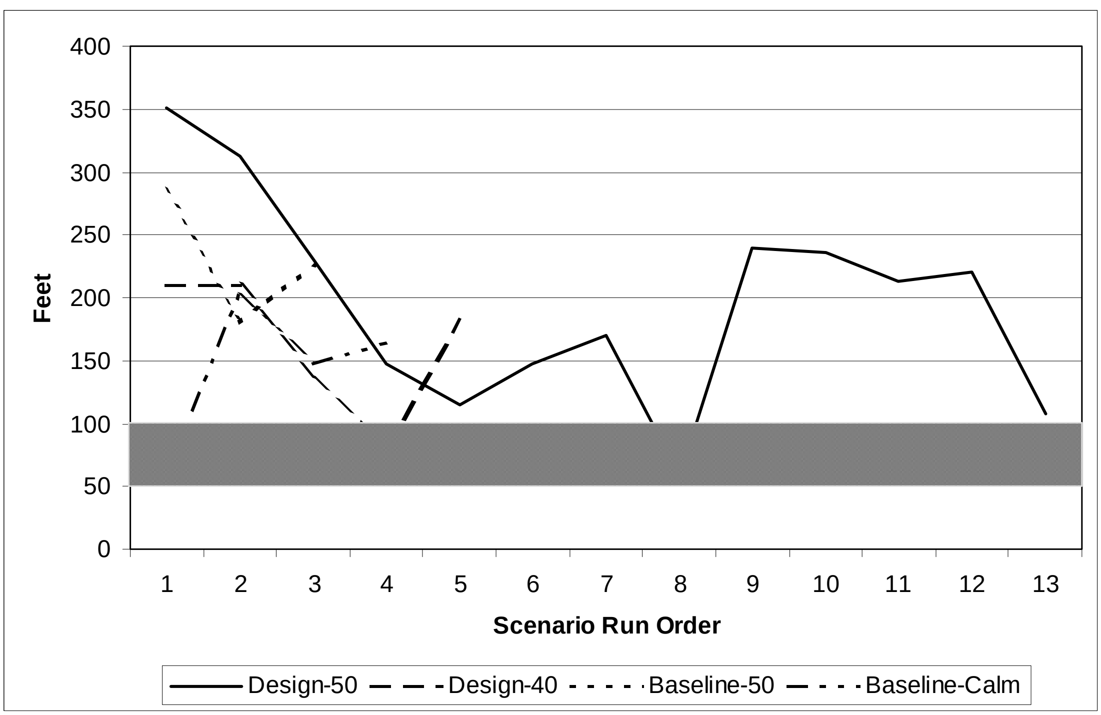

Figure 7. Channel Safety Margin Achieved During Each Scenario Run.

These data, coupled with the higher average distance noted in Figure 6, provide some indication that the partially loaded ship may have achieved a larger distance to the channel boundary than did the fully loaded ship. This finding, however, must be interpreted in view of two considerations: 1) the safety criteria stated by the pilot; and 2) the CPA range data. Whereas many transits resulted in CPA ranges less than the lower pilot-expressed limit, distances to the channel boundary were never below the lower pilot-expressed limit, and usually above the upper limit. These data suggest that the channel safety margins achieved in all groups were satisfactory. This is particularly true in view of the cross wind and current conditions, which acted to move own ship away from the channel boundary.

The Baseline-50 group achieved a lower average CPA range than the Design-50/40 groups. The CPA range and distance to channel boundary are traded-off during the passing. Hence, the higher distance to channel boundary was, at least in part, due to a smaller CPA range. Since the average CPA ranges were below the pilot-expressed lower limit, and none of the channel clearance distances were below the pilot-expressed lower limit, it is suggested that the combined performances of the fully loaded and partially loaded own ships were equivalent.

In addition, when comparing the Design-50 group with the Baseline-50 group, it should be noted that only 3 transits were made in the Baseline-50 group. Although these 3 transits resulted in clearances higher than many of the Design-50 group, the small number of transits in this group limits the interpretation (Note, the first 3 transits of the Design-50 group achieved approximately the same average distance as did the Baseline-50 group).

It is reasonable to conclude from these data that the fully loaded S-Class ship was able to achieve adequate channel safety margins, equivalent to those of the partially loaded ship.

E.2.3 Combined: Distances to Traffic Ship and Channel Boundary

As noted earlier and expressed by the pilot, a general strategy in conditions with a strong cross wind and current setting own ship towards the center of the channel, as in the test scenarios, would be to place own ship closer to the channel boundary than the passing ship. The strong set would allow more room to recover, if need be. An alternative strategy would be for own ship to split the distance to the meeting/passing ship and the channel boundary when passing.

Figure 8 presents the average distances to the passing ship and channel boundary at the time of CPA, for each group (These are the same data as presented in Figures 3 and 5). As can be seen in the figure, the Design-50 and Design-40 group transits both resulted in approximately equal average distances to the passing ship and channel boundary. This conforms to one of the strategies noted above, but not to the preferred strategy expressed by the pilot for the conditions with a strong cross wind and current. Importantly, these data suggest that the performances of the 47' draft S-Class ship under 50 knot and 40 knot wind conditions were approximately equal.

The two baseline groups' transits resulted in larger differences between the distance to the traffic ship and to the channel boundary. The average CPA range achieved in the Baseline-50 group was considerably smaller than the average distance to the channel boundary. This is opposite to the strategy preferred by the pilot under the conditions. Hence, it must be concluded that the fully loaded S-Class ship performed at least as well as the partially loaded ship, with regard to the passing strategy results. In contrast, the Baseline-Calm group did achieve a larger passing distance to the traffic ship than to the channel boundary, in keeping with the preferred strategy expressed by the pilot.

The distances to the passing ship and channel boundary at the time of CPA, for each transit, are plotted in Figure 9. The two curves in this figure present the Design-50 group data of Figures 4 and 6. Two horizontal lines, representing the lower safety margins expressed by the pilot for the CPA range and distance to the channel boundary, are provided in the chart. These curves show that in about two-thirds of the transits the pilot was able to position the fully loaded ship closer to the channel boundary than to the traffic vessel, during the passing situation.

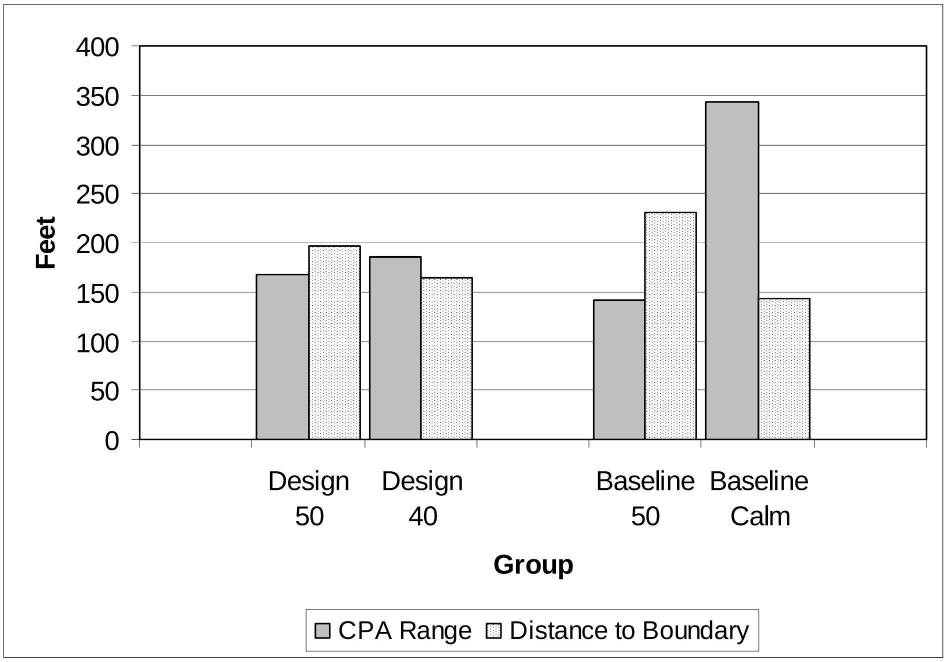

Figure 8. Distances to Passing Ship and Channel Boundary.

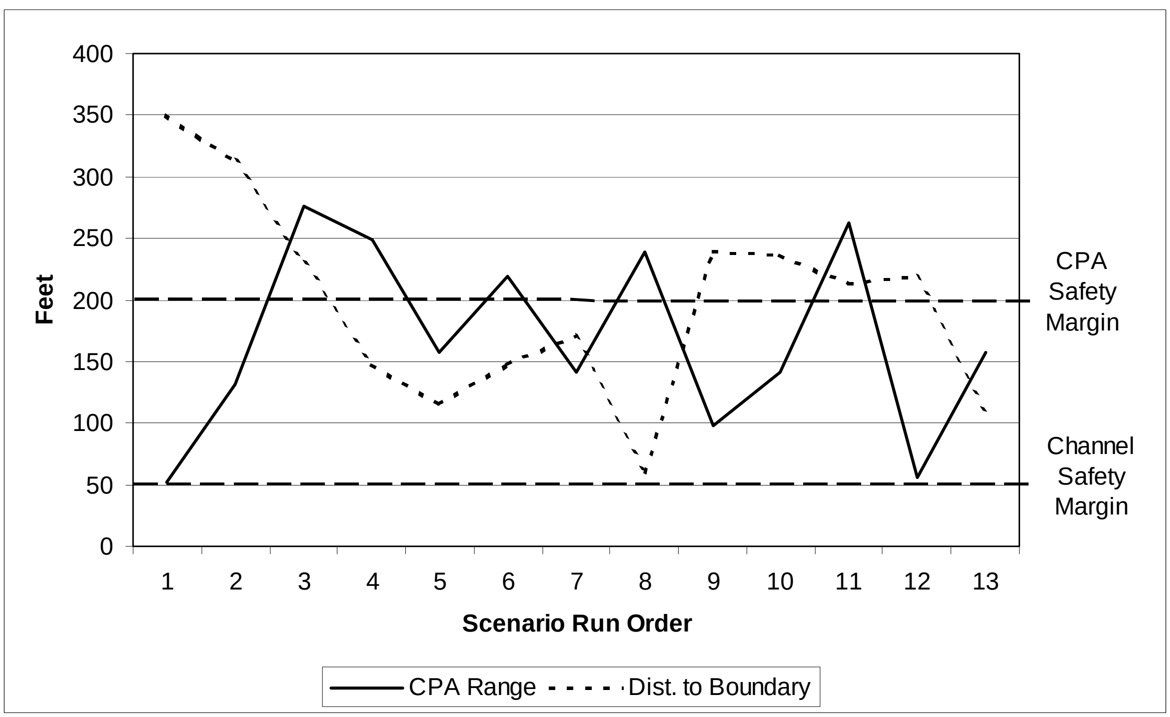

Figure 9. Distances to Passing Ship and Channel Boundary for Design-50 Group Transits.

The data presented in this section suggest that the clearance that can be achieved between very large ships, when passing in the TSC under severe cross wind and current conditions, is less than desired by pilots. The achievable clearance to the channel boundary, on the other hand, is acceptable. Furthermore, the data suggest that the inbound ship could have been closer to the channel boundary than occurred, but prevented from achieving this due to ship control limitations under the severe cross wind and current. Nevertheless, performance of the fully loaded S-Class ship was equivalent to that of the partially loaded.

The preceding data indicate upper limits to the available safety margin, especially under the severe wind and current conditions when substantial crabbing is necessary. The pilot stated he wanted 50-100' minimum safety margin to the channel boundary, and 200-300' minimum clearance with the outbound vessel. This results in a combined minimum safety margin of 250-400' clearance. Adding the two average clearances of Figure 8 (CPA range and Distance to Boundary) for the Design-50 group shows an available total clearance of less than 400', ostensibly due to the large crab angles of own ship and the traffic ship. In essence, it would be difficult for a long wide ship to simultaneously achieve CPA and channel boundary clearances above the respective upper safety margin goals expressed by the pilot, when under the severe cross wind and current conditions. In other words, at best a long wide ship can achieve a combined clearance between the upper and lower safety margin goals, when under the severe cross wind and current conditions.

E.2.4 Effects of Wind and Current Directions

Transits in the Design-50 group, as noted earlier, were run with two wind/current directions:

1. Wind from 17^o with current to 198^o
2. Wind from 45^o with current to 225^o

Figure 10 presents the average distance separating own ship and the traffic ship at CPA for the two wind and current combinations. Brackets indicating the standard error of the mean are also presented in the figure. As can be seen, the average CPA ranges are similar for both wind directions (with corresponding currents), with considerable overlap between the two standard errors of the means. This indicates that no meaningful differences in CPA range performance can be identified between the two wind/current directions.

E.2.5 Effects of Traffic Ship Type

The average distance between own ship and the traffic ship for the Design-50 group is presented in Figure 11, as a function of the type of traffic ship. Brackets indicating the standard error of the respective means are included in the figure. The averages were based on 9 transits meeting an outbound 47' draft S-Class traffic ship, and 4 transits meeting an outbound 50' draft collier. As can be seen, the averages are nearly identical for both sets of transits. Furthermore, considerable overlap exists in the standard error of the means for both groups. Hence, the type of large traffic ship met in TSC had no effect on performance of the 47' draft S-Class ship transiting inbound through the TSC.

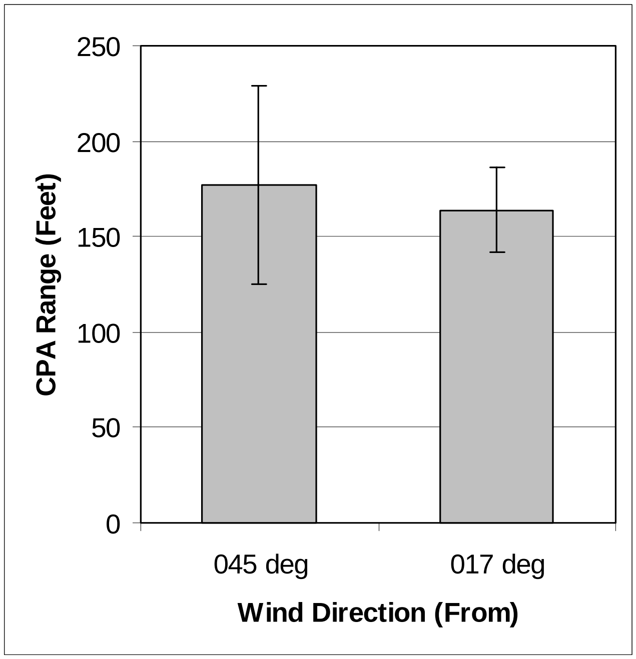

Figure 10. Average CPA Range at Different Wind & Current Directions.

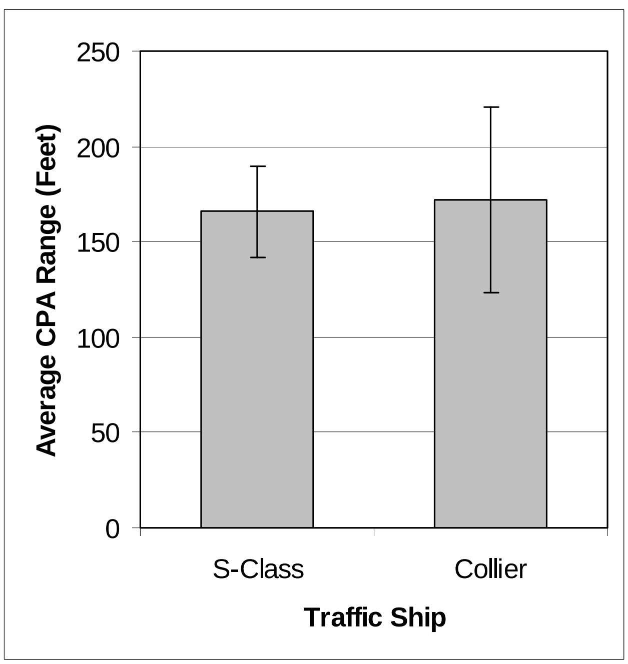

Figure 11. Average CPA Range for Different Traffic Ships.

E.2.6 Pilot Judgments About Meeting & Passing Performance

The pilot made several important points in the Summary Questionnaire, after completing all scenario runs, that are germane to the issue of meeting and passing in the TSC:

- The channel width was judged to be adequate under most circumstances.
- The overall safety of the inbound transit for meeting/passing, in the planned 50' depth TSC design, was judged as average.
- The channel width was judged as not adequate for very large ships meeting/passing in the TSC, when under cross winds of 40-50 knots.
- Constraints should not be imposed on inbound and/or outbound traffic in the TSC. However, caution should be exercised when: 1) high winds are present, and 2) when meeting large ships. Other factors should be considered, including tide.

E.2.7 Summary of Meeting & Passing Performance

The findings of this section compliment those of Section E.1 Channel Navigation: the pilot was able to adequately control the fully loaded S-Class ship to pass a large outbound vessel in the 52' deep TSC. This finding is based on the observation that performance of the pilot with the fully loaded ship was equivalent to that with the partially loaded ship. The major points of this finding are:

- The average CPA range achieved by the fully loaded S-Class ship was no less than that achieved by the partially loaded ship (the baseline ship), when under similar wind and current conditions.
- The ranges of CPA distances achieved by the fully loaded S-Class ship across the scenario run series were similar to those achieved by the partially loaded ship, under the severe wind and current conditions. Despite this equivalence, over half of the CPA ranges in both groups were below the lower limit expressed by the pilot before participating in simulator runs.
- The distances to the channel boundary during the passing situation (i.e., at the time of CPA) were approximately equivalent for the fully loaded S-Class own ship and the partially loaded own ship. Furthermore, the average distances to the channel boundary for the fully loaded and partially loaded S-Class ships were well above the minimum clearances identified by the pilot before participating in simulator runs.
- All of the transits made in the fully loaded S-Class own ship resulted in distances to the channel boundary that were greater than the lower limit expressed by the pilot.

Although some differences were noted between the fully loaded and partially loaded S-Class vessels, on balance the performances with both vessels were approximately equivalent. On this basis, the evidence suggests that the safety of meeting and passing a large outbound ship is equivalent for fully loaded and partially loaded S-Class ships under severe wind and current conditions.

Although this investigation was not designed to address the width of the TSC, but rather to investigate the comparative performances of the fully loaded and partially loaded S-Class ships, some evidence was found to suggest that, in the presence of strong cross wind and current, passing distances achievable between large ships in the TSC are less than the lower acceptable safety margin identified by pilots (Note, only a single pilot participated in this investigation). This finding pertains to the current situation with large ships transiting the TSC, as well as to the TSC after the proposed modifications.

E.3 CHANNEL DEPTH

Channel depth, which had not been identified as an issue of concern during study design discussions with port representatives, became a major issue during the data collection phase of the project. It was known that the channel depth could potentially be a problem for the fully loaded S-Class ship, due to limited UKC in the proposed 50’ deep TSC. Hence, the 52’ deep TSC was configured, as discussed in Section D, Methodology. But, the extent of this potential problem was not anticipated. Consequently, channel depth was not identified as an issue for investigation.

E.3.1 Grounding Problem on the Simulator

The pilot expressed concern about TSC water depth in regard to the fully loaded ship with a 47’ draft, prior to making any runs on the simulator (i.e., in the initial Safety Criteria Questionnaire). Specifically, he stated that there was a potential problem with regard to speed. In addition, he judged 2’ of UKC (at speed) as necessary for safe operation, in general. He also stated that he would want 3–5’ or more for a containership, and at least 5’ of UKC for an S-Class ship. He also noted that the amount of UKC wanted for safe operation would depend on own ship speed, and if meeting other traffic.

The validation runs in the 52’ deep TSC highlighted a potential grounding problem. Specifically, as noted earlier, the squat of the fully loaded S-Class ship precluded ship transiting above 12 knots in the TSC on the simulator. The amount of squat encountered by the ship at speeds above 12 knots was sufficient to result in a high potential for grounding during a transit, even from minor perturbations. It was not until the screening runs were being conducted at the start of the data collection period that the extent of the grounding problem became known. The reader should be cautioned to recognize that the grounding problem being addressed occurred during simulator transits, which could be somewhat at variance with at sea performance due to a variety of factors. Simulation is at its weakest when dealing with the extreme shallow water conditions that existed with the fully loaded ship in the 52’ deep TSC scenarios.

The fully loaded S-Class ship had a draft of 47’. The new-design TSC was configured on the simulator with a depth of 52’. This left the non-moving ship with 5’ of UKC. Note, this was the minimum clearance desired by the pilot for an S-Class ship; but, the ship is stationary with this clearance. The screening transits showed that even 12 knots was too fast, resulting in a high potential of grounding the fully loaded S-Class ship when any perturbation caused sufficient roll or pitch.

The amount of bow squat that occurs with the fully loaded S-Class ship, as a function of speed, is listed in Table 5 (Millward, 1990). This table also lists the corresponding residual UKC at the bow. As can be seen in the table, the UKC is small at any speed, with grounding occurring before a speed of 14 knots is reached. These values, even at 8 knots, are below the clearance desired by the pilot. Note, other factors not considered in the simulation may mitigate this problem at sea. Nevertheless, the potential for grounding is clear.

Under calm weather conditions, and when not passing another large ship in the channel, the fully loaded S-Class ship may be expected to perform in accordance with the data presented in Table 5. Perturbing forces that cause the ship to roll or pitch, such as the severe weather and passing effects that existed in the test scenarios, will exacerbate the problem of potential grounding. The vertical displacement of a 140’ beam flat-bottomed hull due to roll and pitch is presented in Table 6. As can be seen in the table, a roll of only 2^o would cause a vertical displacement of well over 2'. Similarly, pitch of $1/4^o$ would cause a vertical displacement of well over 2'

Table 5. Bow Squat and Under the Keel Clearance of Fully Loaded S-Class Ship in 52' Deep Channel.

Speed (kt)	Squat (ft)	Under Keel Clearance (ft)
8	1.48	3.52
10	2.40	2.60
12	3.63	1.37
14	5.26	-0.26

Table 6. Vertical Displacement of Hull Due to Roll and Pitch.

Roll (°)	Vertical Displacement at Beam (ft)	Pitch (°)	Vertical Displacement at Bow (ft)
0.5	0.61	0.25	2.37
1.0	1.23	0.50	4.75
1.5	1.84	0.75	7.12
2.0	2.46	1.00	9.49

At a steady speed of 12 knots, squat reduced the amount of UKC to less than 2'. The hull's lower shoulder would touch ground when the ship rolled less than 1.5^o. Hence, the amount of squat encountered by the ship at a speed of 12 knots was sufficient to result in a high potential for grounding during transits under the severe cross wind and current conditions. Thus, the maximum transit speed investigated during the data collection scenario runs was reduced further, to 10 knots.

It was learned during the data collection scenario runs that the fully loaded ship had a high potential to ground at even a 10 knot speed (i.e., Slightly more than 2 ½' of UKC was available). The ship grounded in many of the transits. The severe cross wind and current caused the ship to heel over and roll a bit. Moreover, the interaction of the two large vessels passing close together caused more rolling, and often the grounding of own ship in the TSC. Fortunately, the grounding occurred after the two vessels had passed, and thus did not interfere with the vessel control data and analysis. Nonetheless, based on the simulated transits, the fully loaded S-Class ship should be expected to have a relatively high potential for grounding in a 52' deep TSC when under severe wind and current conditions, and when meeting/passing another large vessel. Additional investigation should be undertaken to better-determine the extent of this grounding potential.

E.3.2 Pilot Judgments About Channel Depth

The pilot made several important points in the Summary Questionnaire, after completing all scenario runs, that are germane to the issue of channel depth and safe transiting:

- The overall safety of the inbound transit for meeting/passing, in the planned 50’ depth TSC design, was judged as average. This included consideration of ship controllability, risk of collision, and risk of going outside the channel boundary. In contrast, the overall safety of the inbound transit was rated as marginal, with regard to grounding.

- Rolling was a problem with both the fully loaded and partially loaded ships when meeting/passing, under the cross wind and current conditions.

- A 12 knot, or higher, transit speed would be preferred under severe wind and current conditions, to maintain better ship control. However, due to the potential for grounding evidenced during the simulated transits, an initial transit speed of 10 knots is suggested. As experience is gained with the S-Class ship, and with appropriate environmental conditions, higher speeds may be possible.

- A 50’ channel depth is marginal for the fully loaded S-Class ship, such that safety would be marginal in severe wind and current conditions.

- The safety of bringing the fully loaded S-Class ship inbound through the TSC was rated as worse than the partially loaded S-Class ship, because of the grounding potential.

- The safety of the 50’ channel would be acceptable in 25 knot wind conditions, but a problem in winds above 30 knots.

- The S-Class would be able to safely transit in the majority of situations; but caution is necessary with regard to wind and current conditions.

- Other factors should be considered when making a transit in an S-Class ship, including tidal conditions, the times of meeting large outbound ships in the TSC.

- The priorities for upgrading the TSC are, in order:

  - Dredge to 50’, as currently planned.
  - Dredge whole channel width to 52’ depth.
  - Dredge channel wider to 1,200’

E.3.3 Summary of Grounding Issues and Findings

Discussions between the CAORF staff and the Norfolk pilot identified several issues that should be considered as regards the real potential of the fully loaded S-Class ship to run aground in the deepened TSC:

- The TSC configuration used during the transits of the fully loaded S-Class ship was 52’. A channel depth of less than 52’ would result in an even greater propensity for the fully loaded ship grounding.

- The amount of squat is considerable, increasing by 73% between 8 and 10 knot speeds, with the result that the UKC in the 52’ deep TSC is reduced by 26%. At a steady speed of 10 knots, the UKC is a little more than 2 ½’.

- A very small amount of roll (e.g., less than 1 ½°) can cause the fully loaded S-Class ship to ground, when at a speed of 12 knots.

- The grounding that occurred in most transits was primarily due to vessel roll during the passing situation. Although vessel pitch may have contributed to the problem, it did not appear to be the primary cause. The severe cross wind and current conditions, together with large rudder angles to maintain the track, caused the fully loaded ship to heel and roll a bit; interaction between the two large ships when passing caused the ship to roll more, often to the extent of grounding.

- The validity of 6 degree-of-freedom digital simulation models at very shallow conditions has not been widely tested, due to the inherent risk associated with testing under such conditions at sea. The investigation team discussed the possibility of unaccounted-for factors affecting the ship's propensity to roll and ground, such as the pivot point rising, under-keel cushion forces, etc. It is possible that the hydrodynamic forces pertaining to pitch and roll may behave substantively different under the extreme shallow-water conditions encountered in this study.

- Review of ship roll data together with discussions between the CAORF staff and the Norfolk pilot resulted in the judgment that the fully loaded S-Class ship simulation appeared have insufficient roll damping. This issue was investigated further by DMI, the developer of the S-Class simulation models. Their conclusion supported the judgment reached at CAORF: the fully loaded S-Class ship models did, in fact, have insufficient roll damping. The frequency of grounding experienced during the test transits, therefore, may not be representative of what should be expected at sea. The amount of roll encountered at 10 knots during the passing situation would likely be somewhat less.

The findings suggest that the fully loaded S-Class ship will have little UKC in a 52' deep TSC, at any speed. The amount of squat may ground the ship at a speed approaching 14 knots. At speeds up to 12 knots this ship has a potential to ground from roll or pitch. The high propensity to ground that was experienced in the simulated transits was likely exaggerated, due to insufficient roll damping. Furthermore, limitations in the hydrodynamic ship simulation models at the very shallow water conditions investigated by this study, may overstate the propensity to ground at sea. Nevertheless, the very limited UKC presents a real risk of grounding in conditions that may cause substantial rolling or pitching.

F. CONCLUSIONS AND RECOMMENDATIONS

F.1 CONCLUSIONS

The inbound transit of the fully loaded S-Class ship is concluded to be safe, since its control was equivalent to that of the partially loaded ship, meeting the criteria of relative safety (i.e., New design compared with the baseline of safety).

The criterion of safety traditionally accepted in simulation studies is the comparative performance of the new design (i.e., new ship and waterway characteristics) with the baseline design (i.e., existing ship and waterway characteristics). The baseline design is considered safe, by default, since it has performed acceptably in the past and continues without question today. This relative measure of safety, which is considered the most valid typically available, enables data to be collected for comparative evaluation of safety. On this basis, it is concluded that transits of the fully loaded S-Class ship in the 52' deep TSC should be acceptably safe, with regard to channel navigation. The safety associated with the potential of this vessel grounding is an important, but separate, issue.

The results of this study suggest that the proposed TSC modification will be safe for bringing fully loaded S-Class ships into Norfolk Harbor under wind conditions up to 30 knots. At severe wind conditions (i.e., above 30 knots) the safety of an inbound transit in the fully loaded S-Class ship should be considered marginal, with caution exercised in making the decision to bring the ship in. This is due to a potential for grounding in a 52' deep channel, resulting from the very limited UKC and the potential for the ship to roll and/or pitch, particularly when meeting/passing another large ship.

The results further suggest that transits of large ships of the S-Class size are marginal today, when meeting/passing a large traffic ship under severe cross wind and current conditions (i.e., winds above 30 knots). The width of the existing TSC is concluded to be adequate under most circumstances, but marginal for very large ships meeting and passing under cross winds above 30 knots.

Additional conclusion details follow:

1. **The relative safety of the fully loaded and partially loaded S-Class ships was judged to be equivalent, with regard to control of the ship in the TSC.** This conclusion is based on the following results:

   - Adequate control was available with the fully loaded S-Class ship transiting the 52' deep TSC, under the severe cross wind and current conditions. This ship was able to successfully transit and meet/pass another large ship in the TSC, during all test transits.

   - Control of the fully loaded S-Class ship was found to be equivalent to that of the partially loaded ship. The fully loaded S-Class ship handled better than the partially loaded S-Class ship under the severe cross wind and current conditions. Whereas the fully loaded ship was able to hold course in the channel at a speed of 8 knots, the partially loaded ship required a higher speed to achieve a minimum level of acceptable control. The fully loaded ship was, however, constrained to an upper speed limit of 10 knots, due to a potential for grounding under the severe wind and current conditions. The partially loaded ship, on the other hand, was able to transit at a higher speed, and thus attained a level of control equivalent to that of the fully loaded ship. As a result, the pilot judged the controllability of both ships to be equivalent.

- The two ship configurations required equivalent crab angles and rudder angles to transit the TSC, at their respective speeds, under severe wind and current conditions.

- Transits in the fully loaded S-Class ship resulted in an average CPA range to the traffic ship of at least as large as that achieved in transits with the partially loaded ship, when under severe cross wind and current conditions.

- The distances to the channel boundary during the passing situation were approximately equivalent for both the fully loaded and partially loaded S-Class ships under severe wind and current conditions. Furthermore, the average distances were above the minimum safety criteria expressed by the pilot.

- The data suggest equivalent safety between the design and baseline conditions (i.e., fully loaded S-Class ship in the 52’ TSC, in comparison with the partially loaded S-Class ship in the existing TSC) with regard to meeting and passing in the TSC.

2. **The TSC width is concluded to be adequate under most circumstances, but marginal for very large ships meeting and passing under cross winds of 30 knots and higher. This conclusion applies to large ships in general, including the fully loaded and partially loaded S-Class ships. Constraints should not be imposed on ships; rather, caution should be exercised when high winds are present and when a ship is likely to meet and pass another large ship. The following findings support this conclusion:**

   - The equivalent level of ship control exhibited by the fully loaded and partially loaded S-Class ships in their respective TSC designs, indicates equivalent safety in transiting the TSC. Since performance of the partially loaded ship was deemed an adequate measure of acceptable safety, it is reasonable to conclude that the fully loaded ship is also safe to transit the 52’ deep TSC (Note, this conclusion does not address the potential for grounding).

   - The results suggest that a marginal level of safety is present when either ship transits the TSC under severe wind and current conditions, particularly when meeting/passing a large outbound ship. The average CPA range to the traffic ship achieved during transits in both the fully loaded and partially loaded S-Class ships, although considered equivalent, were below the safety criterion identified by the pilot prior to participating in the simulator transits. This finding does not question the safety of the fully loaded ship in comparison with the partially loaded ship; it does, however, highlight the difficulty and hazard of a large ship meeting and passing another large ship in the TSC, when under severe wind and current conditions. This finding advises that caution should be exercised in deciding to transit the TSC when cross winds above 30 knots are present.

3. **The 52’ deep TSC (i.e., proposed modifications) has marginal safety for transits by the fully loaded S-Class ship under severe cross wind and current conditions (i.e., above 30 knots), particularly when meeting/passing another large ship. A potential problem of grounding exists.**

   - The amount of squat associated with the fully loaded S-Class ship, having a draft of 47’ in a 52’ deep channel, severely reduces the UKC. Squat is greater than 5’ at 14 knots, which would ground the ship in a 52’ deep TSC. At a speed of 12 knots, UKC is less than 1 ½’.

   - Speeds above 10 knots should be considered marginal, especially in the presence of strong cross winds and when meeting/passing a large ship.

- Ship roll, particularly when meeting/passing a large ship under severe wind conditions, exacerbates the problem of limited UKC due to squat, resulting in an increased potential for grounding. The fully loaded S-Class ship doing 10 knots often grounded during the simulated transits, after meeting/passing a traffic ship, as a result of roll. Subsequent investigation indicated that the amount of roll provided by the simulation model was excessive. Consequently, a similar frequency of grounding may not occur at sea, under similar conditions. Nevertheless, the very small UKC available at speeds of 10 knots or higher, together with the likelihood of some roll from strong cross winds, large rudder angles, and when meeting/passing a large ship, indicates a logical potential for grounding in the 52' deep TSC.

- The safety of bringing the fully loaded S-Class ship inbound through the TSC was rated by the pilot as worse than that of the partially loaded S-Class ship, because of the grounding potential.

Further investigation is necessary to definitively resolve the issue of potential grounding by the fully loaded S-Class ship.

F.2 RECOMMENDATIONS

The recommendations stemming from the findings of this study are:

1. The ACOE should proceed with the current plans for dredging the TSC to a depth of 50 feet.

2. If funding is available, the TSC should be dredged to a depth greater than 50 feet (e.g., 52 feet), to provide a greater margin of safety from in-channel grounding by very large ships, such as the fully loaded S-Class ship.

3. With additional funding availability, the channel should be made wider (e.g., 1,200 feet) to provide a better margin of safety for piloting large ships under severe wind and current conditions.

4. The potential for the fully loaded S-Class ship to ground in the proposed TSC should be thoroughly investigated, to definitively determine the likelihood of grounding as a function of the following factors: a) wind, current and wave conditions; b) own ship speeds; c) meeting/passing conditions; and d) channel depths.

5. Information should be compiled and disseminated to appropriate organizations and persons (e.g., pilots, ship operators), providing guidance regarding the hazards associated with bringing large deep draft ships into the harbor under severe wind and current conditions. This should address a) the potential for grounding and its causal factors; and b) ship control issues under severe wind and current conditions.

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GLOSSARY

ACOE	US Army Corps of Engineers
ACOE-ND	US Army Corps of Engineers, Norfolk District
Analysis Approach	Investigative approach that relies primarily on descriptive statistics and pilot judgments. This approach starts with a test plan. However, the test scenario of next run may be modified based on the findings of the preceding runs, to seek for more useful information to meet the study objectives. This approach contrasts with the Balanced Experiment Approach in that study findings are the result of participant opinions, based largely on observational data.
ARPA	Automated Radar Plotting Aid
Balanced Experiment Approach	A formal experiment approach that relies on inferential statistical analysis to identify causal relationships between the variables of interest, based on the statistical significance of collected data. This approach follows the pre-determined test plan throughout the data collection process, with no deviations. This approach contrasts with the Analysis Approach in that the statistically determined cause-and-effect results are integrated with pilot judgments and other data, to arrive at the study findings.
CAORF	Computer Aided Operations Research Facility
Collier	Coal carrier
CPA	Closest Point of Approach
CSO	Control Station Operator
Descriptive Statistics	Descriptive statistics are used to describe the basic features of the data in a study. They provide simple summaries about the data sample and the measures. An example is the statistics of average.
DMI	Danish Maritime Institute
DNV	Det Norske Veritas
ERDC	Engineer Research and Development Center
Inferential Statistical Analysis	Inferential statistics attempt to reach conclusions that extend beyond the immediate data alone, inferring characteristics of test variables from the data of limited samples. For example,

	inferential statistics may be used to determine if the observed difference between two groups of data is significant, or just a random occurrence.
MLLW	Mean lower low water
NOAA	National Oceanic and Atmospheric Administration
Ownship	The ship represented by the bridge simulator
STCW	Standards of Training, Certification, and Watchkeeping; an international agreement that the U.S. and other 112 maritime states-parties have signed (based on 1995 statistics)
TEU	Twenty Equivalent Units, a measurement unit depicting the cargo handling capacity of a containership
TO	Test Observer
TSC	Thimble Shoal Channel
UKC	Under the Keel Clearance
USMMA	United States Merchant Marine Academy
VBSS	Visual Bridge Ship-handling Simulator
VPA	Virginia Pilot Association
WES	Waterways Experimental Station

APPENDIX A

COMPUTER AIDED OPERATIONS RESEARCH FACILITY

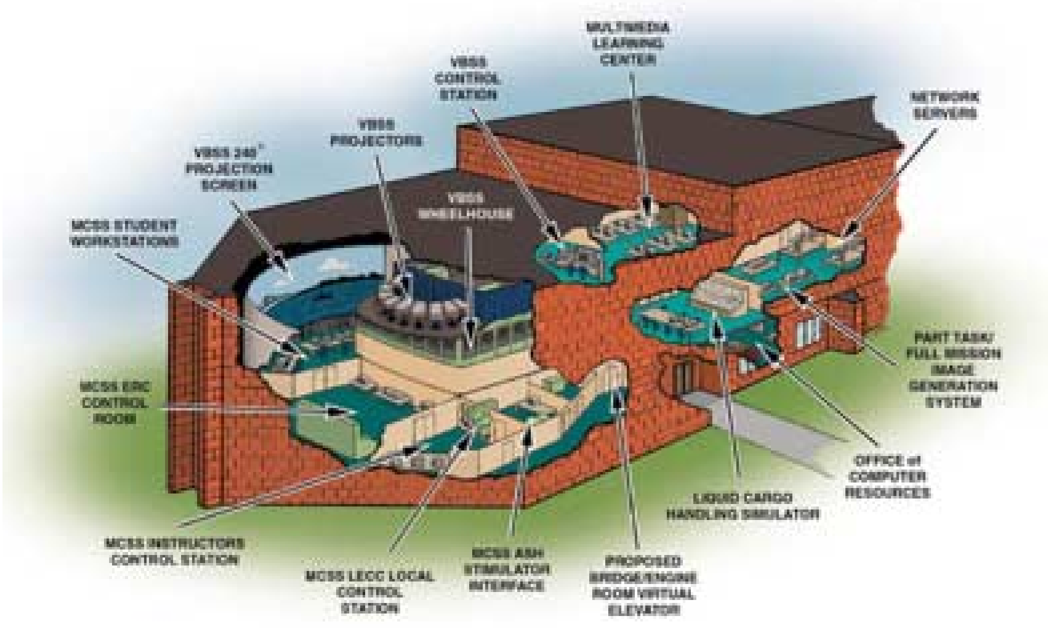
A BRIEF HISTORY

In 1962, the U.S. Merchant Marine Academy (USMMA) placed the Nuclear Ship *Savannah* power plant simulator into successful operation, a pioneering effort that soon became the model for many shore-based nuclear power plant simulators. That same year, the USMMA also placed a radar simulator in operation and aspired to build a more comprehensive navigation simulator with some form of visual imagery. Thirteen years later, the Computer Aided Operations Research Facility (CAORF) became the culmination of that aspiration.

In 1975, the U.S. Maritime Administration (MARAD) installed a complex Visual Bridge Ship-handling Simulator (VBSS) at the Academy for the purposes of maritime training and controlled research into man/ship/environment problems (Puglisi, 2000). The CAORF simulator was the first marine simulator ever to use Computer-Generated Imagery (CGI), and thus set the standard for all simulators of its kind that followed. Duplication of the bridge environment, detailed modeling of ship handling responses, a sophisticated control station, and the capability to simulate any vessel in any port or area in the world soon became the core of a complex human factors laboratory dedicated to the purpose of examining the human element in a number of marine operations.

Since that time, CAORF has provided answers in various areas of applied marine research, including:

- Improving the safety and versatility of port and waterway configuration
- Evaluating ship and equipment designs, and
- Establishing regulatory requirements and standards for simulation training and certification.



Cutaway Drawing of CAORF Building

Four decades later, the need for improved training, increasing educational requirements and advances in technology have driven the transformation of CAORF to its present configuration. Currently the facility now houses multiple computer-oriented applications, including:

- Administrative and Academic network servers and monitoring
- A Network Engineering Research Laboratory (NERL)
- Two (2) interactive Visual Bridge Simulation Systems (VBSS)
- A Machinery Control System Simulator (MCSS) that replicates the functional operation of a medium speed diesel engine room power plant
- A Liquid Cargo Handling Simulator
- A Multimedia Computer Laboratory, and
- The Office of Computer Resources (OCR).

VBSS Simulator Wheelhouse

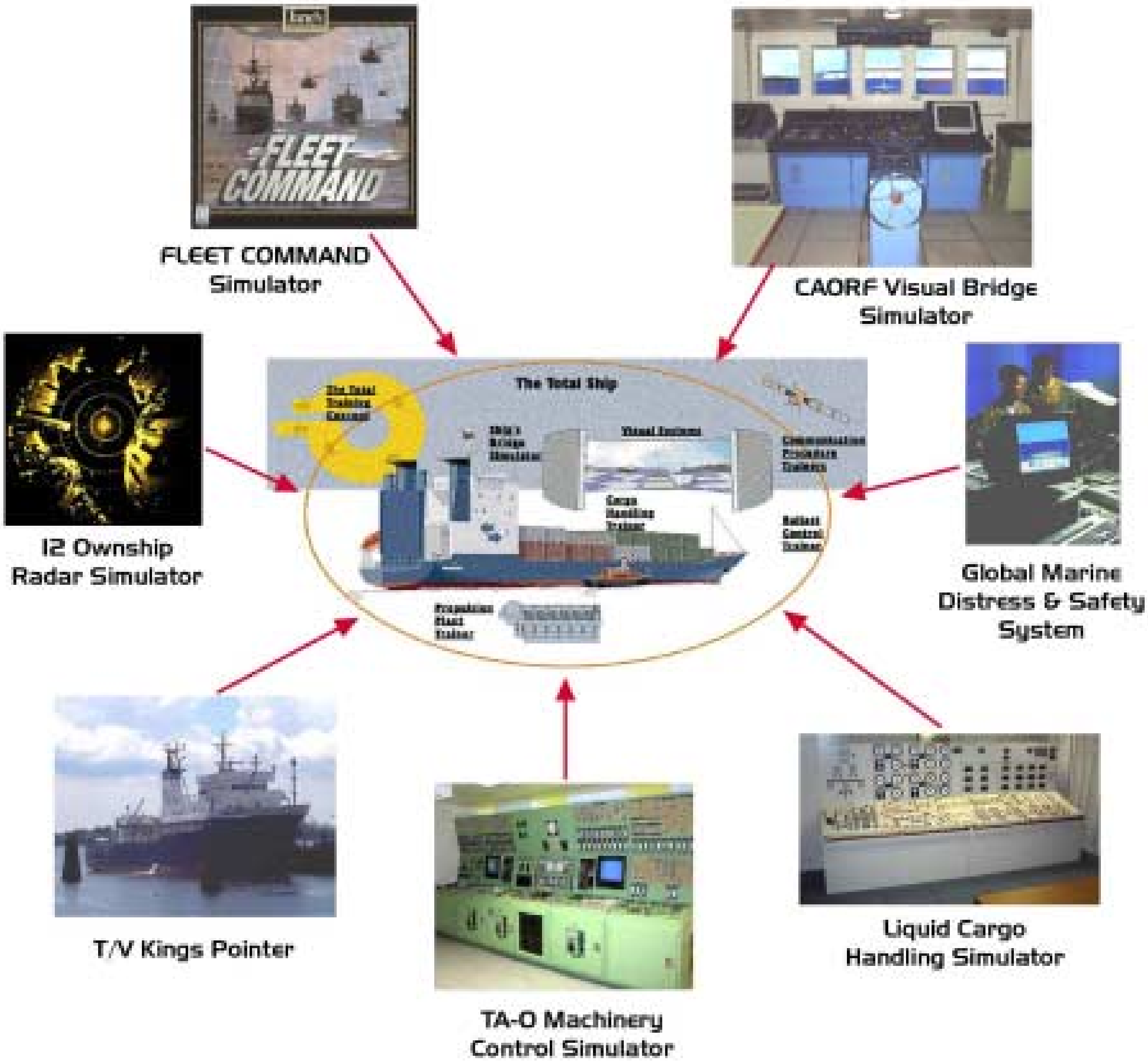
The VBSS has been upgraded to a modified KNCSI POLARIS™ system using a Danish Maritime Institute *Den-Mark 1* Mathematical Model and *MultiGen-Paradigm* Image Generation, and integrated with the facility's MCSS Simulator software. Utilizing nine *Davis 3D-Perception* DLP (Digital Light Projection) projectors, a 240-degree field of view visual scene (with a radius of 29 feet), additional aft visual scene views, an extensive bridge mockup complete with a full complement of equipment meeting *Standards of Training, Certification, and Watchkeeping* (STCW) and *Det Norske Veritas* (DNV) compliance requirements, environmental effects (consisting of wind, water current, depth, and bank forces), and high-fidelity own ship and passing ship hydrodynamic effects, the system realistically presents the total marine scene. Integration of aft visual scene views and a Virtual Reality (VR) helmet to provide over-the-side visualization is also on the horizon as the Academy continually strives to meet the multimedia educational challenge of tomorrow.

VBSS Control Station

MCSS Engine Room Console

Liquid Cargo Simulator Console

USMMA TOTAL SHIP SIMULATION CONCEPT



RESEARCH PROCESS

The Computer Aided Operations Research Facility (CAORF) was established for controlled research into man/ship/environment problems. The main focus of the Visual Bridge Simulation System (VBSS) is to provide a realistic simulation of the bridge environment, ship response, waterway and port, and to investigate how these factors interact with and influence the shiphandler's ability to maneuver vessels under various conditions (Puglisi 2000).

The emphasis on the "man-in-the-loop" affords a well rounded approach, the purpose of which is to examine the human element in marine operations.

When a specific question is identified, preliminary analysis is made by marine research specialists at CAORF to determine what simulation approaches are better suited to meet client need. The client and CAORF staff will draw up a specific statement of objectives that defines the research plan. A program is then developed and executed, including the following tasks:

Experiment Design – definition of variables of interest, performance measures, and requirements for data analysis.

Planning and Preparation – development of scenarios, specification of types of ships, speeds, courses, and initial positions of ships in the scenarios, and collection of pertinent data.

Data Base Construction – Generation of visual, radar, situation display, and depth/current data bases.

Subject Acquisition – acquisition and scheduling of practicing deck officers (masters, mates, pilots) for participation in the scenarios as the "man-in-the-loop."

Conduct of Experiment – collection of data from on-line and/or off-line simulation.

Data Analysis – analysis of experimental data (plots, recorded parameter values, video tape, audio, observational).

Report Preparation – presentation of results, findings/recommendations in final report form.

SYSTEM HARDWARE

The simulator is a KNCSI POLARIS™ interactive system with the highest performance Silicon Graphics, Inc. (SGI) graphics.

Computer Image Generator – SGI Onyx-2/Infinite Reality-2 image generator constructs the computer generated visual images of the surrounding environment.

- Images in full color are projected onto a cylindrical screen having a radius of 29 feet, subtending 240° horizontal and 24° vertical fields of view
- Capabilities such as shading and texture mapping to provide high fidelity image presentation
- Moving horizon for presenting six degree of freedom motions
- 1.68 minutes/pixel horizontal graphic resolution and soft edge matching to provide seamless visual scene

Ship's Bridge – A simulated ship bridge, 20 feet (6.1 m) wide by 14 feet (4.3 m) deep which contains all equipment required for STCW/DNV compliance, including a large screen display consisting of a 58 foot diameter screen to provide proper depth of field required for accurate range and bearing estimation.

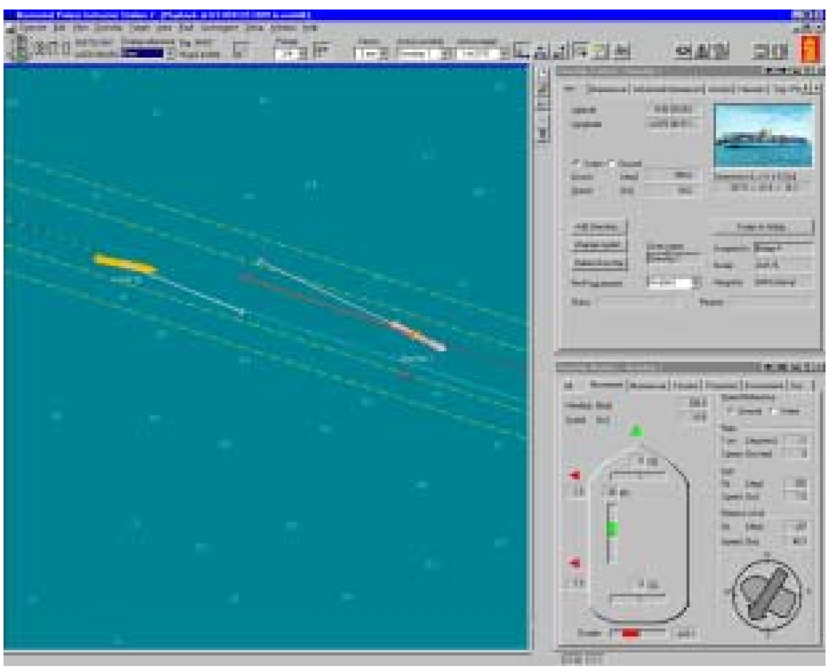
- Steering stand with
  - Gyro repeater
  - Rudder order indicator
  - Rudder angle indicator
  - Rate of turn indicator
- Overhead console analog display of
  - Wind speed
  - Wind direction
  - Temperature
  - Port rudder angle
  - Starboard rudder angle
  - Rate of turn
- Overhead console digital display of
  - Heading
  - Speed
  - Time
  - Doppler log
- Magnetic compass, ceiling-mounted periscope-type
- Floor console consisting of panels for
  - Steering system
  - Engine telegraph
  - Throttle control
  - Thruster control
  - Combinatory control
  - RPM and start air indicators
  - Gyro repeater
  - Gyro/steering gear control
  - Log/distance/time
  - Watch responsibility/engine control
- A collision avoidance system
- An ARPA radar
- Electronic Chart Display Information System (ECDIS)
- Bridge wing gyro repeater with pelorus mounted
- Floor console consisting of panels for
  - VHF
  - VHF DSC
  - Navigation lights
  - Signal lights
  - Sound signals with manual and automatic timer whistle control

- Engine alarm
  - Fire indicator
  - Distress alert
- Table console consisting of panels for
  - GPS
  - Loran-C
  - NavTex
  - Depth echo sounder
- Sound powered phone

Instructor Control and Observation Station – Central location from which the simulator experiment is initialized, controlled, and monitored.

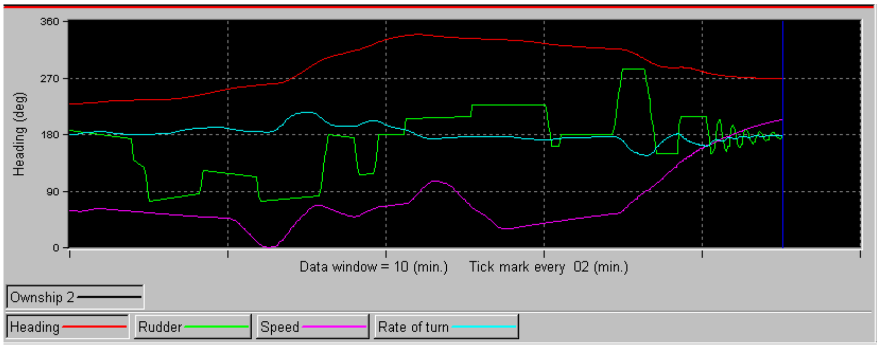
- Multiple bridge control (currently 2, but up to a maximum of 8 virtual bridges)
- Traffic ships, assist tugboats, environmental conditions, and mechanical failures can be controlled by operators
- Performance of the vessel and test subjects are monitored and recorded by the observers
- All communications between bridge and outside persons are carried out from this station

A multitude of information is available at the instructor control station, for presentation on a variety of displays. One of the primary control station displays is shown below. This display consists of two primary information areas, a geographic plot to the left and a presentation of detailed scenario information to the right. The geographic plot shows the gaming area of current focus as well as the actions of ownship and traffic vessel(s). History tracks are shown for both ships.

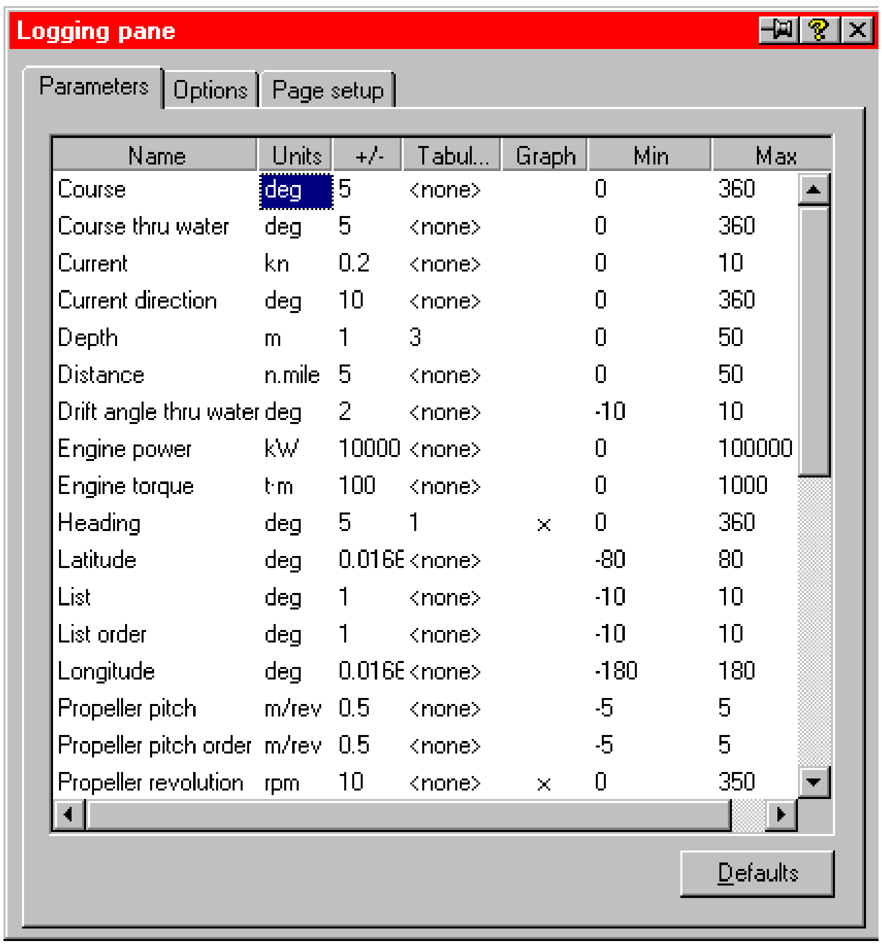


Control Station Display

The bottom area of the display can be expanded to present many scenario parameters in either graphic or tabulated data formats, selectable by the Control Station Operator (CSO).



Graphics Display of Selected Parameters Plotted Over Time at Control Station



Logging Pane from Simulator Exercise Assessment (SEA) System to automate parameter data collection and presentation for Debriefing and Assessment

CSOs monitor and control the scenario using these displays. Instructors and experiment staff use these displays for monitoring the details of the evolving scenario. They also use these displays for post-scenario analysis in debriefing area.

SIMULATION MATH MODEL PLATFORM, MODELING TOOLS, AND SHIP MODELS

Mathematical Model Platform – The ship motion simulation math model of VBSS is based on DMI Den-Mark1 math model platform that models all six Degrees of Freedom (DOF) ship motions. The component models include:

- Ownship hydrodynamics
  - Hull
  - Rudder(s)
  - Propeller(s)
  - Thruster(s)
- Environmental effects
  - Current
  - Wind
  - Wave
  - Tide
- Hydrodynamic interactions between ownship and traffic ships as well as with proximate boundary
  - Passing ship effects
  - Shallow water effects
  - Bank effects
- External assisting forces
  - Tugs
- Contacting forces
  - Hawser
  - Fender
  - Anchors
- Machinery dynamics
  - Engine
  - Steering gear
  - Thruster system
  - Anchor winch
  - Hawser winch
- Propulsion Control
  - Combinator
- Piloting Control
  - Autopilot

Modeling Tools – Includes modeling software, fast-time simulation software, real-time simulation software for the DMI Den-Mark1 math model platform.

- Ship primary model development tool is DMI MsDat NT version. The software includes a DMI ship towing tank maneuvering test data base, and a neural network scheme to generate ship hull hydrodynamic model for further adjustment and validation. The software also includes other databases for propeller, rudder, etc. to generate the look up tables for simulations. Another complimentary tool is DMI software OCEAN, which calculates the wave effects data files for calculating wave induced forces and moments.

- Fast-time simulation tool is Den-Mark1 simulation program on NT or UNIX platform
- Real-time simulation tool is DMI SimFlex simulation program for NT with desktop workstation Graphic User Interface (GUI)
- Real-time simulation utilizes Kongsberg Norcontol Simulation, Inc. (KNCSI) Polaris and Panorama systems

Ship Models – CAORF VBSS has the capability to simulate various types of ship. The ownship models currently available at CAORF include:

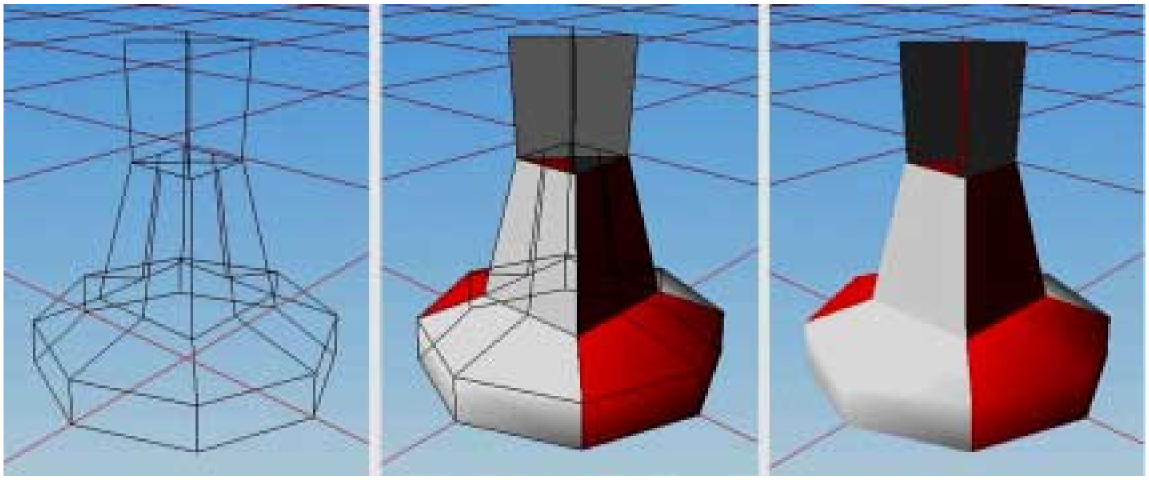
MODEL DESCRIPTION	**LOAD COND**	**LOA** *m*	**BEAM** *m*	**DRAFT** *m*
3K DWT Passenger Ferry	Design	152.0	23.1	5.1
35.8m Stern Trawler	Loaded	41.1	9.6	5.4
50M Coaster Service Cargo Ship	Loaded	55.0	9.3	3.5
M-Class Containership	Loaded	294.1	32.2	13.1
293K DWT Tanker	Loaded	343.7	56.4	21.8
4800 TEU Containership	Loaded	318.2	42.8	14.0
6,600 TEU Containership @47'	Loaded	347.0	42.9	14.3
6,600 TEU Containership @38'	PLoaded	347.0	42.9	11.6
150K DWT Collier	Loaded	289.6	44.2	15.2
T-AGOS 2	Design	68.3	13.1	4.6
Cadet 40K DWT Tanker	Loaded	182.9	32.3	11.4
Cadet 40K DWT Tanker, Ploaded	PLoaded	182.9	32.3	10.1
T-AO 187 Fleet Oiler	Loaded	206.5	29.7	10.5

DATABASES, CONSTRUCTION PROCESS, AND DATABASE INVENTORY

Types of Databases

By definition, a *database* is merely a collection of related computer records that can be accessed, manipulated or utilized in a systematic way. At the Computer Aided Operations Research Facility (CAORF), whereas the entire integrated model of a specific geographic area is referred to as *a data base*, the model is actually comprised of six different databases that are each constructed separately: the *Visual*, *Situation Display*, *Radar*, *Depth Contour*, *Water Current* and *Sound System* databases. Detailed explanations of these databases will be given on an individual basis within the remainder of this document.

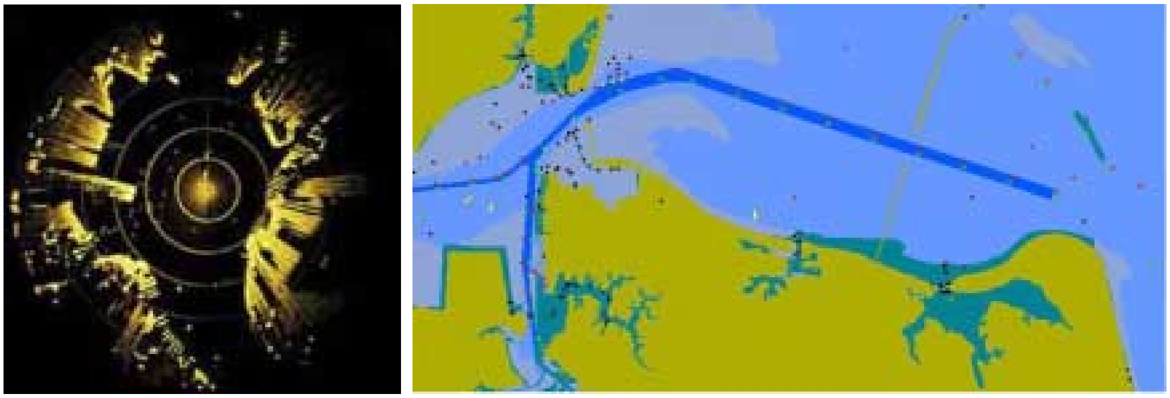
- **Visual Database:** The *Visual Database* is a model of all that is seen from *ownship* (the ship represented by the bridge simulator) as it traverses a waterway. All the buildings, buoys, landmasses, towers, tanks and traffic ships seen from ownship are included in this model. Any structure to be placed in the visual scene begins with a wire-frame model and ends with a colored, shaded and texture-mapped three-dimensional representation.



Typical buoy image construction for visual scene

- **Radar Database:** The function of the *Radar Database*, simply enough, is to simulate, in real time, signals generated by a shipboard radar transceiver and, in addition, to generate an idealized radar picture. The numerical data to this database define both terrain elevation and radar reflectivity. It is a network of line segments, polygons and discrete points organized in such a manner that when processed by the Radar Signal Generator (RSG) will produce a realistic radar image.

- **Situation Display Database:** The *Situation Display Database* is also referred to as the *Instructor's Station Database* due to its use mainly by instructors and control station operators to observe and coordinate experiments or training sessions being run on the simulator. The purpose of this database is to display an idealized chart of a harbor area with coastal outlines, navigational aids (buoys, ranges, etc.) and the numerical depth soundings and channel markings throughout the harbor. With this picture as a background, ships will be displayed as they move through this area at various scales available via the Control Station. Utilizing this as an underlay, ships can be plotted and displayed via full-color hardcopy printouts as they travel through the database.



Finished radar and situation display databases, respectively.

- **Depth Contour Database:** The *Depth Contour Database* consists of a composite database built from various bathometric data available for a harbor area. The result produces a three-dimensional mesh that accurately models the shape and contour of the ocean floor, and generates realistic depth sounding values when processed by the ship's fathometer.

- **Water Current Database**: A *Water Current Database* consists of a collection of discrete points each containing individual water speed and direction values stored via fixed vector structures. Using this, proper forces can be calculated and exerted on both the ownship and traffic ships to produce realistic effects.

- **Sound System Database:** The *Sound System Database* is used to generate sounds for a particular visual scene, including directional and distance effects as one approaches or moves away from a specific sound source. Currently, the system is capable of replicating a number of audio cues, including specific ship sounds, environmental sounds, weather-related sounds, and sounds associated with certain navigational cues.

Collection of Pertinent Information

Before any work can begin, certain information is required on which to base the construction of a database. The information needed to construct each of these databases can be obtained from various sources, including: coordinate systems data supplied by the Defense Mapping Agency (DMA) or Army Corps of Engineers (ACOE), engineering drawings or blueprints, nautical charts, topographical maps, digitized data, tide and current tables, on-site photographs, and various observations supplied by expert mariners familiar with the geographic area to be modeled.

Various nautical charts of a region give an overview of the general geographic area, while a more topographical representation can be derived from coordinate systems data, contour maps and blueprints of the area. Information regarding specific structures such as buildings or bridges can also be obtained from blueprints. In addition, photographs taken of the geographic areas to be modeled are always utilized to enhance the visual scene and aid in its construction. Photos such as these are extremely important, if not indispensable, since they supply various color and texture-mapping details along with giving a three-dimensional representation of details that cannot be obtained solely from two-dimensional charts and drawings.

Hydrographic data normally takes the form of depth soundings and depth contours supplied from nautical charts, data from tidal and current tables, and detailed bathometric readings supplied by the ACOE or facilities like the and Development Center/Waterways Experimental Station (ERDC/WES).

Similar information is needed for the building of traffic ship and ownship bow models to be used in the related exercises. In addition, high-fidelity ship hydrodynamic effects supplied by the Danish Maritime Institute (DMI) or similar facilities are used in the detailed modeling of all ship handling responses.

Once all this information is acquired and correlated, the various databases and data files can be laid out and construction initiated.

Database Construction

The first step in the construction of a database is to prepare the charts and drawings to be used. This involves physically locating and labeling certain points, structures and reference lines by hand. The chart or drawing is then fixed to a special electronic table, called a *Digitizer* or *Digitizing Tablet*, where the various line segments, polygons and discrete data points are *digitized*. Digitizing involves the assigning of X, Y, and Z-coordinates to the various structures marked on the prepared chart, and is done via a computer rather than by hand. A polygon, for database purposes, is defined as a closed series of edges. These polygons give the visual scene its three-dimensional appearance.

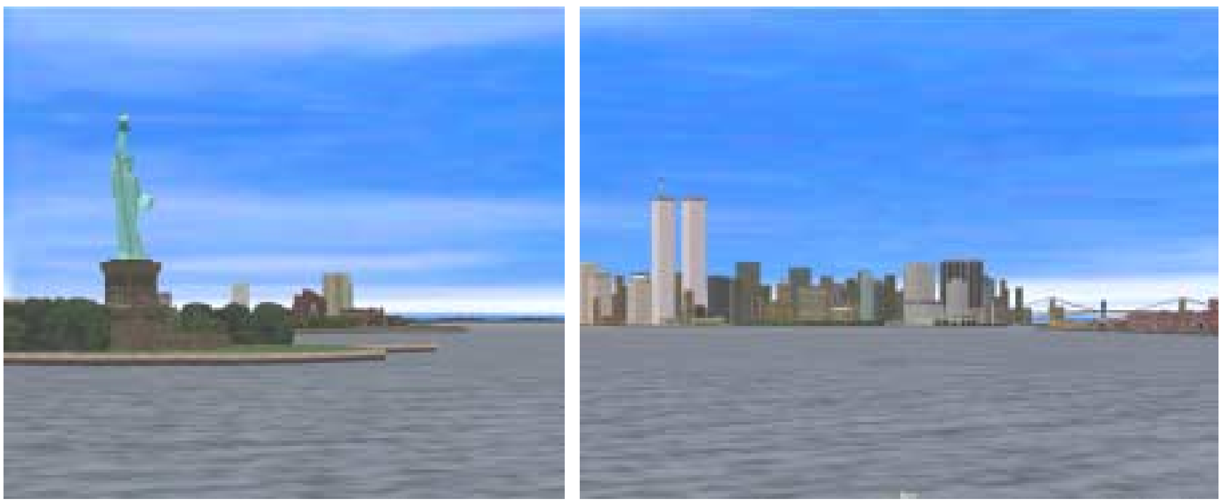
***GTCO*™ Digitizing Tablet with a prepared chart attached.**

After digitizing is completed, the resultant files are reformatted by use of a various software routines.

The first database built is normally the *Instructor's Station Database*. The original data file is run through various software programs with related data input in order to form the *Situation Display*. The display is then examined for correctness via an off-line *KNCSI POLARIS*™ and *PANORAMA*™ workstations that gives a graphic representation of the geographic area on a computer monitor.

The second database to be created is the *Depth Contour Database*. Various layers of the original data file, along with related tidal data, are run through a number of software programs in order to produce a three-dimensional mesh that accurately models the contour of the ocean floor. An alternate method of constructing this mesh allows direct conversion of ACOE depth data into a format useable by the simulator. The final *Depth Contour Database* is first examined for correctness via off-line plotting routines, and later using online data sampling from both the Control Station and the bridge's fathometer.

The third database to be constructed is the *Visual Database*, which is the most complex of all the databases. It is this database that eventually provides the pilot or watch-stander with a visual representation of the harbor as seen from the bridge of a vessel. Three-dimensional structures are set up via *MultiGen Creator* graphic software using the original data file, coordinate systems data, and various on-site photographs of the geographic area. Color and visual surface textures are associated with each structure at this time. It is during this intricate and time-consuming process that the landmasses, navigational aids, traffic ships, ownships and miscellaneous buildings and structures are created as graphic computer files. Once these files are set up, they are initially examined for correctness on an off-line *SeaView* workstation, after which they are transferred to a separate computer system and repeatedly examined and fine-tuned on the simulator.



Selected views from the New York Harbor Visual Database.

The *Radar Database* is the fourth database to be constructed. In order to create this database, the original *MultiGen* visual files and associated reflectivity data are run through an additional software program. The files are then converted into a suitable format that can be processed by the Radar Signal Generator (RSG) to produce a realistic radar image. When completed, the *Radar Database* is examined on an off-line *KNCSI POLARIS*™ workstation for accuracy and correctness.

The next database to be constructed is the *Water Current Database*. Using the *Instructor's Station Display* as a backdrop, current vectors containing velocity and phase angle information are created at discrete points via a *KNCSI POLARIS*™ software interface, and transferred to a separate computer system where the data can be accessed by the simulator. An alternate method allows direct conversion of ERDC/WES water current data into a format useable by the simulator.

The *Sound System Database* is the only database that is not necessarily dependent on a specific geographic area to be modeled. The database itself is a collection of audio files depicting ship sounds, environmental sounds, weather-related sounds, and sounds associated with certain navigational cues. These sound files can be either associated directly with certain *MultiGen* visual files during the creation process or activated on the simulator from the Control Station.

Validation/Revision

When all the databases for a specific geographic area have been completed and examined offline, they then undergo *preliminary online validation* by members of the CAORF staff who check out all aspects of the databases for realism as well as accuracy. This online checkout involves various test runs on the bridge simulator, during which any inaccuracies to the database are noted. After the preliminary validation, the process is repeated in the form of a second inspection made by the individual client.

In the case of a research and development project or outside commercial training, this inspection is normally conducted by expert pilots or masters supplied by the client and/or USMMA and familiar with the specific harbor area. If the database is to be used solely for the purpose of USMMA Midshipmen Training, the checkouts are performed by members of the Department of Marine Transportation located at the Academy.

Any necessary revisions or corrections to the databases are then implemented based upon these two validation sessions.

Databases Currently Available

The following geographic databases are currently available for use on the CAORF simulator:

- Generic Open Sea
- New York Harbor, New York
- Norfolk Harbor, Virginia
- Port Cristobal, Panama
- Rotterdam, Holland
- San Francisco Bay, California
- Santa Barbara Channel, California
- Santa Cruz Channel, California
- Singapore Strait, Indonesia
- Strait of Hormuz, Persian Gulf
- Valdez, Alaska

APPENDIX B

QUESTIONNAIRES

Contents **Page**

SAFETY CRITERIA QUESTIONNAIRE
NORFOLK THIMBLE SHOAL CHANNEL PROJECT

Name________________________________ Date ___ / ___ / ___ Scenario #_____

Please answer the following questions about the expected scenario conditions. Please provide observations and comments as appropriate; write in any available space, including the backsides. Additional sheets will be provided if needed.

1. Please rate each dimension in terms of the expected transits in the Thimble Shoal Channel. Circle the number that is most appropriate, between the ends of each scale. If you are not sure of any items, use your best judgment.

   A) Skill required to complete the transit:

   No Skill — High Skill

   1 2 3 4 5

   B) Transit difficulty:

   Easy — Difficult

   1 2 3 4 5

   C) Attention required to make the transit:

   Low — High

   1 2 3 4 5

   D) Stress level during the transit:

   Low — High

   1 2 3 4 5

   E) Degree of experience required to make the transit:

   Low — High

   1 2 3 4 5

2. What should be the minimum safety margin (clearance) to the channel boundary when you are inbound and meet an outgoing vessel?

______ feet

Comments:____

3. What should be the minimum safety margin (clearance) to the channel boundary when you are inbound in the channel and are <u>not</u> meeting another vessel?

______ feet

Comments:____

4. What should be the minimum acceptable safety margin (clearance) with the outbound vessel when you are meeting?

______ feet

Comments:____

5. When meeting an outbound vessel in Thimble Shoal Channel, which of the following represents the best meeting strategy: Position own ship to

_____ split the available lane.
_____ achieve greater clearance with the meeting vessel than with the channel boundary.
_____ achieve greater clearance with the channel boundary than with the meeting vessel .

Comments:____

6. In a "normal" inbound transit in the Thimble Shoal Channel, including meeting other vessels, what is the maximum rudder angle you would expect to use (typically)? Here "normal" refers to daytime, clear visibility, and moderate wind conditions.

± ______ degrees

Comments:____

7. In a "normal" inbound transit in the Thimble Shoal Channel, including meeting other vessels, what is the maximum Engine Order you would expect to use (typically)? Here "normal" refers to daytime, clear visibility, and moderate wind conditions.

____

Comments:____

8. What are the limiting environmental conditions for piloting a vessel in/out of the harbor using the Thimble Shoal Channel?

Wind direction ______, speed ______kts.
Current direction ______, speed ______kts.
Wave direction ______, height ______ft.

Should these differ for inbound or outbound? If so, how?______________________________

____

9. Is squat a concern when piloting in the Thimble Shoals Channel? ____No ____Yes

Comments:____

10. How much under-keel clearance do you judge as necessary for safe operation?

Bow ________ft. Squat at midship _________ft.

or:

Stern ________ft. Trim by stern _________ft.

Please provide comments about any additional criteria that should be considered when determining transit safety.

PILOT SUMMARY QUESTIONNAIRE
NORFOLK THIMBLE SHOAL CHANNEL PROJECT

Name______________________________ Date ______ / _____ / _____

Please answer the following questions about the set of scenario runs you have just completed. Please provide observations and comments; write in any available space, including the backsides. Additional sheets will be provided if needed.

1. Please rate each dimension in terms of your overall judgment about the Thimble Shoal Channel transits, based on the simulator runs. Circle the number that is most appropriate, between the ends of each scale. If you are not sure of any items, use your best judgment.

   A) Skill required to complete a transit:

   No Skill — High Skill

   1 2 3 4 5

   B) Transit difficulty:

   Easy — Difficult

   1 2 3 4 5

   C) Attention required to make the transit:

   Low — High

   1 2 3 4 5

   D) Stress level during the transit:

   Low — High

   1 2 3 4 5

   E) Degree of experience required to make the transit:

   Low — High

   1 2 3 4 5

2. What inbound transit speed do you suggest? ______kts.

   Should this differ under certain conditions? _____No ____Yes

   If "Yes", please explain the conditions and the respective recommended speeds. ___________

   ____

3. Is the channel width adequate? ____No ____Yes

   If "No", why not?____

   ____

   If "No", please identify on a chartlett the sections that should be changed, and the recommended changes (channel width).

4. Is the 50' channel depth adequate (For example, with regard to the squat you experienced on the simulator)?

   ____No ____Yes

   If "No", why not?____

   ____

   If "No", please identify on a chartlett the sections that should be changed, and the recommended changes (channel depth).

5. Rate the overall safety of the inbound transit under the planned 50 ft depth channel design.

   Very safe ______
   Average ______
   Marginal ______

   Comments:____

6. Rate the safety when meeting (under the planned 50 ft depth channel design).

   Very safe ______
   Average ______
   Marginal ______

   Comments:____

7. Should constraints be imposed on inbound and/or outbound traffic under certain conditions (e.g., large vessels, strong winds, meeting, speed)?

____No ____Yes

If "Yes", please explain you rationale, and recommend appropriate constraints.____________

____

8. Have you experienced wind and current conditions as severe as those simulated during the scenarios?

____No ______Yes

If "No", what were the worst wind and current conditions you have experienced while bringing a large containership inbound through Thimble Shoal Channel?

Wind: _____kts., from the ____________direction

Current: _____kts., from the ____________direction

9. Based specifically on your transit experience in this study, did you find the shiphandling of the fully loaded S-Class vessel (47 ft depth) to be better-than, about the same, or worse-than the shiphandling of the partially loaded S-Class vessel (38 ft depth)?

better than _____
about the same _____
worse than _____

Comments:____

10. Based specifically on your transit experience in this study, rate the safety of bringing fully loaded (47 ft draft) S-Class vessels inbound through the Thimble Shoal Channel, in comparison with partially loaded S-Class vessels (38 ft draft)?

better than _____
about the same _____
worse than _____

Comments:____

11. Please describe any shiphandling problems you experienced during the simulated transits.

Comments:____

____

12. Based on your simulator runs, what is your opinion about the proposed channel design?_____

____

____

13. Based on your past experience, did you find that the CAORF vessel handled as you would have expected ships of this class to handle?

____Yes ____No (please explain)

Comments:____

14. Did you feel that your shiphandling performance on the simulator continued to improve after completing the familiarization trials? ______Yes ______No

Did you feel that at some point your shiphandling performance began to deteriorate due to fatigue or boredom?

____Yes ____No

Comments:____

15. Please rate the details and accuracy of the visual scene (geographic layout, structures, landmarks) according to your needs to ascertain your position during the simulated transits:

Excellent ______
Good ______
Sufficient ______
Somewhat deficient ______
Poor ______

Comments:____

____

16. Were the aids to navigation (buoys and ranges) represented in the visual scene adequate for handling the fully loaded S-Class vessel?

Excellent ______
Good ______
Sufficient ______
Somewhat deficient ______
Poor ______

What changes do you suggest to placement and types of simulated navigation aids used in the study?____

____

17. Please rate the accuracy of the handling characteristics of the simulated vessel, based on your experience with this class of vessels in the past:

Excellent	______
Good	______
Sufficient	______
Somewhat deficient	______
Poor	______

Comments:____

____

18. Were there specific characteristics of the simulations, or differences from the real world, which you think may have affected your shiphandling performance (style), such that the results would be different in actual Thimble Shoal Channel transits?

____Yes (Please explain) ____No

Comments:____

____

19. What changes do you recommend for subsequent studies in Norfolk harbor, to the visual scene, ship models, procedures, and any other aspects of the simulation and study process?___

____

____

20. Please provide any additional comments you think may be relevant to the optimal design of the Thimble Shoal Channel.____

____

____

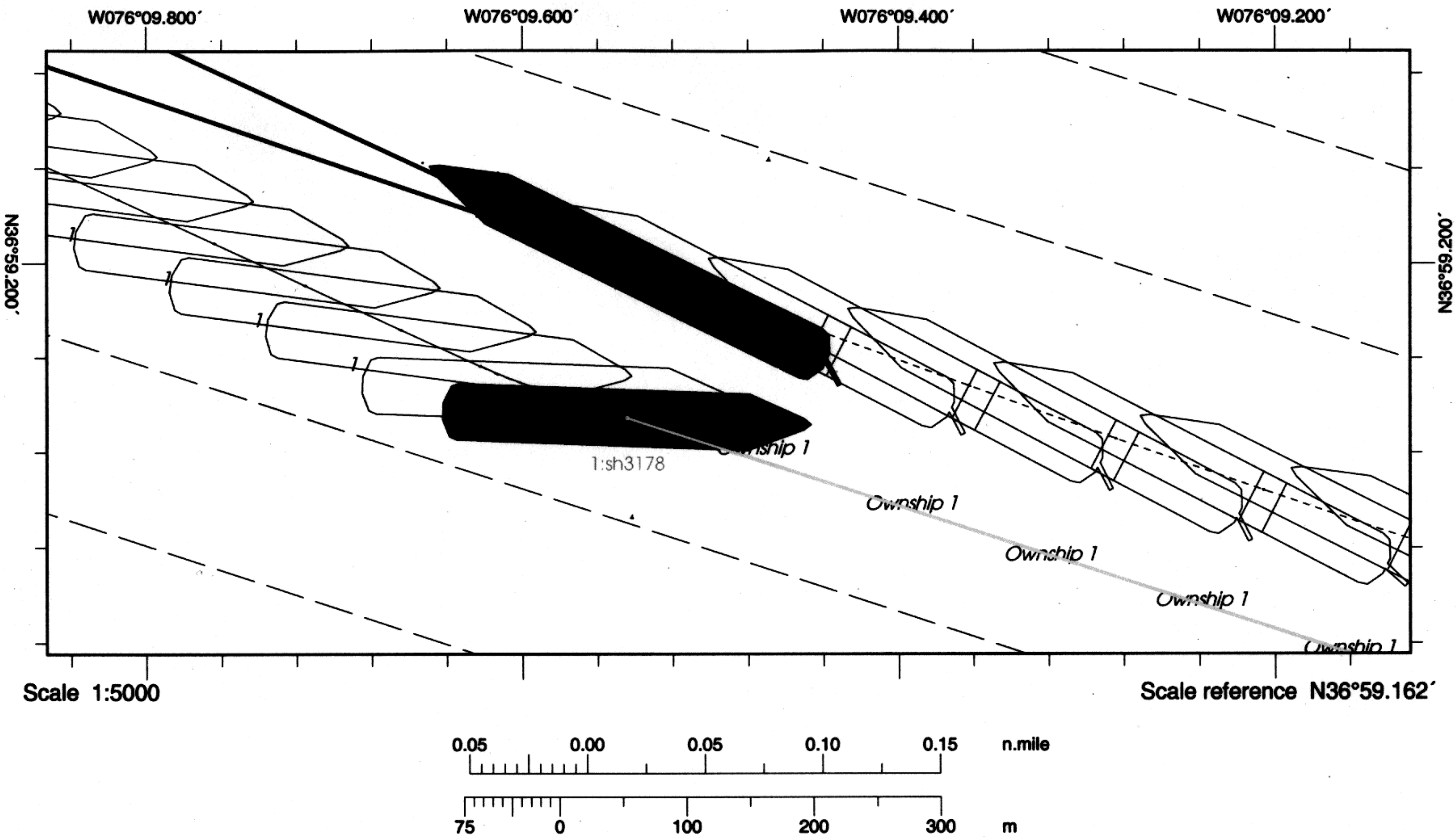
21. Please provide any additional comments you think may be relevant to improving the simulation and/or research process for future studies.______________________________

____

APPENDIX C

SCENARIO RUN TRACK PLOTS

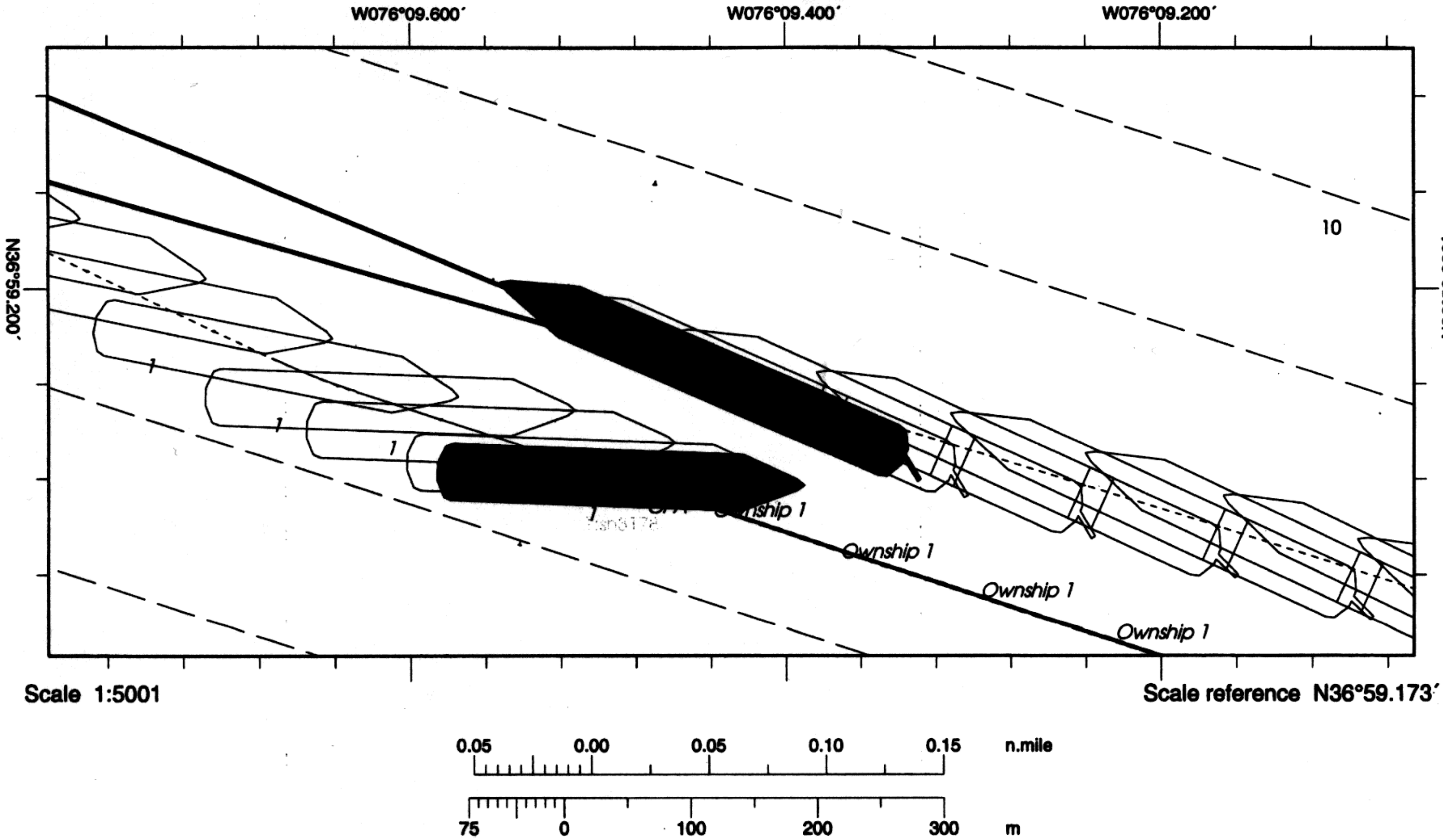
SCENARIO 1



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 12kts
Outbound: Collier 50ft Draft, Speed 8kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 45+ ft

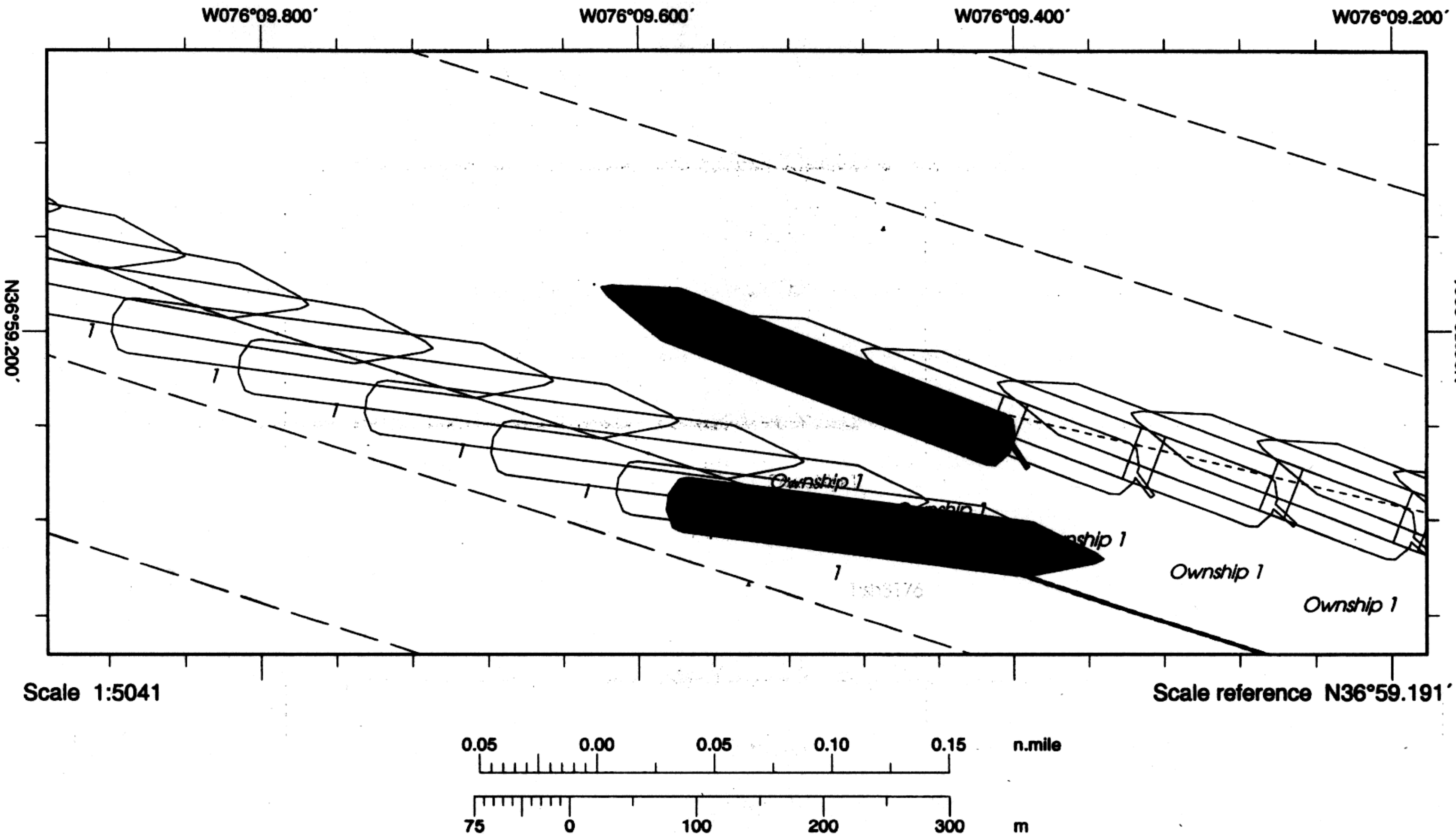
SCENARIO 2



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: Collier 50ft Draft, Speed 8kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 52 ft

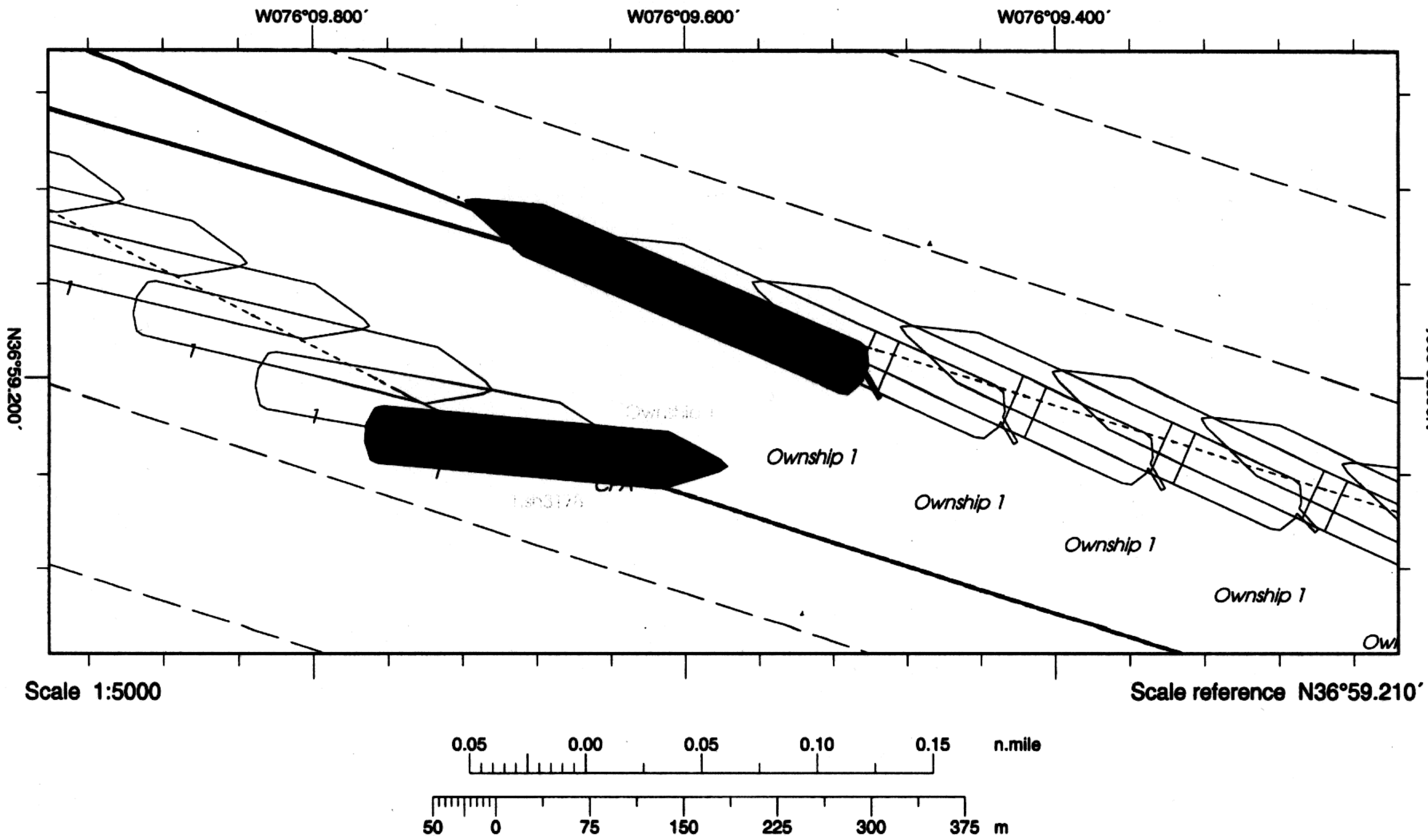
SCENARIO 3



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 52ft

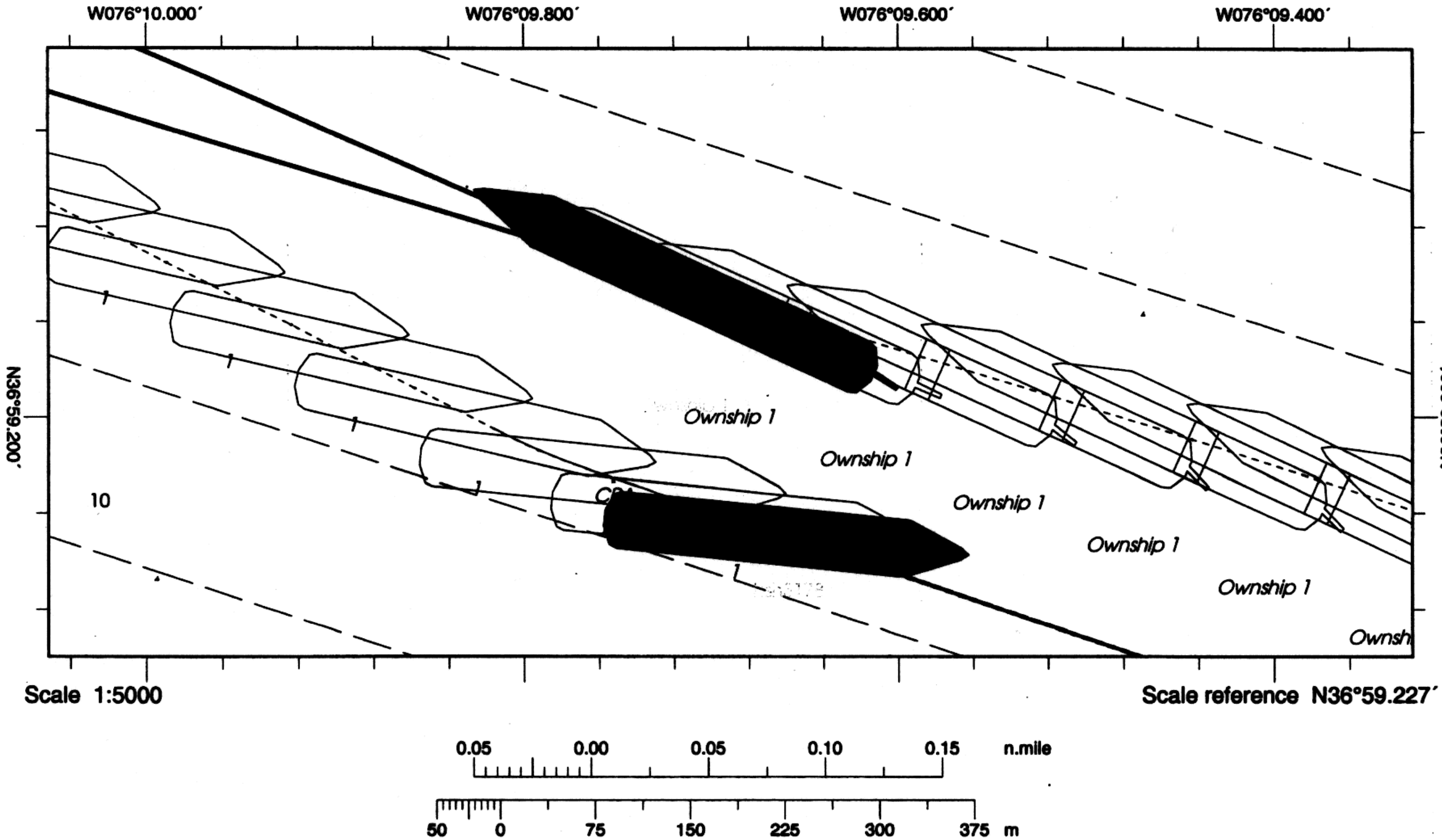
SCENARIO 4



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 12kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 45+ ft

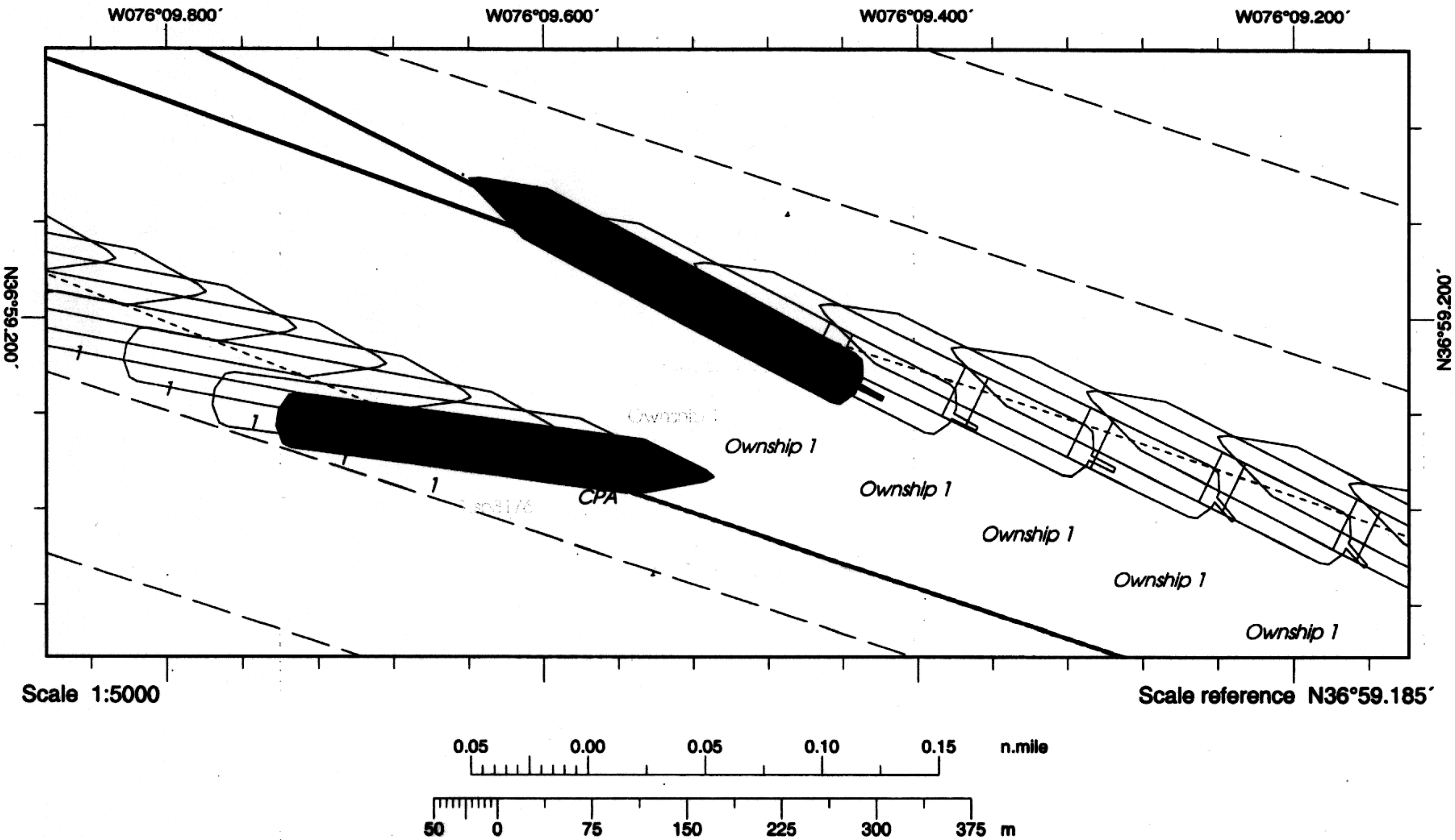
SCENARIO 5



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 52 ft

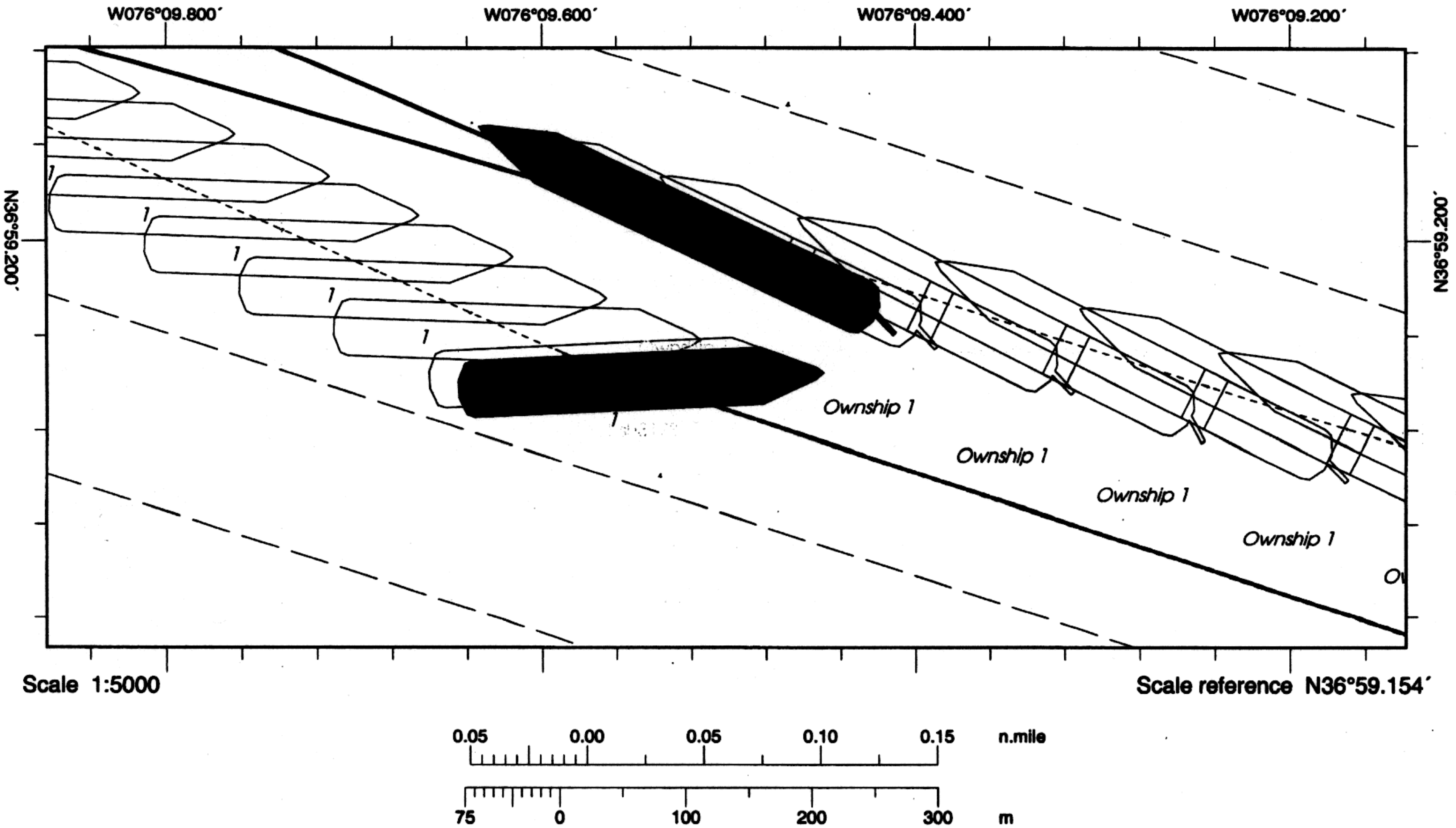
SCENARIO 6



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: S-Class 47ft Draft, Speed 8kts
Wind: 50kts from 45 Deg
Current: 1.5kts to 225 Deg
Channel Dept: 52 ft

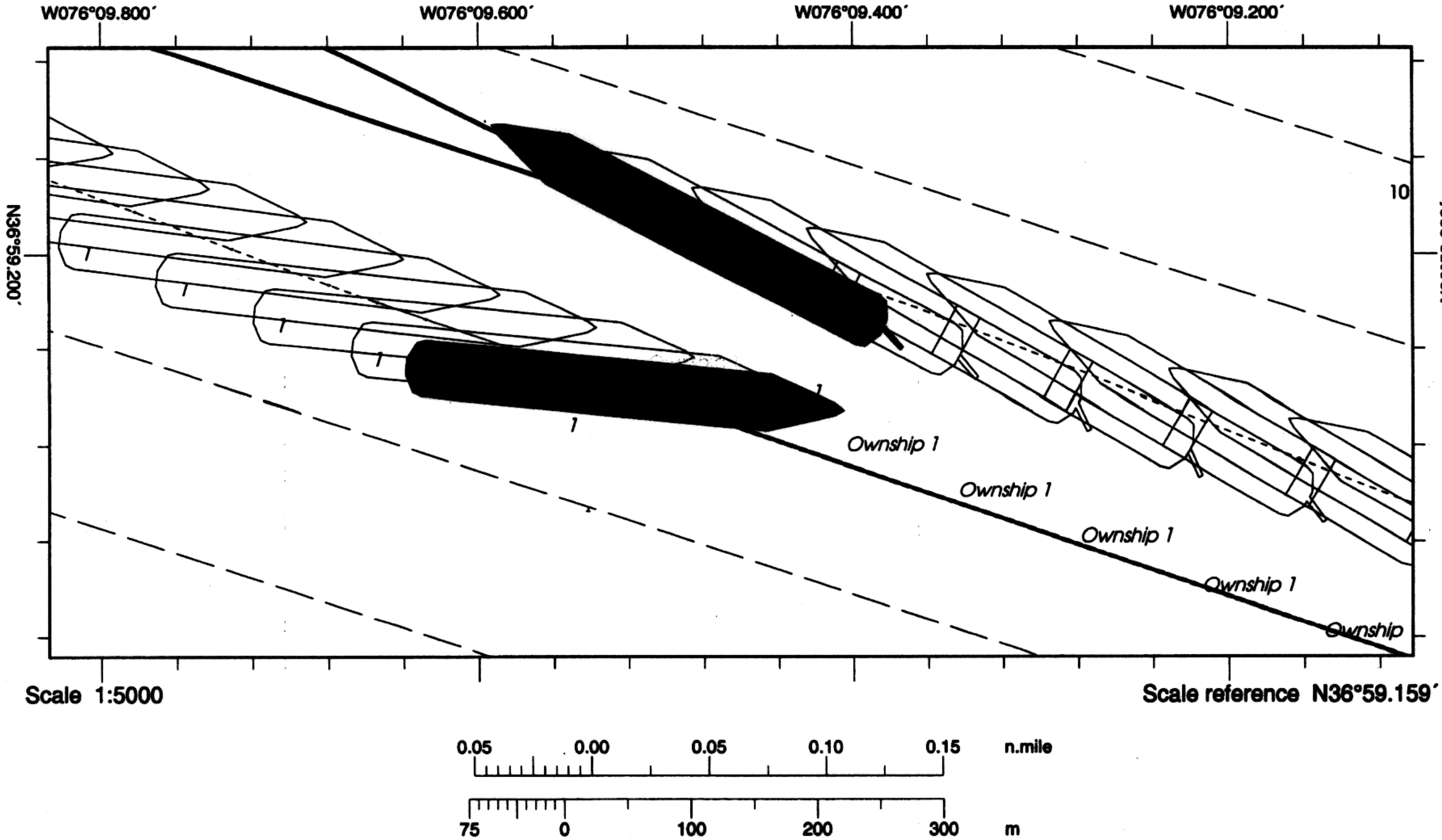
SCENARIO 7



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 12kts
Outbound: Collier 50ft Draft, Speed 8kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 45+ ft

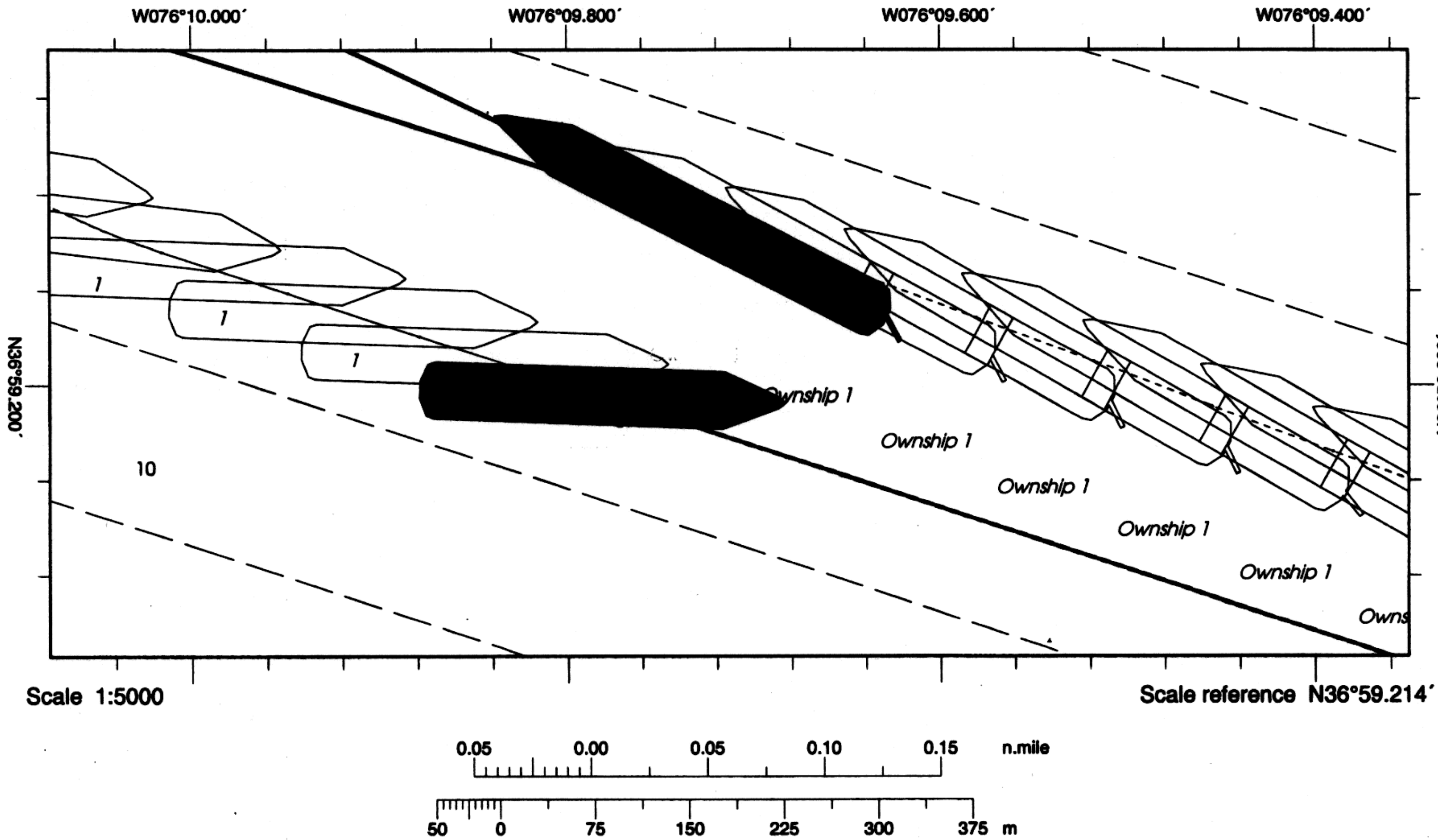
SCENARIO 8



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: S-Class 47ft Draft, Speed 8kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

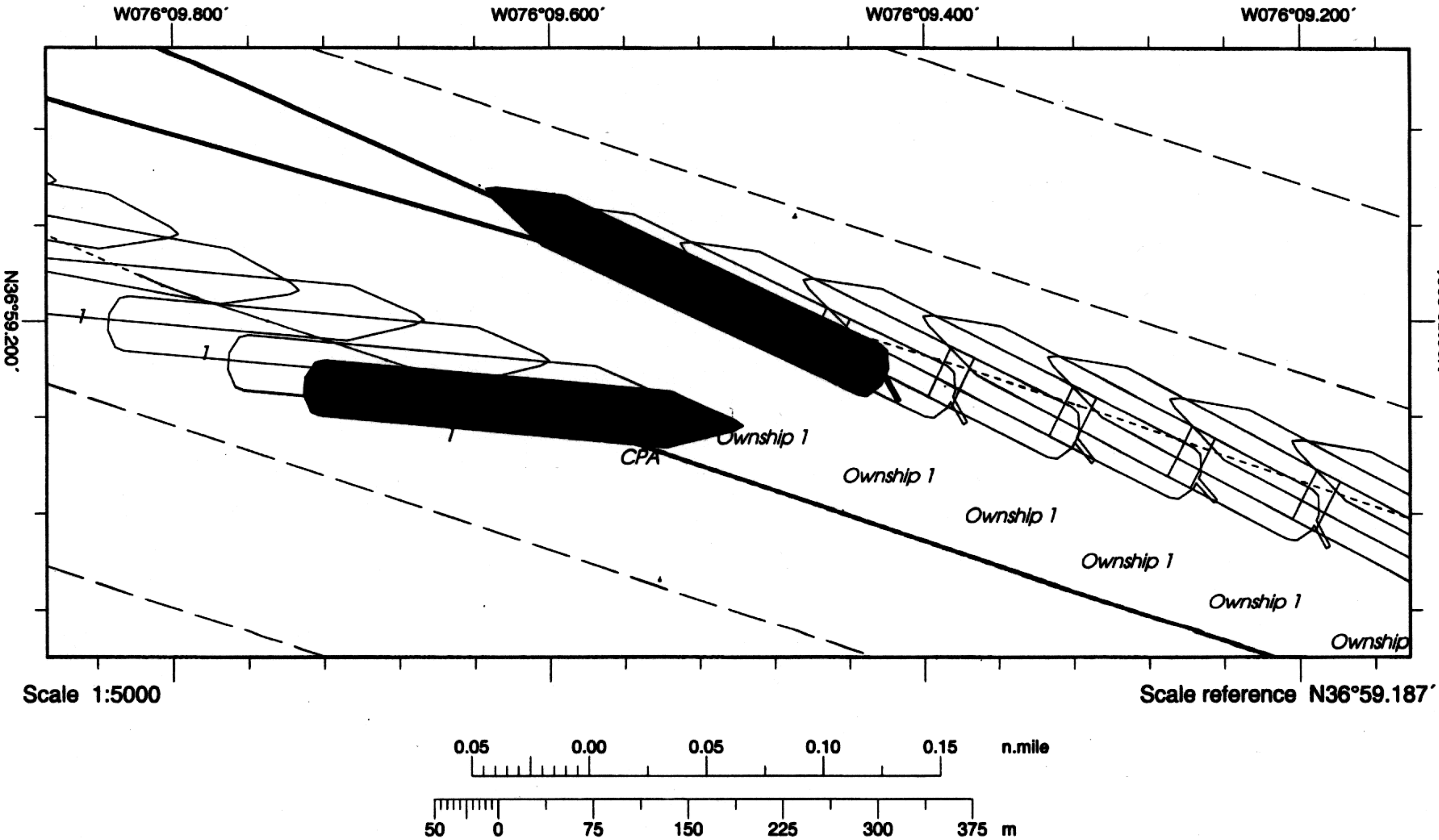
SCENARIO 9



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

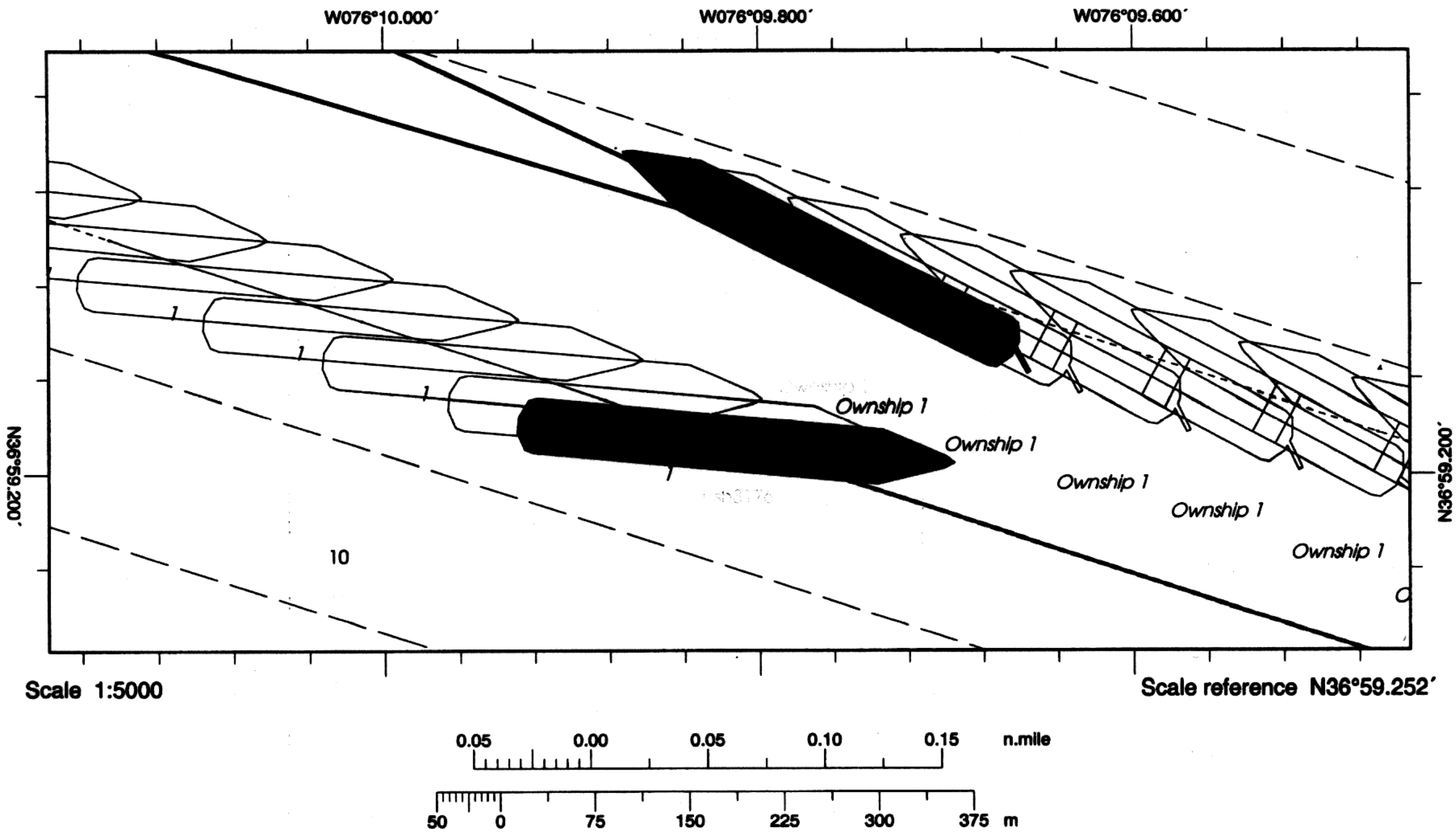
SCENARIO 10



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

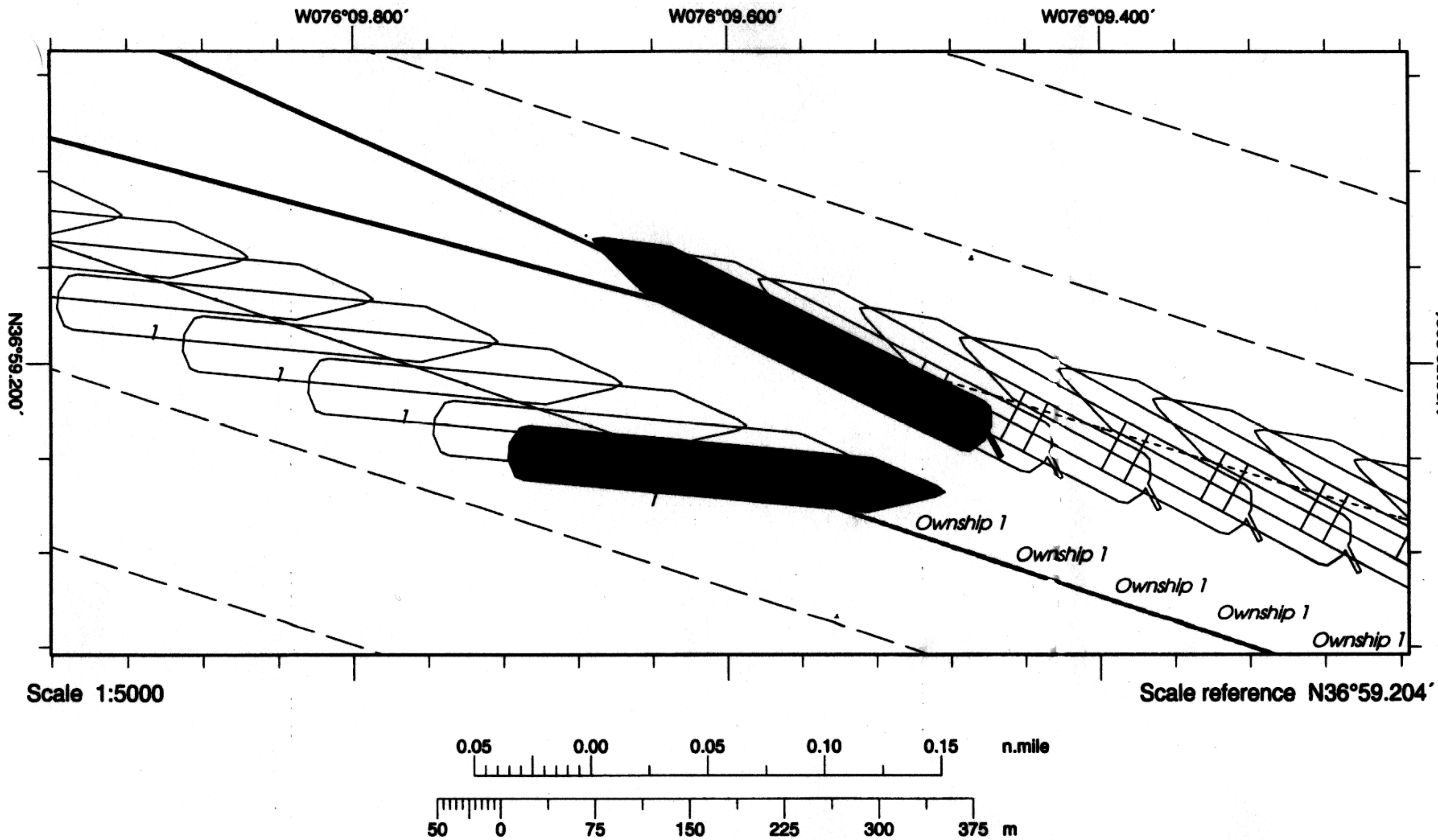
SCENARIO 11



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 9kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

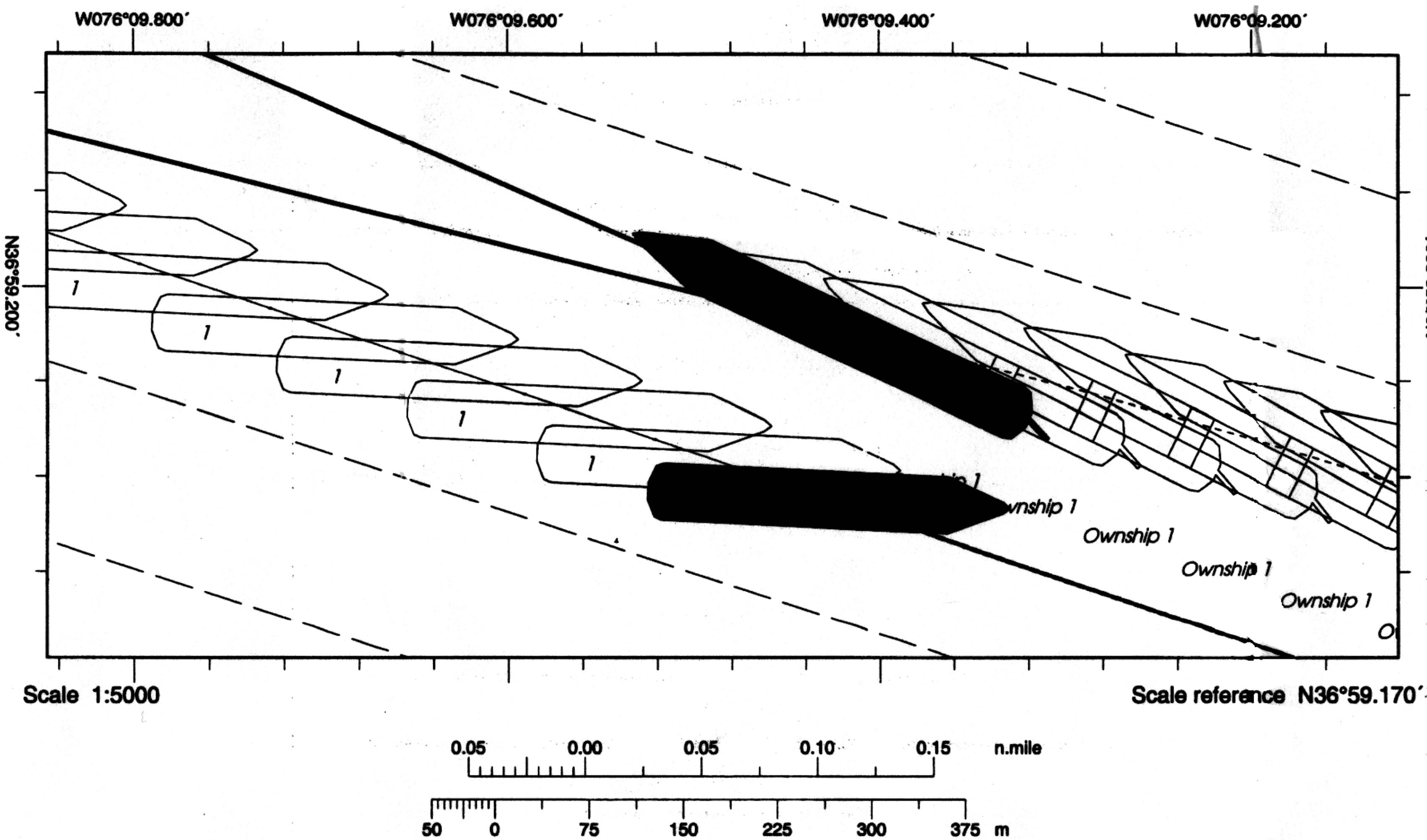
SCENARIO 12



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

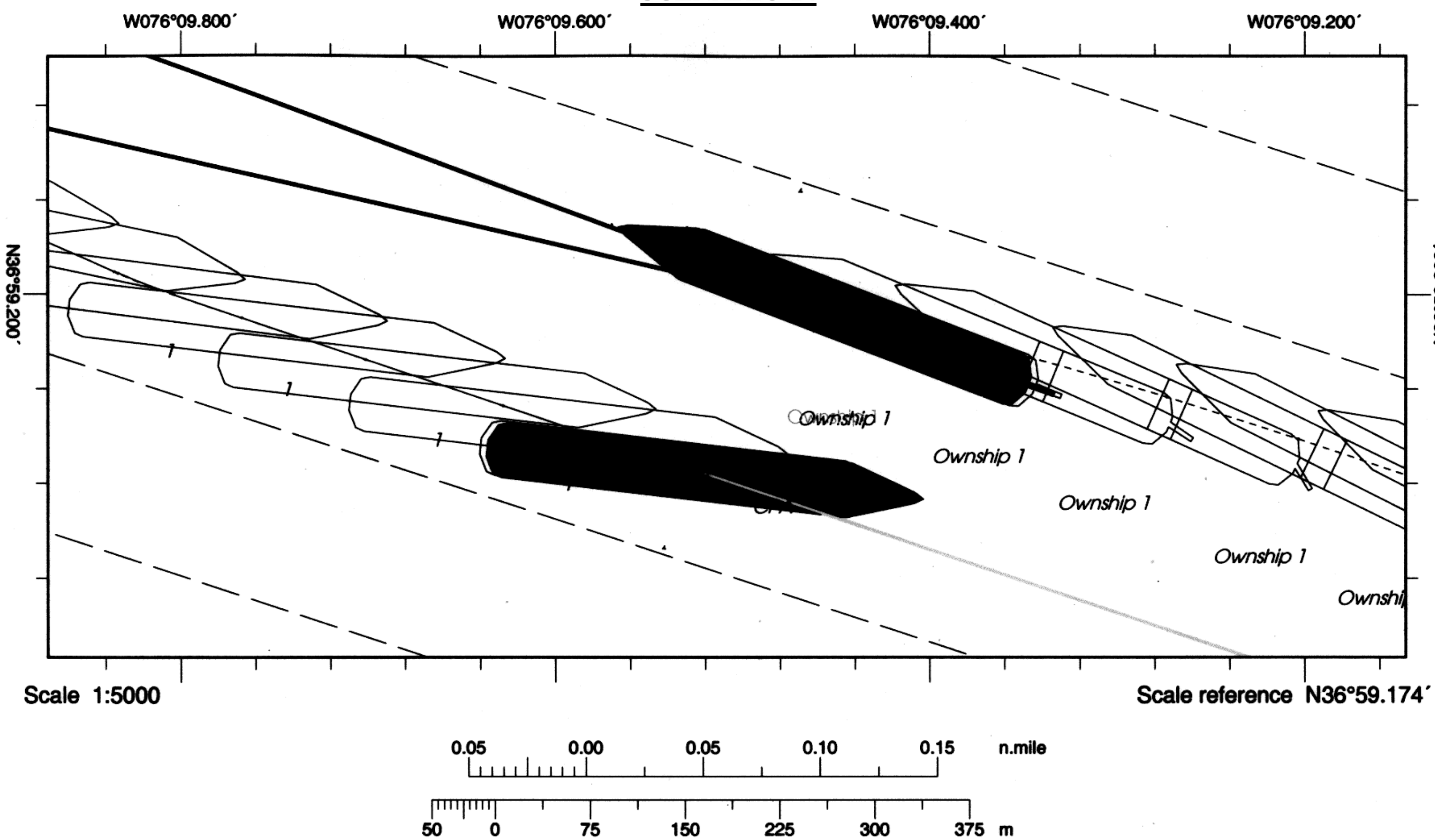
SCENARIO 13



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 52ft

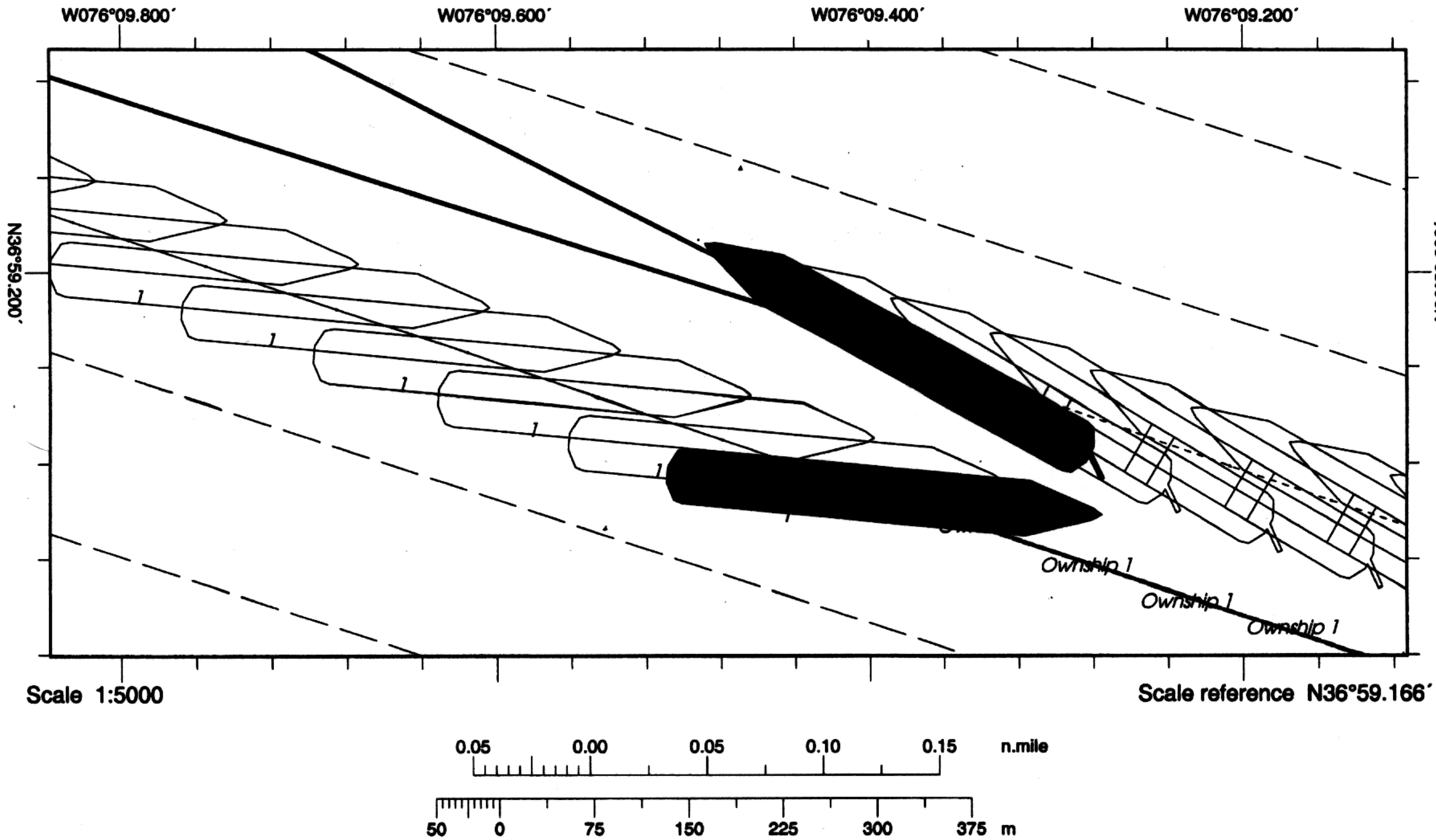
SCENARIO 14



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 10kts
Outbound: S-Class 47ft Draft, Speed 10.5kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 54ft

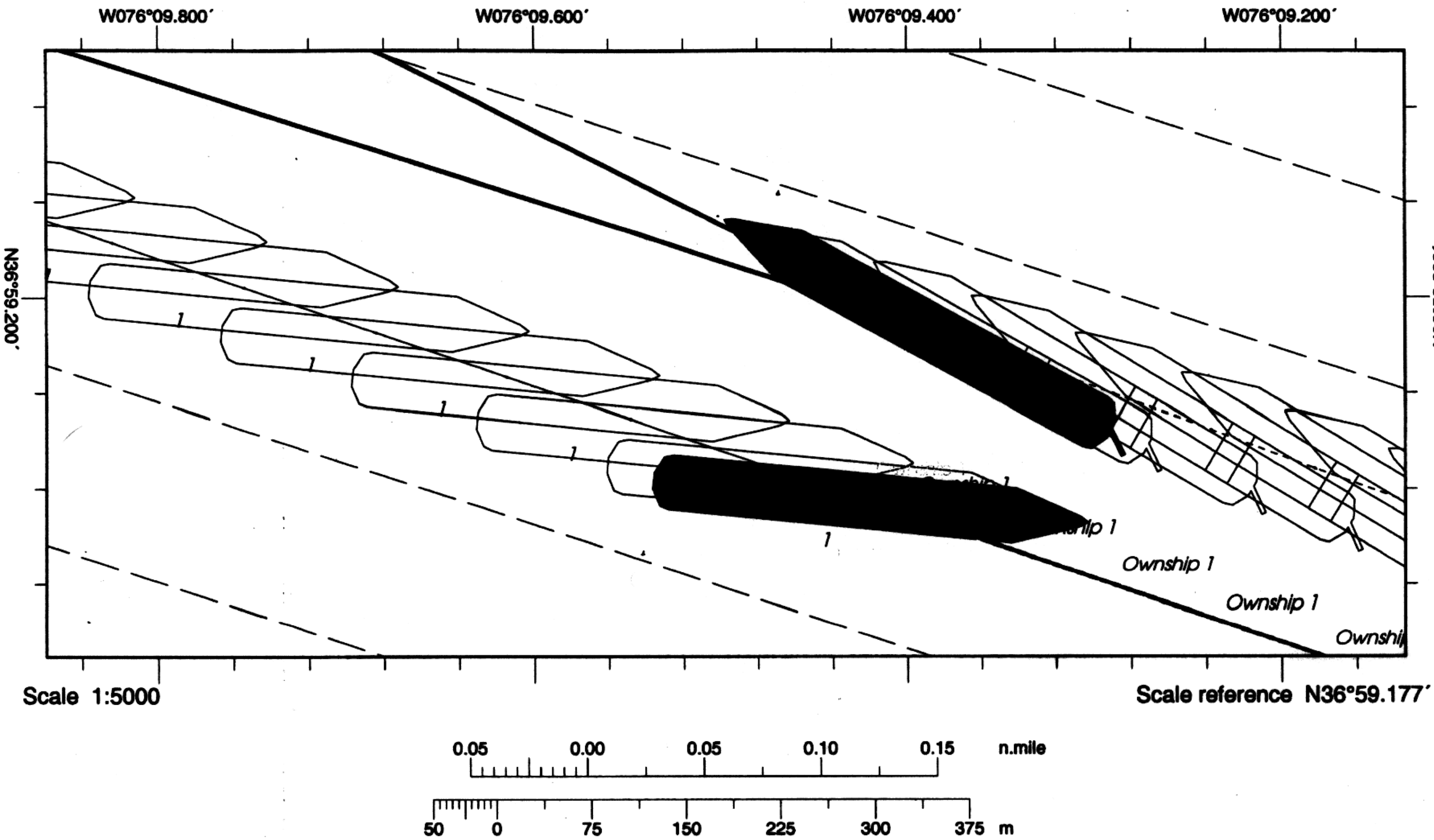
SCENARIO 15



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 10.5kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 54ft

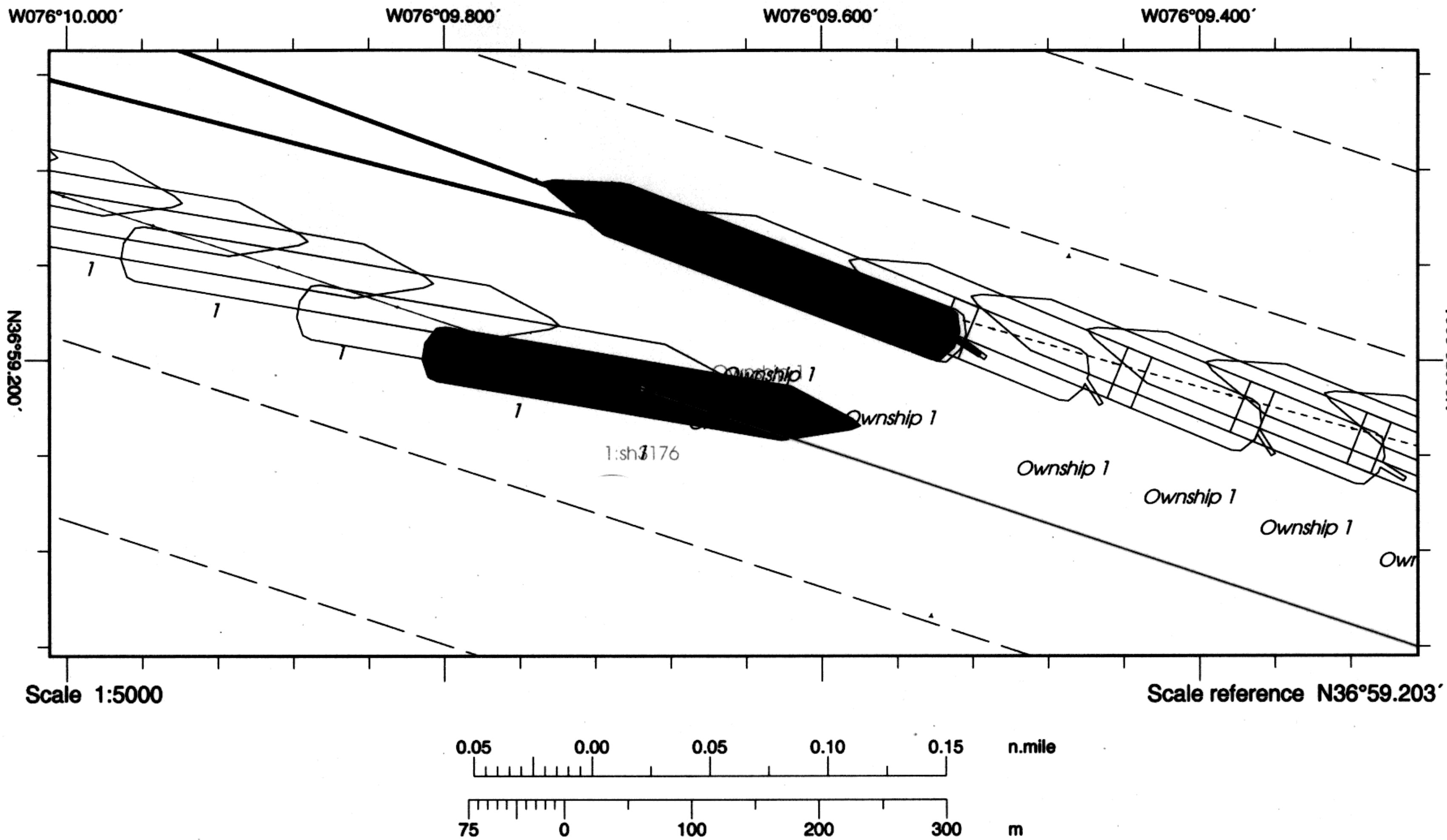
SCENARIO 16



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 10.5kts
Wind: 50kts from 017 Deg
Current: 1.5kts to 198 Deg
Channel Dept: 56ft

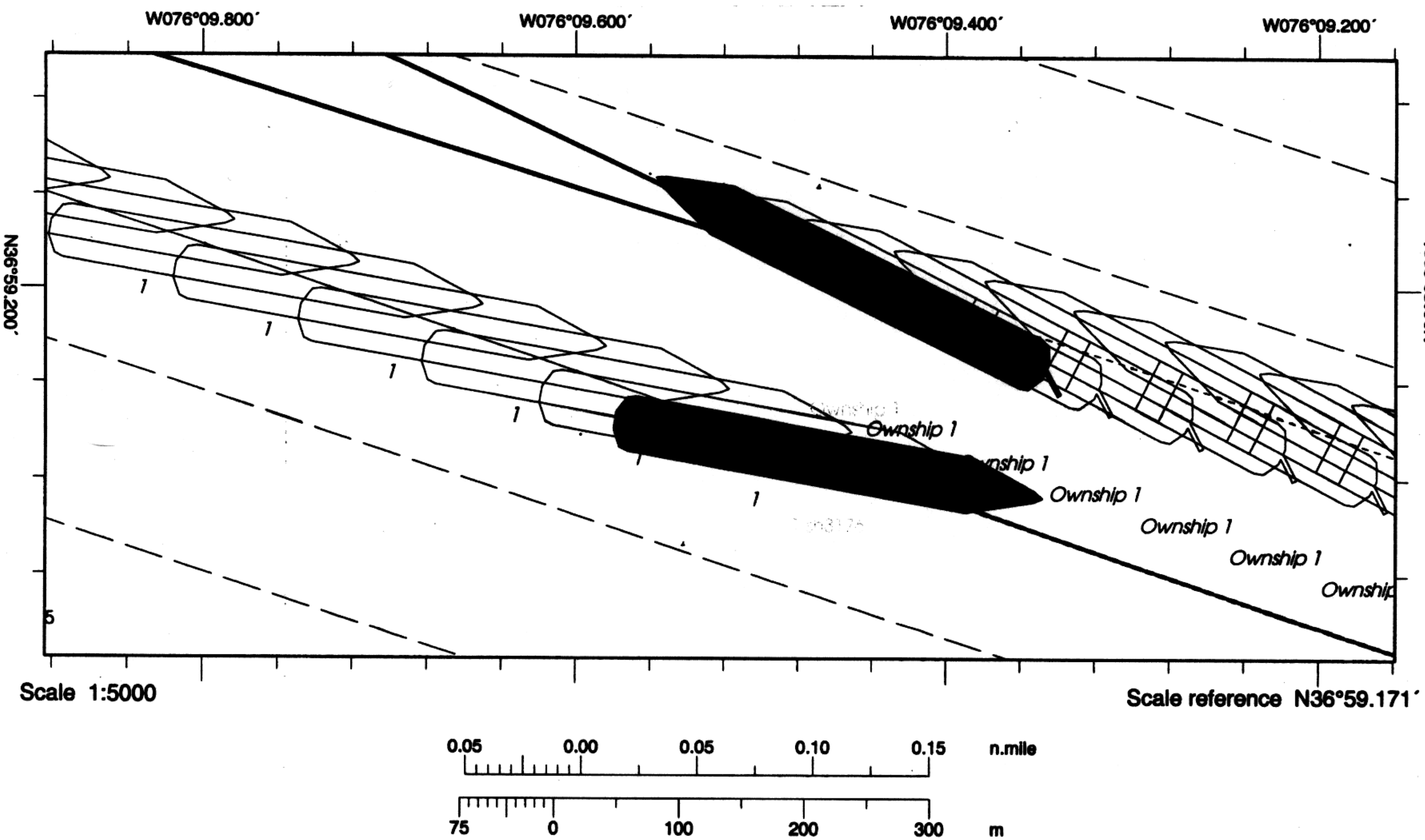
SCENARIO 17



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 40kts from 45 Deg
Current: 1.2kts to 225 Deg
Channel Dept: 52 ft

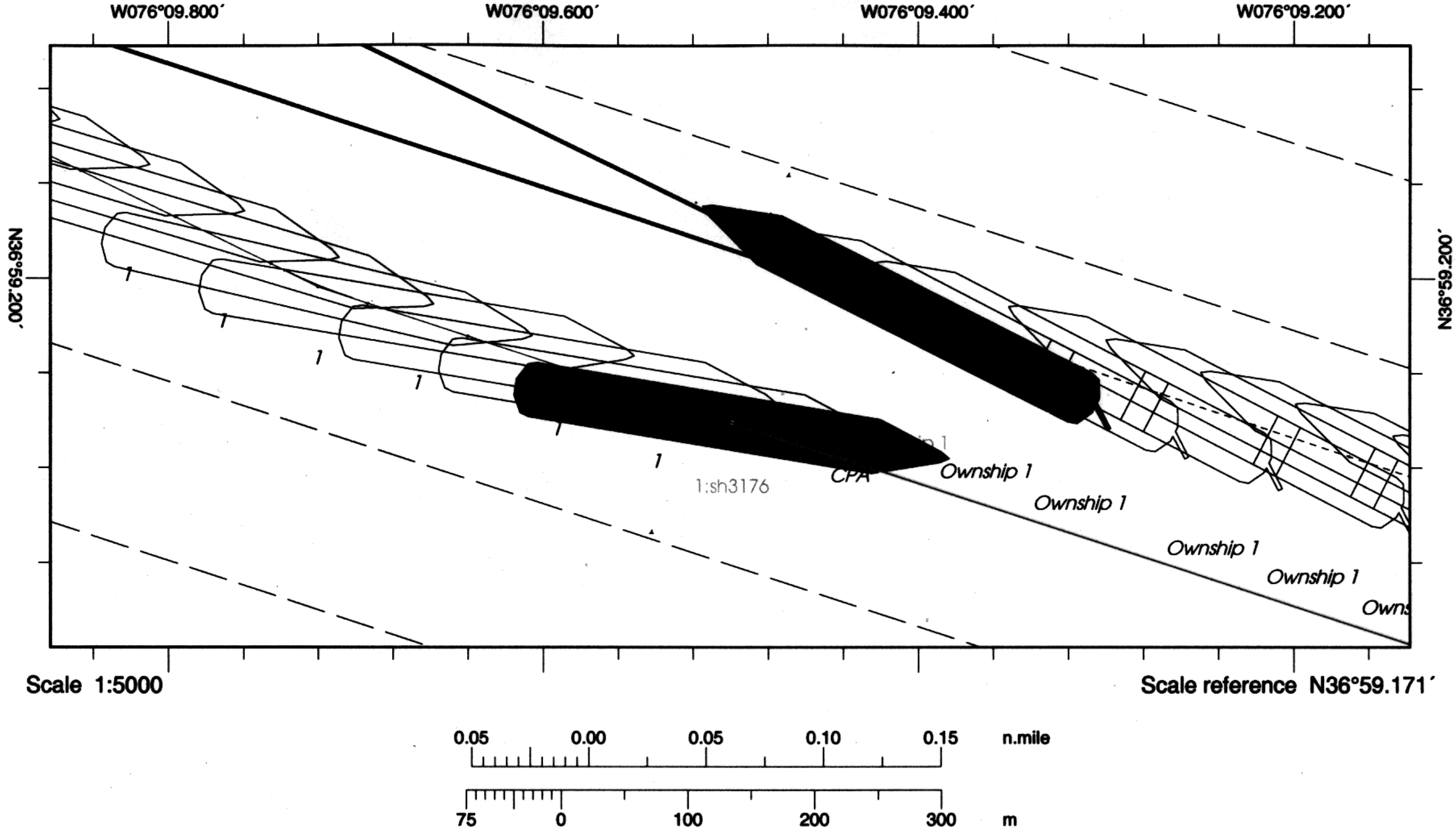
SCENARIO 18



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 10kts
Wind: 40kts from 45 Deg
Current: 1.2kts to 225 Deg
Channel Dept: 52 ft

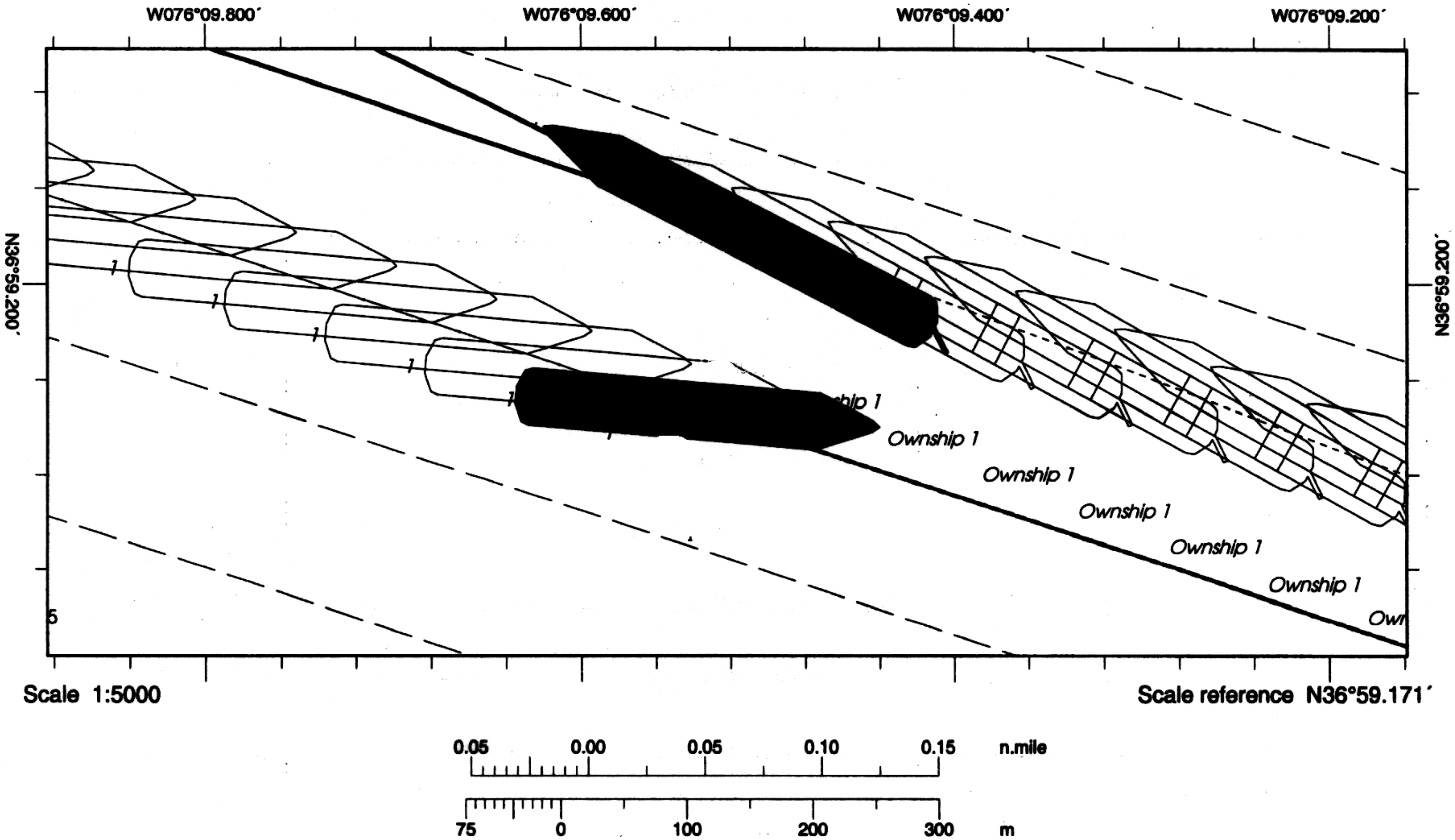
SCENARIO 19



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: S-Class 47ft Draft, Speed 8kts
Wind: 40kts from 45 Deg
Current: 1.2kts to 225 Deg
Channel Dept: 52ft

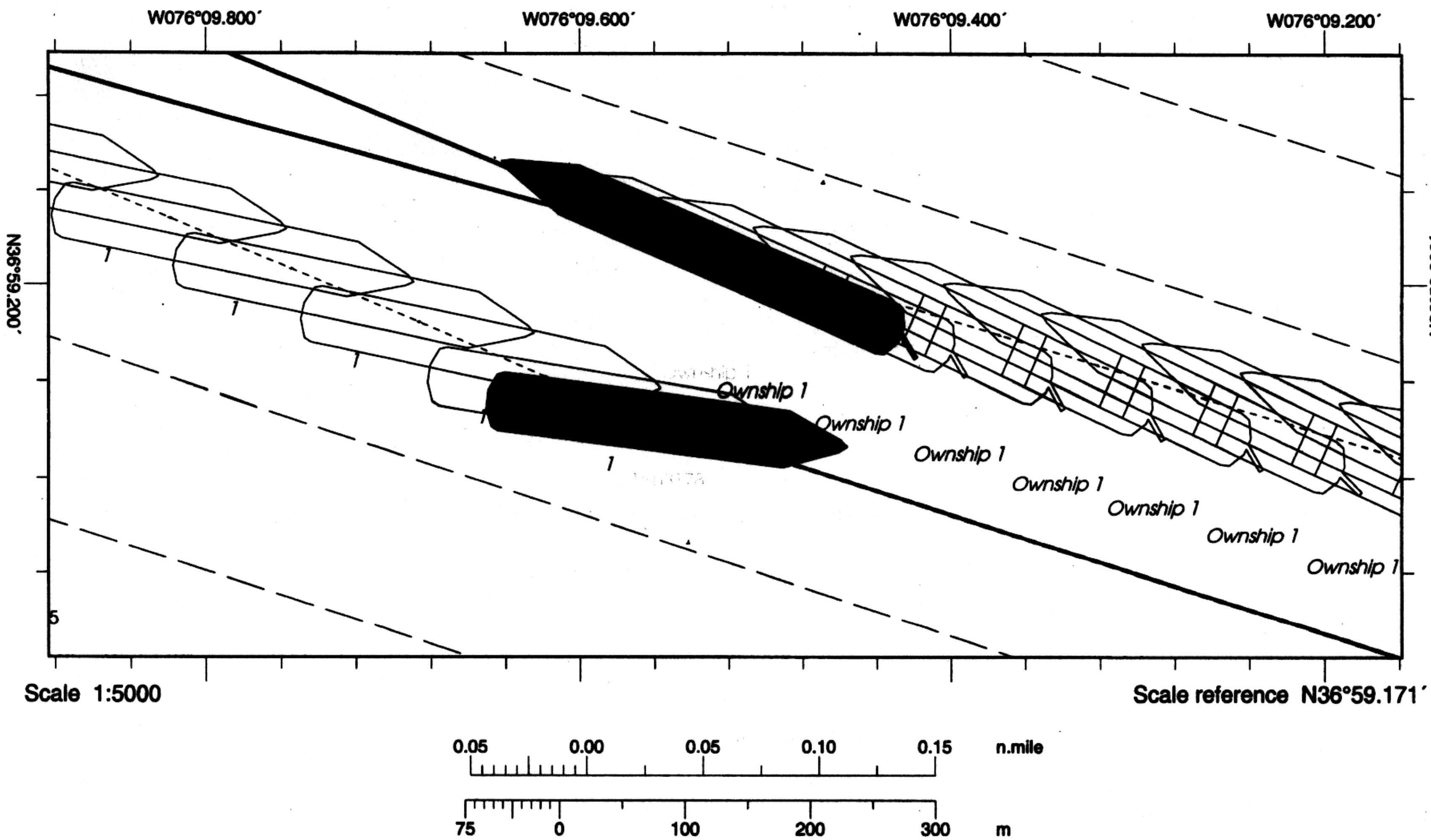
SCENARIO 20



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: Collier 50ft Draft, Speed 8kts
Wind: 40kts from 45 Deg
Current: 1.2kts to 225 Deg
Channel Dept: 52 ft

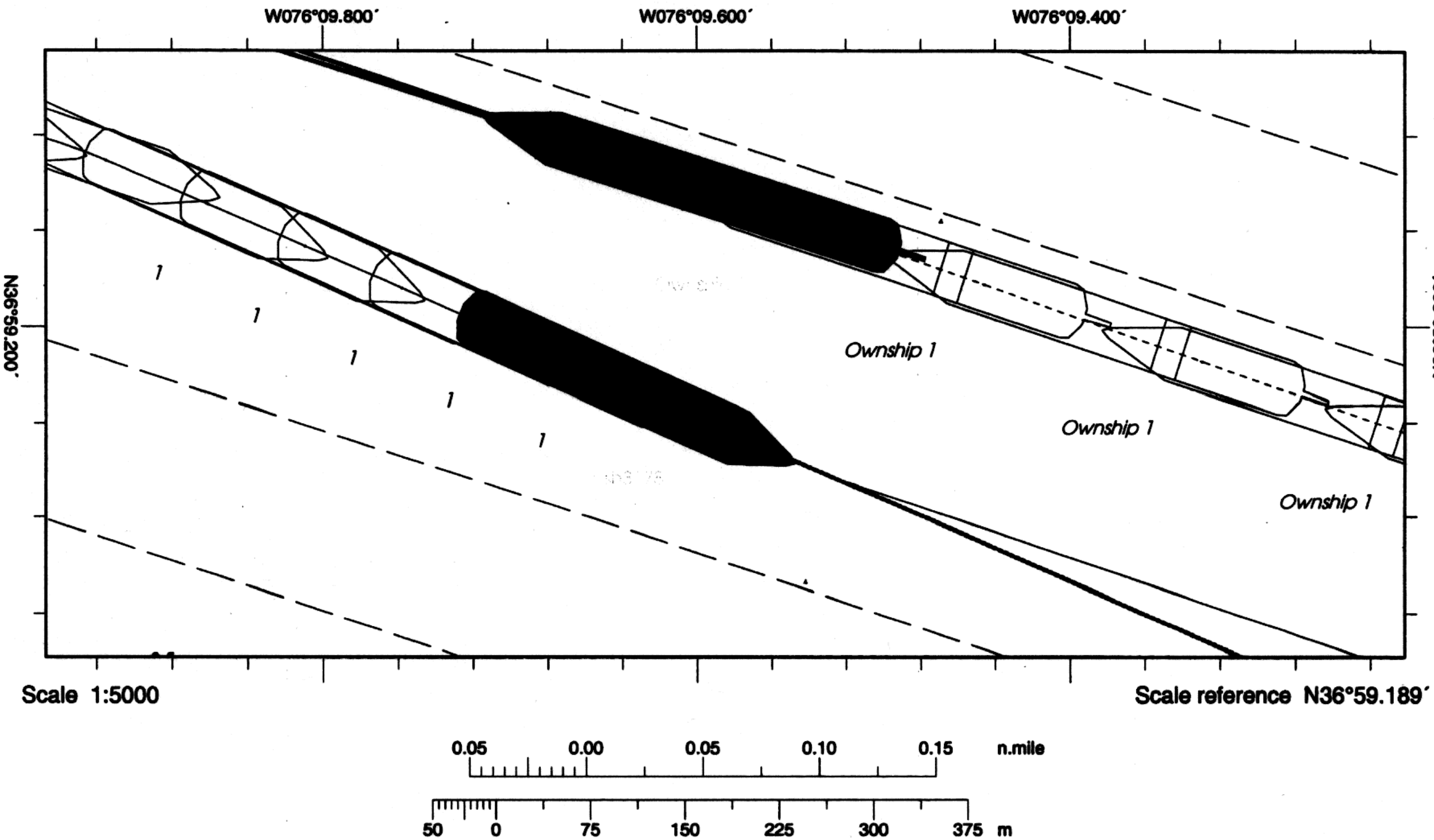
SCENARIO 21



Scenario Conditions:

Inbound: S-Class 47ft Draft, Speed 8kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: 40kts from 45 Deg
Current: 1.2kts to 225 Deg
Channel Dept: 52 ft

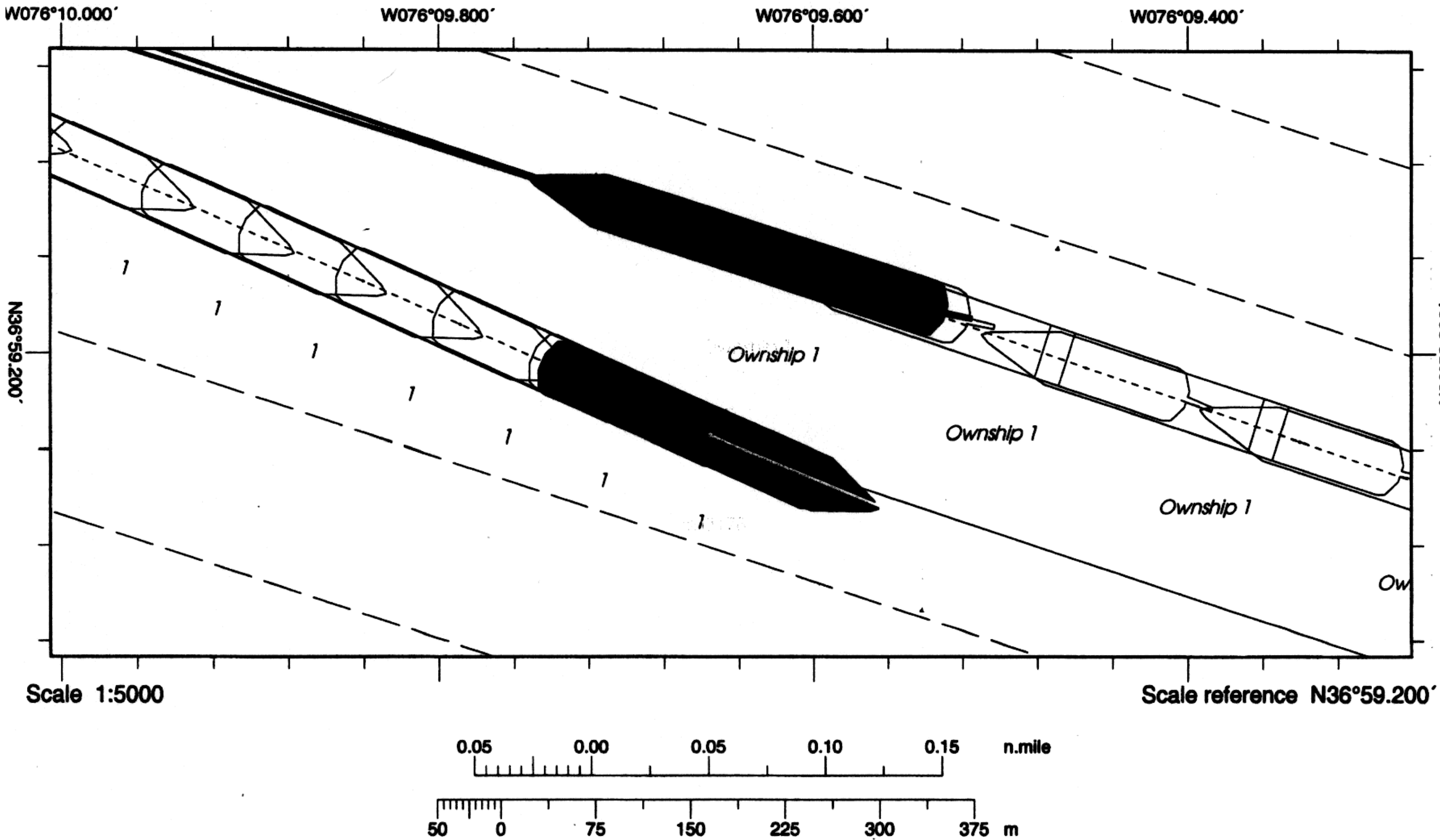
SCENARIO 22



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 16kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: Calm
Current: ERDC DB
Channel Dept: 45+ ft

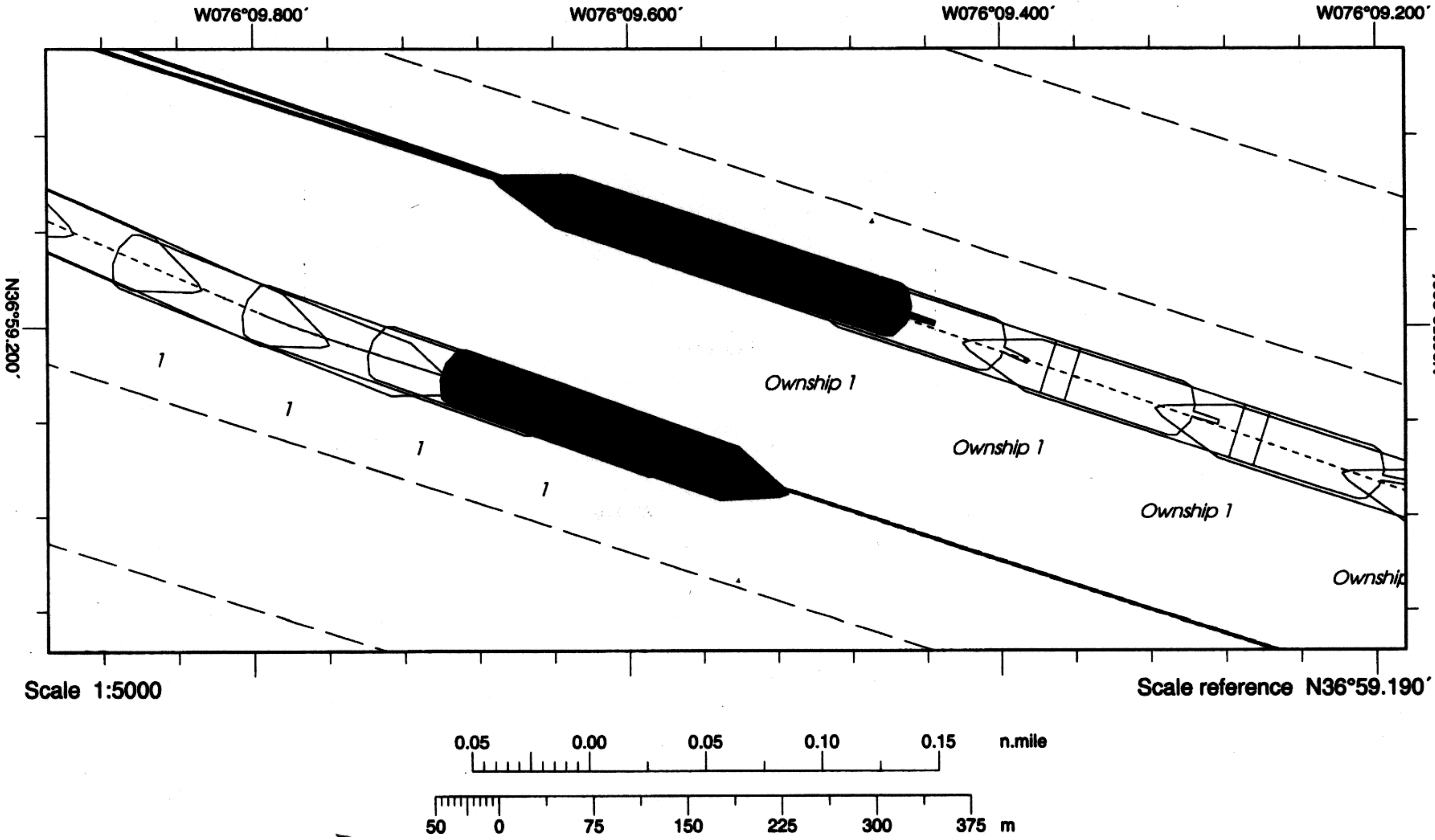
SCENARIO 23



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 16kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: Calm
Current: ERDC DB
Channel Dept: 45+ ft

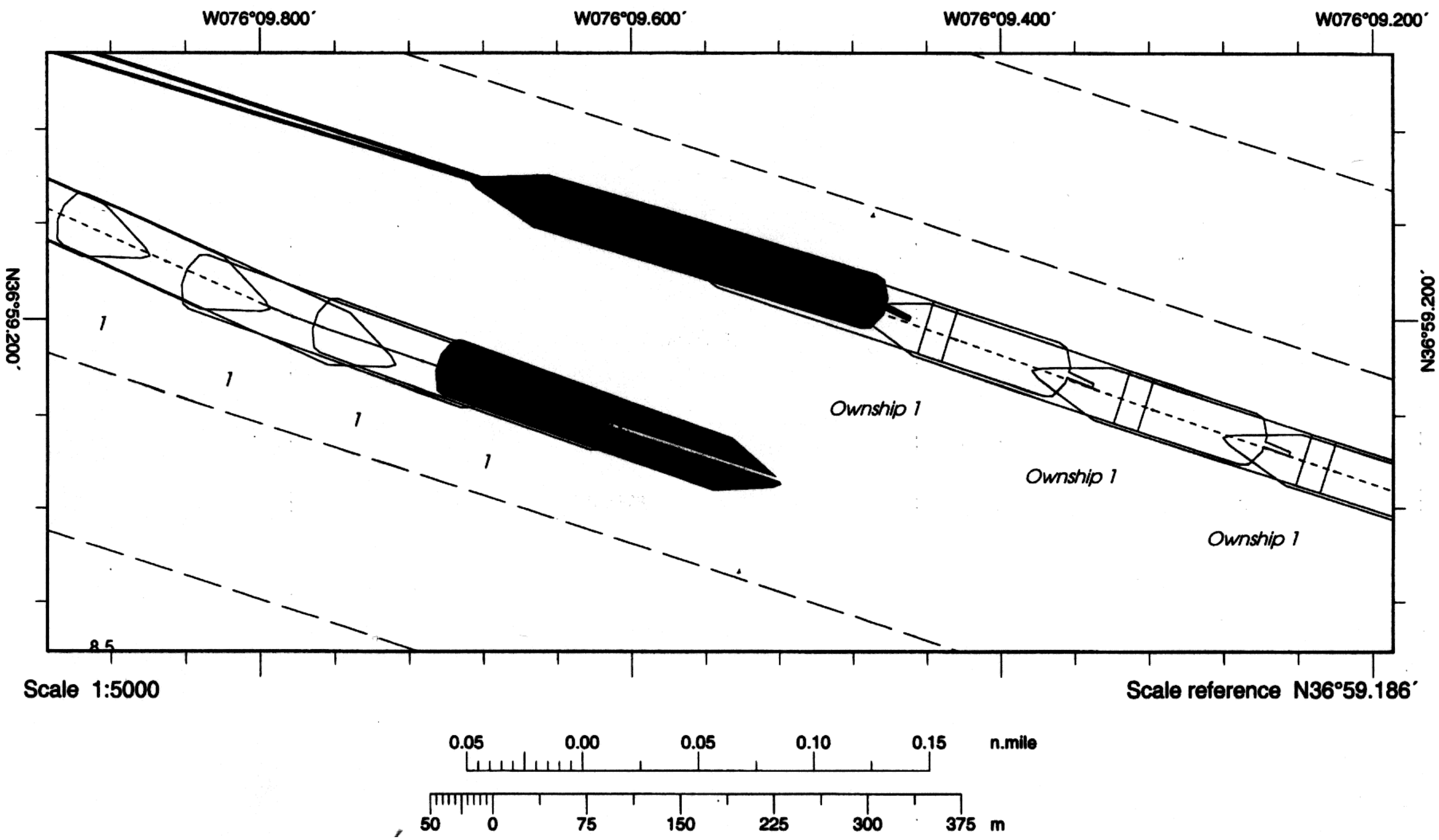
<u>**SCENARIO 24**</u>



<u>**Scenario Conditions:**</u>

Inbound: S-Class 38ft Draft, Speed 14kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: Calm
Current: ERDC DB
Channel Dept: 45+ ft

SCENARIO 25



Scenario Conditions:

Inbound: S-Class 38ft Draft, Speed 14kts
Outbound: Collier 50ft Draft, Speed 10.5kts
Wind: Calm
Current: ERDC DB
Channel Dept: 45+ ft