EVALUATION OF DEEP DRAFT COASTAL PORT DESIGNS

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ABSTRACT

The emphasis on creating port systems to accommodate larger vessels has led to a requirement for additional port and harbor design tools which can evaluate the safety of a proposed design. Recent CAORF research suggests that the application of ship simulation to deep draft channel design can provide an added dimension beyond that available from traditional design criteria. The advantage of this feature is that it provides an understanding of the interaction between the ship operator and the proposed channel system. The addition of the human variable in the context of a full-scale, real-time evaluation provides the link between the engineering design and the safe operating environment that is the goal of the port developer

This paper discusses recent CAORF research associated with evaluation of a deep draft coastal port design. The knowledge gained from the research has important consequences for similar designs both as a result of the conclusions obtained and the understanding of key issues related to deep draft coastal port designs.

INTRODUCTION

Historical channel and port design has relied heavily on the influence of design criteria that were developed nearly thirty years ago. Expansion of today's harbors is dependent on developing positive benefit to cost ratios associated with direct transportation savings. The costs of port improvements are high. The consequence is that the margins for safety and conservatism that underlie the existing design criteria have been stressed to the limit. The tolerance for errors in design is gone. Increasingly ports are examining alternatives which would allow larger vessels into existing or marginally improved waterways in order to project the greatest economic return for expenditure of limited waterway development capital.

The result is that existing design criteria are inadequate for today's problems. Generalized criteria can be acceptable only for the most cursory evaluation of the adequacy of alternative port designs. CAORF simulation offers an opportunity to examine the relevant variables associated with a given port design in a controlled research environment. The complex interdependence between waterway variables makes each port unique. At CAORF, the issues which determine the ability of large vessels to transit a proposed channel system can be identified and examined in advance of substantial commitment of resources to dredging and construction in the port.

Within the past 2 years, the general research program at CAORF has provided the knowledge and experience required to examine practical port design issues with the objective of improving channel design criteria in keeping with the goals of improving waterborne commerce while maintaining adequate margins of safety for vessels in United States' ports. Patterns are beginning to emerge from the research which suggest that ship simulation is an indispensable tool in the port design process. While previous papers have discussed the use of simulation in the broad area of port design, this paper focuses on problems related to deep draft coastal port designs. Three major sections are (a) development of the experimental variables, (b) selection of performance measures, and (c) specific areas where research has identified shiphandling problems and recommendations which have resulted from the research which have general application to port design. The paper is structured in the context of a hypothetical port design project although the results reported were obtained during evaluation of specific port development design alternatives.

BACKGROUND

The proposed project involves the widening and deepening of an existing entrance channel to accommodate very large crude carriers (VLCCs) and other large vessel traffic. The channel will be deepened to 72 feet and widened to 800 feet outside the jetty and 600 feet inside the port. A turning basin 2300 feet in diameter will be created at the intersection of the inland waterway forming a docking basin capable of berthing up to three large vessels.

Three alternative docking and turning basin configurations have been proposed. Each has been evaluated with respect to economic considerations and wetlands impact. See Figure 1.

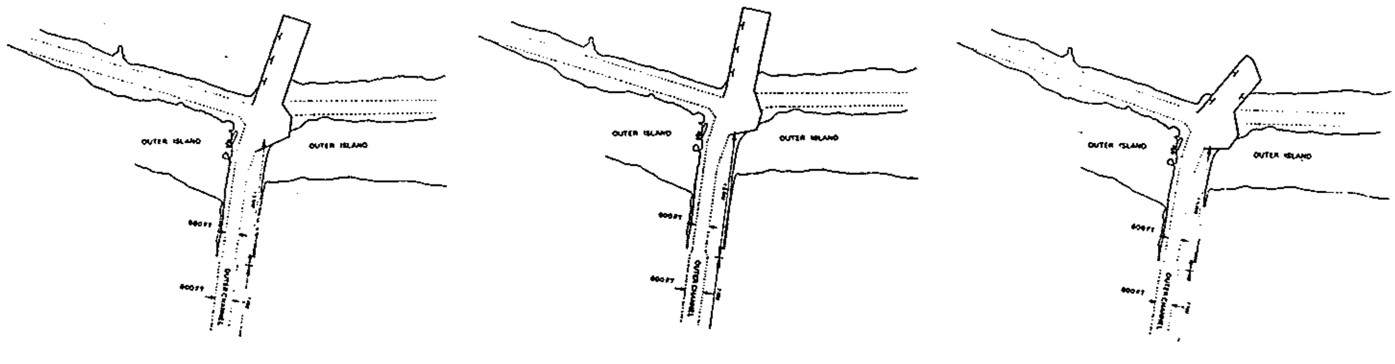


Figure 1. Alternative Docking Basin Configurations

A central issue in the design, however, is the relative safety of alternative docking basin configurations with respect to operation of very large ships in the port. The environmental and economic analyses can not be considered complete without examination of the safety issues involved in large ship transits into the port. A single shipboard accident caused or contributed to by basin design would significantly alter the long term economic and environmental balance.

OBJECTIVES OF THE INVESTIGATION

A CAORF simulation study was undertaken to provide data and analysis indicative of the safety issues involved in the operation of large vessels in the proposed deepwater port. Specifically, the investigation addressed:

a. The ability of pilots aboard a 250,000 dwt oil tanker to negotiate an improved harbor channel under unfavorable environmental conditions. (Conditions were selected to represent boundary conditions for ship operations expected to be encountered under normal operations).

b. The impact of alternative docking basin configurations on VLCC docking and undocking operations.

To accomplish the study objectives, visual and environmental data bases of the area associated with approaches to the harbor facility were produced. Local pilots, operating a 250,000 dwt tanker, conducted a number of simulated inbound and outbound transits to each of the alternative docking basins in the presence of significant follow currents and a 30-knot south-southeasterly wind. Three 6,000-horsepower tugs were provided to assist in the transits.

The full-scale CAORF bridge simulator was selected for this investigation because of its ability to comprehensively model the physical factors involved in the port environment while incorporating the effect of the experience, judgment, and control strategies of local pilots into the research process.

EXPERIMENTAL APPROACH

The simulation scenarios for the experiment were composed of visual and environmental data bases of the approaches to the proposed docking facility, including the outer bar, approach channels and segments of the intersecting waterway (Figure 2).

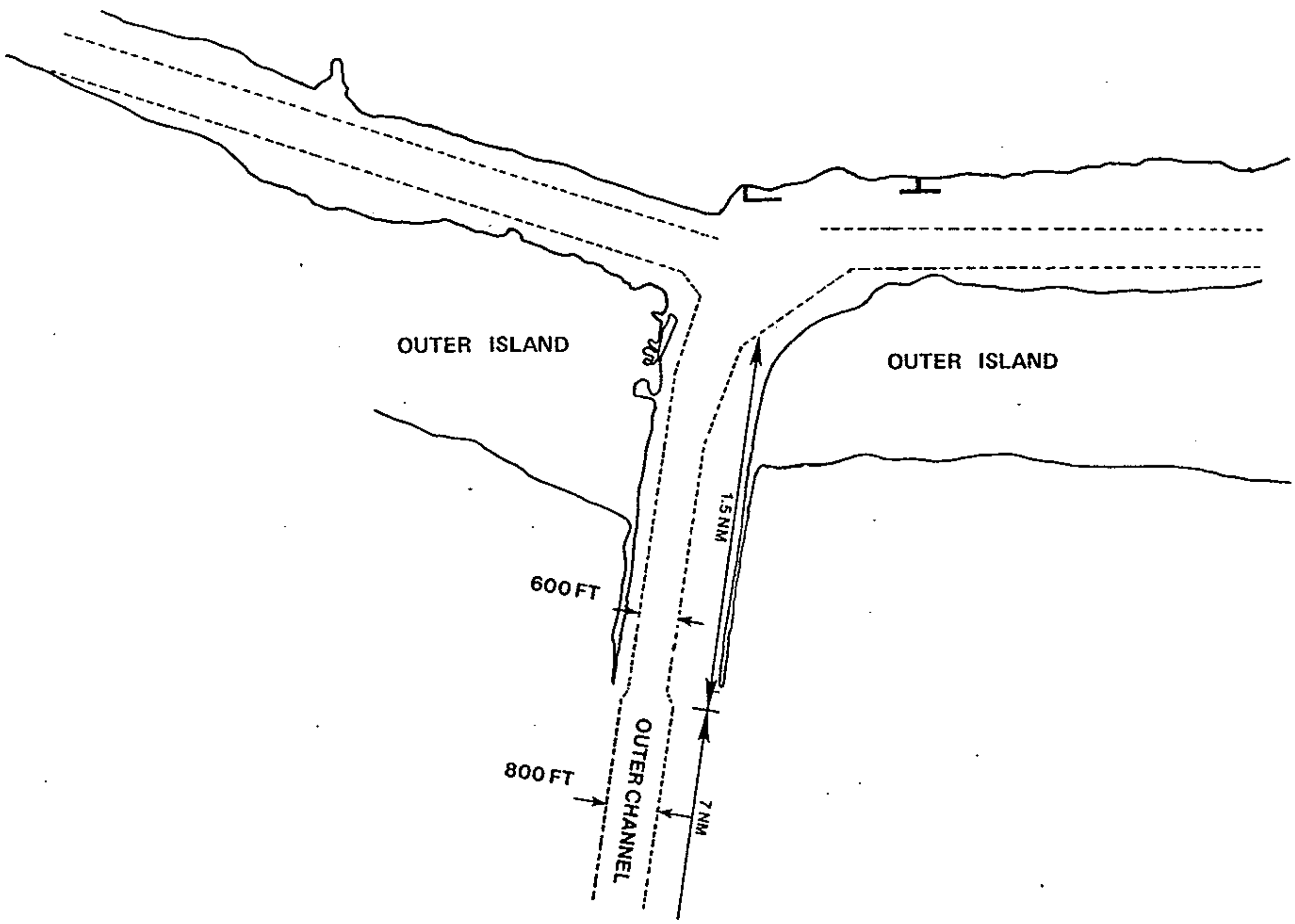


Figure 2. Simulation Scenario

A 250,000 dwt oil tanker model was used for the simulation runs. A fully loaded model was used for all inbound transits, and a ballasted model was used during the outbound transits.

The visual data base consisted of modeling the general characteristics of land forms in the port area, configuration of the channels, jetties, aids to navigation (buoys, lights, and ranges), and representative structures in the area through which vessel transits were to be conducted. Buoys were initially located using navigational charts of the area and repositioned to conform to their location in the channel on advice of the pilots during the presimulation/checkout phase of the experiment. Additionally, quarter ranges were added because the pilots indicated that the existing Corps of Engineers' dredging ranges are important aids to navigation. The dredging ranges mark the outer quarters of the channel and, in combination with the centerline range, provide a highly sensitive crosstrack reference for the pilot.

The alternate docking and turning basins were superimposed over the basic visual scene in the proper location and were orientated on the basis of engineering drawings provided by the port. The jetty on the north side of the approach channel was modeled according to the proposed port improvement plan.

The environmental parameters for the simulation experiment consisted of daylight, good visibility, a south-southeasterly 30-knot variable and gusting wind, and a flood or ebb tidal current.

Maximum velocity prevailing winds were selected for the experimental conditions after examining wind data for the area from a variety of sources. Although winds in excess of 20 knots have a very low frequency of occurrence (less than 5 percent), it was considered prudent to model a strong wind to ensure a conservative margin for vessel operating conditions.

Development of an appropriate current data base posed a problem. Data was available from the Corps of Engineers and from previous current surveys of the existing waterway. The effect of the proposed dredging on the current patterns and velocities in the channels, however, was uncertain. Consultations with the Army Corps of Engineers and a Port and Ocean Engineering consultant resulted in development of a current data base model which incorporated their best engineering estimates of the effects of the port improvement project on current patterns in the entrance channels and in the vicinity of the docking basin.

Discussions with the pilots during the presimulation exercises indicated that specific current patterns, particularly the eddies, vary considerably in the area. The current velocities were selected to represent maximum currents likely to be encountered during normal operations. Although the consultants felt that velocities would be reduced following major dredging improvements, the highest modeled currents were left at between 1.5 to 2.0 knots. The direction of current was chosen to follow the general track of the vessel, since following currents present a more challenging shiphandling problem to the pilot.

Once the harbor data bases had been generated and vessel models had been selected for the investigation, two scenarios and a set of initialization conditions were developed. Single inbound and outbound scenarios were selected to maximize simulation efficiency and to establish natural patterns related to transits of VLCCs through the channel system.

PORT APPROACH SCENARIO

This scenario began with ownship in the center of the outer bar channel. Ship's heading was adjusted to approximately compensate for a substantial littoral current setting across the face of the jetty. The initial phase of the transit required the pilot to bring a loaded 250,000 dwt oil tanker across the bar and into the entrance channel. This task required the pilots to establish a course to counteract the effects of the littoral drift and south-southeasterly wind while crossing the bar. As the ship entered the jetty channel, the pilots had to maneuver for the transition from a crosscurrent outside the jetty to a strong flood (following) current within the channel. Once the ship was inside the jetty, tugs were used to slow and position the ship prior to entering the turning basin. The final phase of the approach involved maneuvering the loaded tanker through the docking basin opening across the flood current and positioning the vessel for the final docking evolution.

PORT DEPARTURE SCENARIO

The outbound scenario required the pilot to maneuver a ballasted 250,000 dwt oil tanker away from a pier inside one of the docking basins, using tugs and ship's power, turn the vessel in the presence of a strong ebb current and south-southeasterly wind, drop the tugs, and accelerate out the channel.

TUG FORCE SIMULATION

Tug assistance in docking and low speed maneuvering within the proposed deepwater port is essential since rudder effectiveness and VLCC response options are substantially reduced within the restricted approaches to the port. The CAORF tug force model used to examine VLCC transits through the channel and basin system simulates the application of tug forces and turning moments on the vessel (Figure 3). Tug force magnitudes and directions are ordered by the pilot and applied by the simulation operator. Realistic delays in application of the tug forces were imposed by operating instructions (e.g., 5 minutes were required to shift a tug from port to starboard) and within the tug simulation model (e.g., the time required to execute a change in magnitude or direction of a tug force is an input parameter of the model).

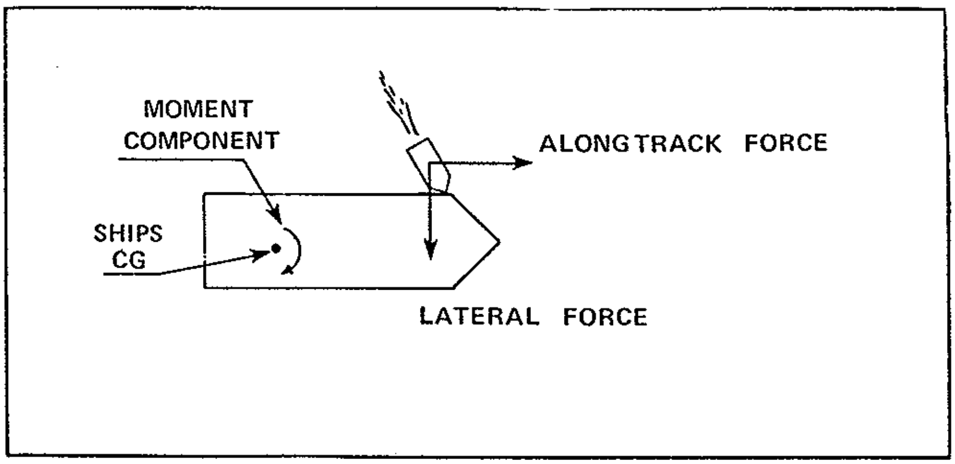


Figure 3. Tug Force Components

The scope of this investigation did not include specification of the proper number and size of tugs to be employed under operational conditions. Rather, sufficient tug assistance was required to examine the impact of the alternative docking basin configurations on ship safety. Up to six tugs, each capable of imparting a maximum of 75 tons of bollard pull on the vessel, were available to the pilot. The size of tug required to achieve that level of force varies by propulsion type and tow line configuration from 5,000 to 8,000 horsepower. Consequently, the pilots were told only that they had 6,000 horsepower tugs available.

INSTRUCTIONS TO THE PILOTS

The pilots were acquainted with the CAORF bridge and the vessel model to be used during the simulation through the presimulation checkout process and a set of familiarization transits. Prior to each experimental run, the pilots were shown charts of the docking and turning basin configuration. The direction (flood or ebb) and relative magnitude of the current were stressed, but specific knowledge of the current was withheld. The pilots were instructed to handle the vessel as they would during an actual transit under the existing conditions.

DATA COLLECTION

Ownship location, orientation, velocity, and tug force data were collected automatically at 3 to 30 second intervals and recorded on magnetic tape. Additionally, crosstrack deviation and drift angle were recorded at 100 foot intervals along the approach and outer bar channel segments. The pilots' ship control orders (helm, course, engine, and tug) were recorded manually as they occurred. Qualitative assessment of performance was conducted by analysts on the bridge, and at the human factors and control stations.

PERFORMANCE MEASURES

Crosstrack displacement of ownship's center of gravity (CG) from the channel centerline provided an initial indication of the location of the vessel within the entrance channel segments. During the inbound simulation runs crosstrack location was noted at 13 points in the channel to describe the process of transiting across the outer bar, through the jetty entrance, and into the approach channel. For the outbound runs, this measure was applied at seven points in the jetty channel after leaving the turning basin. Quantitative analysis of the tracks at each of the selected points resulted in a mean track and a measure of variability ($\pm$2 standard deviations) which has in previous research enclosed the tracks of a large number of simulation runs through a given restricted waterway (Figure 4).

The track of the ship's center of gravity alone, however, does not completely describe the area consumed by a transiting vessel. An important indicator of vessel performance in a restricted channel is the area swept by the extreme points of ship. The swept path at any point is a function of the difference between a vessel's direction of movement and its heading. This "drift angle" results from the combined effect of external forces acting on the vessel including wind, current, and tugs. The greater the magnitude of the drift angle, the greater the swept path (Figure 5) will be. For purposes of calculating the swept path, the drift angle used at each point is the mean angle observed plus 2 standard deviations of the sample data.

The resultant performance measure for analysis of the straight channel segment, then, involves the combination of the crosstrack displacement and swept width measures to provide an indication of the ability of the channel to accommodate 250,000 dwt tankers under unfavorable environmental conditions. Figure 6 illustrates this "track envelope" measure.

Because various combinations of tug strategy and ship control were observed during the simulation, it was not possible to develop a single, precise measure of tug usage that would discriminate ship performance among docking basin alternatives. Consequently, analysis of alternate docking basin configurations combined comparative and qualitative examination of a variety of measures related to ship performance and tug usage in the turning and docking basins. This analysis shows trends in performance that can be further interpreted.

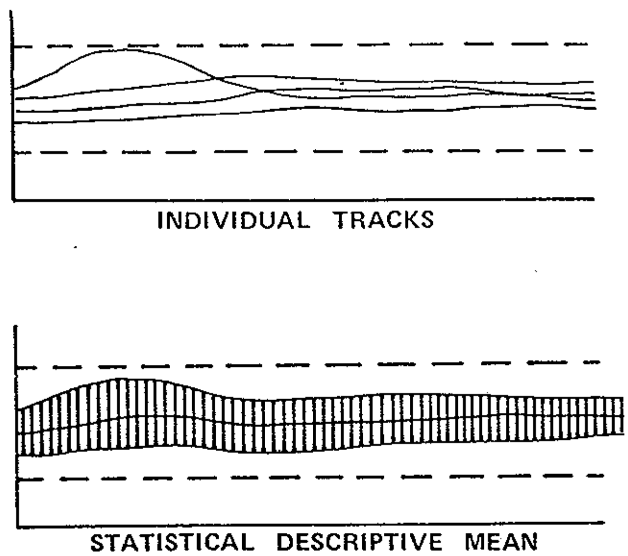
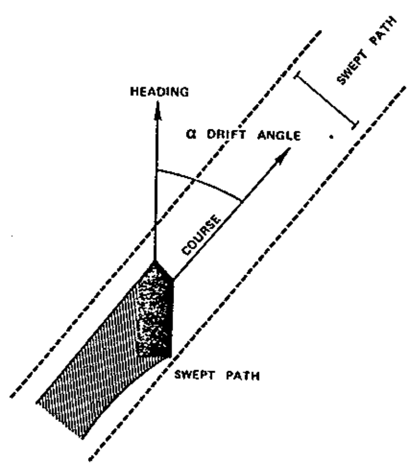


Figure 4. Mean Track of Ship Center of Gravity ± 2 Standard Deviations



$$\text{SWEPT PATH} = \sqrt{L^2+B^2}\ \sin\left[\left(\tan^{-1} B/L\right) + a\right]$$

WHERE

B = BEAM

L = LENGTH

a = $\bar{X}a + 2Sa$

$\bar{X}a$ = MEAN OBSERVED DRIFT ANGLE

Sa = STANDARD DEVIATION OF SAMPLE DRIFT ANGLES

Figure 5. Swept Path Calculation

PORT APPROACH SIMULATION RUNS

Local pilots conducted nine simulation approaches through an improved channel system aboard a loaded 250,000 dwt tanker. Since the initial phase of the transit was conducted under identical conditions of wind, current and channel configuration, it was possible to analyze trackkeeping performance across all runs. Once inside the turning basin, analysis was conducted on three approaches to each of the alternative docking basins.

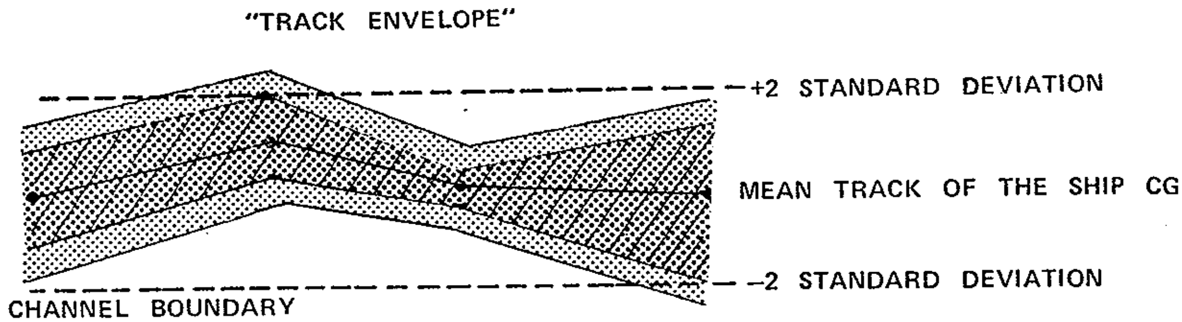


Figure 6. Trackkeeping Performance Measure

Observed Strategies

The pilots took control of the ship approximately 1 mile from the jetty entrance. The ship's speed was 6 knots with the speed over the ground slightly higher as a result of the quartering wind and current. After aligning the ship in the channel using the ranges, the pilots contacted the harbor tugs in preparation for entering the enclosed jetty channel.

After some initial experimentation in the checkout runs, the pilots settled on a three tug configuration. Typically, one tug was attached on the starboard bow (leeward side) just prior to entering the jetty. Once the ship was inside the jetty another tug was attached astern and a third was made fast to the port bow. The stern tug was used primarily as a braking device to slow the ship and to provide added rudder effect, while ownship's engines were kept ahead to augment steerage. The tugs on either bow were used to provide additional braking force and to maintain alignment of the ship in the channel.

The pilots' stated goal was to have the ship stopped in the turning basin. The tugs were then used to align the ship with the docking basin. A combination of ship power and tug force was used to enter the basin. Once the ship was well inside the basin, tug forces were balanced to push the ship laterally toward the pier. During several of the runs the tug on the port bow was shifted to the starboard quarter after entering the turning basin to clear it from the pier side of the ship.

Figure 7 graphically illustrates the track envelope performance measure as it applies to the vessel tracks observed during the nine inbound transits.

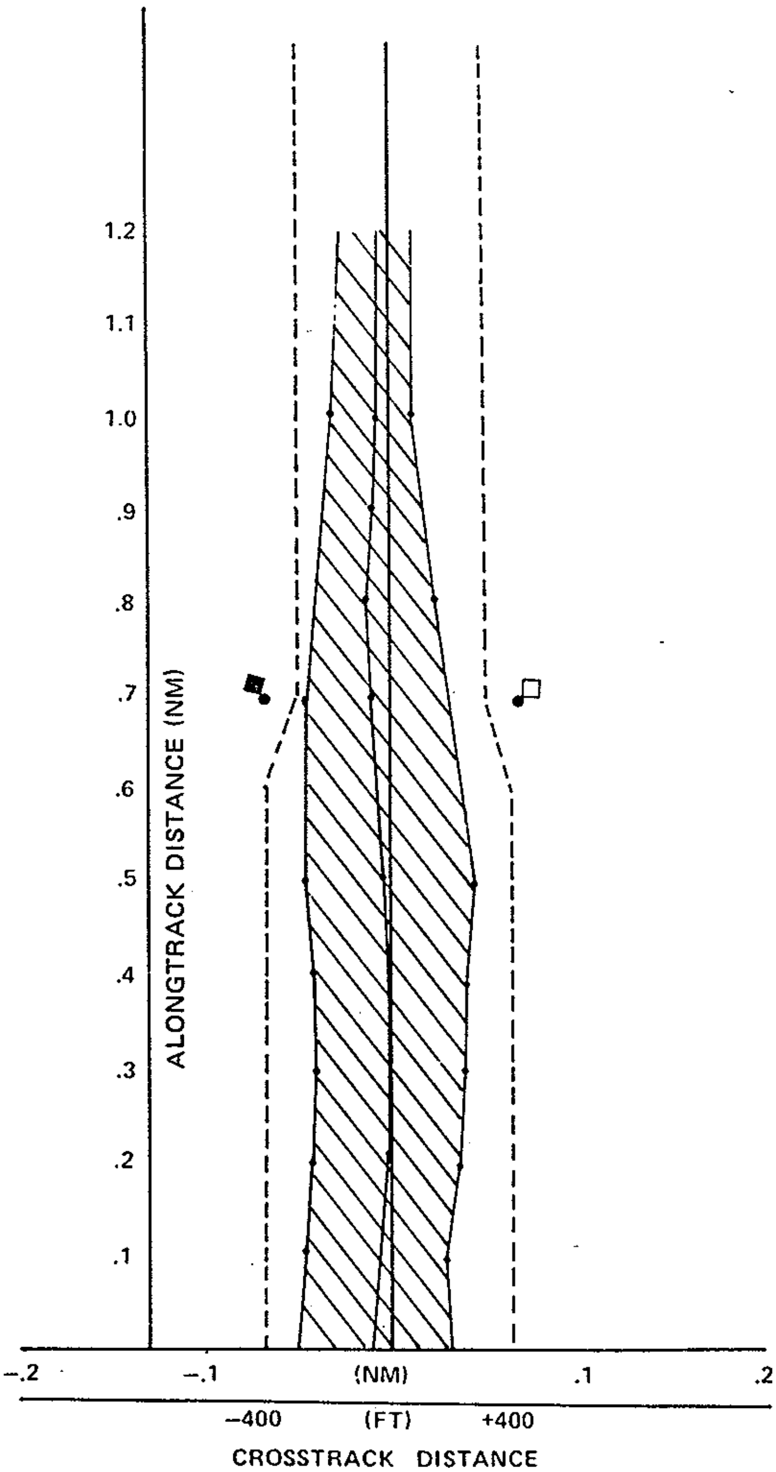


Figure 7. Track Envelope Through the Proposed Jetty Entrance

Over the first few data points the pilots appeared to be returning to the channel centerline after resolving the wind and current effects over the bar. As the ship transitioned through the jetty, the effects of the littoral current were reduced and overshoot was observed as the pilots maintained a compensating drift angle slightly beyond the jetty entrance. Once inside the jetty channel, a small drift angle (less than 1 degree) was maintained to compensate for the south-southeasterly wind. In general, the pilots had few comments on this phase of the approach other than to indicate that the simulated vessel handled exactly as expected across the bar and into the channel, and that the tugs were effective in reducing ship's speed.

Docking Basin Approaches

Analysis of the final approach segment of the simulation runs did not lend itself to the track envelope analysis conducted for the straight channel segments. The sensitivity of a VLCC at slow speed to tug and ship control options suggested that the most valid analysis for this phase of the transit was to examine the vessel tracks and tug force components and combine those descriptive data with the pilot's postrun comments.

The tug force pattern appears to hold the key to understanding the relative merits of the docking basin options. Transit of the ship into docking Basins A and C required less lateral tug force and turning moment than did Basin B. Additionally, Docking Basin B, on average, used more of the available tug power (57 percent) compared to Basins A and C (38 percent and 50 percent, respectively). Although the observed tracks into Basin B were narrower than the other basins, larger tug force and moment requirements may indicate a more difficult approach. This is consistent with the pilots' comments following the simulation runs.

When entering Basin B, one pilot expressed a need to be "more speed conscious because of the greater turn angle" across the current. He further stated that the approach to Basin B would have been much more difficult in the presence of an ebb current. During a subsequent run into the same basin a pilot indicated his concern that the hazard of this design was in crossing the channel in the presence of a strong current. He felt that the tugs had been "worked" the hardest entering this basin.

The pilots' comments regarding docking Basins A and C tended more to basin design than to specific concerns about ship safety. One pilot suggested that a range would be required in the basin to provide a frame of reference to align the ship with the basin. Although he indicated a preference for Basin C because it was oriented further north than the other basins, the other pilot did not like the pier configuration in Basin C, which provided for a dock on the north side of the basin. That configuration, he commented, would reduce the available maneuvering room in the basin, particularly if two VLCCs were moored at the unloading docks directly across from one another. Subjectively both pilots expressed a preference for the orientation of Basin C.

Approaches to docking Basin B under the influence of a strong flood current and southerly wind leave little margin for error or system casualties. It was concluded that smaller angles between the natural channel current pattern and the docking basin provide more acceptable safety margins for large ship docking operations. Further consideration of the operating limitations imposed by environmental factors may be warranted.

PORT DEPARTURE SIMULATION

Nine departure transits were conducted under ebb current conditions aboard a ballasted tanker from the three alternative docking basins. The control process used by the pilots was to back the ship using tugs to maintain alignment until outside of the docking basin. The tugs were then employed to twist the ship in the turning basin until the vessel was aligned with the outbound channel. Ship's power was then used to accelerate out the channel system. Once the ship had attained enough forward momentum to maintain steerage, the tugs were released.

Because of the paucity of visual aids astern of the ship while backing, it was considered inappropriate to quantitatively analyze ship tracks through the early phase of the departure. There did not, however, appear to be any significant, observable differences with respect to basin configuration in the outbound simulation runs.

Trackkeeping During the Outbound Run

Figure 8 illustrates the result of applying the track envelope performance measure to the outbound transit. The indication that the track envelope crosses the channel boundaries at the furthest left data point is probably explained by the pilots' expressed bias to favor the south side in the existing harbor channels because there is presently added water depth available.

CONCLUSIONS

The following conclusions resulted from observation and analysis of the simulated transits.

- The proposed entrance channel system contained the track envelope performance measure.
- The pilots handling the vessel expressed no particular difficulties in transiting across the bar into the approach channel.
- The most critical portion of the transit into the proposed entrance channel occurs at the jetty opening. At this point the effect of the littoral crosscurrent is reduced and the flood (following) current begins to act on the vessel. The closest approach of the track envelope to the channel boundary was observed at that point as a result of a lag in perception of the current changes.
- Once inside the jetty the tugs were able to slow the ship effectively and stop it in the turning basin.
- Analysis of the alternative docking basin configurations indicated certain trends which may be qualitatively linked to the safety of the configurations.
  - The two more northerly configurations required the tugs to exert less twisting and lateral force on the ship. The northerly basins provide a more natural vessel approach to the basin in the presence of a flood current in the crossing channel.
  - The above finding is consistent with the pilots' observations that the most northerly basin was the easiest to enter.

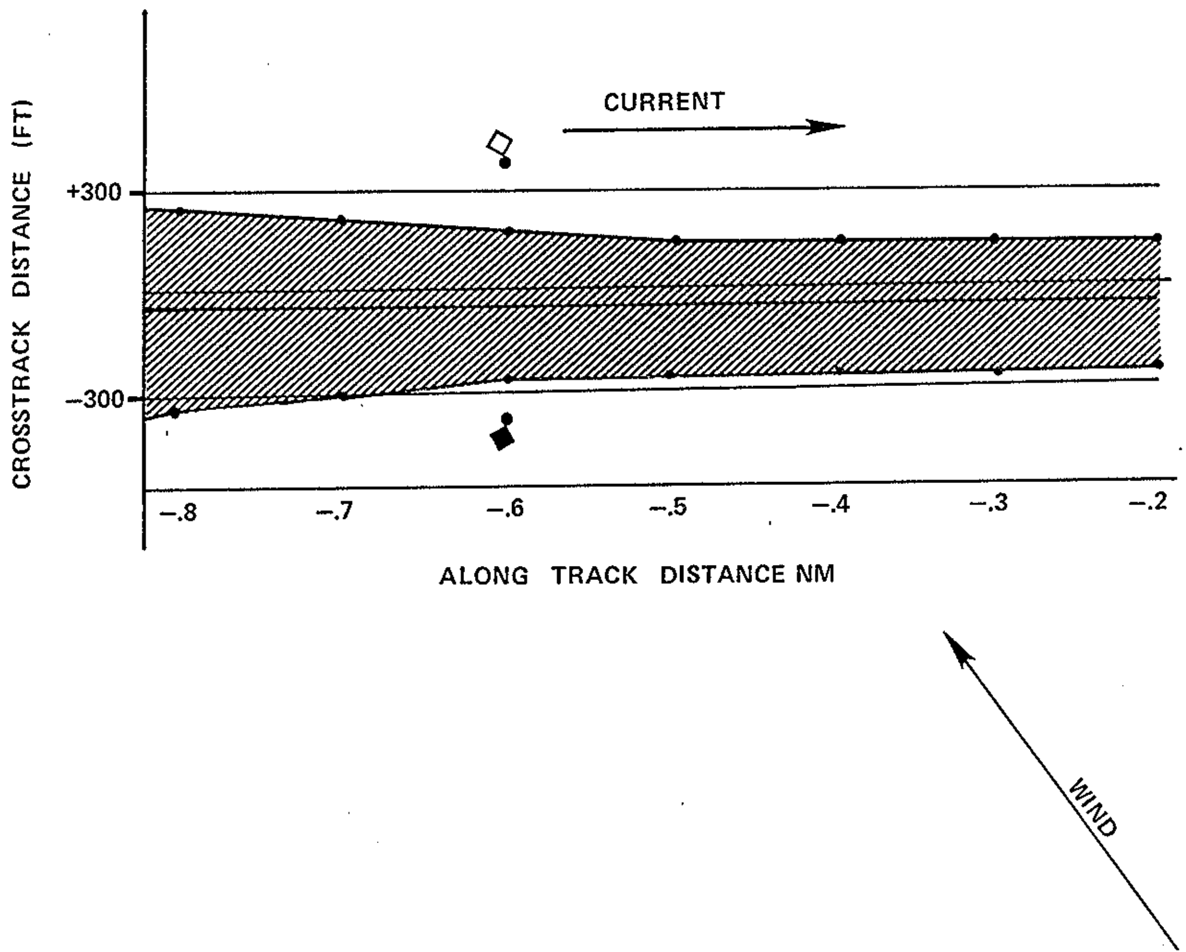


Figure 8. Track Envelope Observed During Outboard Transits

- No apparent differences were observed between docking basin configurations for the undocking evolution. The lack of an image to the rear of the vessel may have affected the backing operation.
- Overall the wind had a tendency to push the ballasted vessel back into the basins. Ship's power and tug assistance, however, appeared adequate to counteract the wind force. The factor should be considered, however, in establishing operational limitations with respect to wind direction and velocities.
- The outbound track envelope was contained within the channel boundaries except at the first observed point. The pilots' tendency is to stay to the south in the existing channel because of the added water depth available. This tendency was probably carried over to the simulation and would account for the slight excursion of the track envelope over the south channel boundary before the first channel buoy.