SHIP NAVIGATION SIMULATOR STUDY
SAVANNAH HARBOR WIDENING PROJECT
SAVANNAH, GEORGIA

by

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The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products.
The US Army Engineer Waterways Experiment Station (WES) ship simulator was used to evaluate the proposed channel widening of the Savannah Harbor from Fig Island Turning Basin to Kings Island Turning Basin. The widening would extend the north side of the channel 100 ft. The present channel width of 400 ft causes difficulties in the maneuvering of the 950-ft New York Class containerships that began calling in Savannah approximately 2 years ago. For this reason, the simulation study was conducted using a numerical model of this containership.

To generate channel currents for input into the simulation, a hydrodynamic finite element model of the Savannah Harbor was developed as part of the study. Boundary conditions for this model were obtained from a larger numerical model of the entire Savannah estuary system developed by the WES Hydraulics Laboratory Math Modeling Group. Prior to testing, available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)

Channels (Hydraulic engineering) (LC)
Finite element method (LC)
Ships—Maneuverability (LC)
Savannah Harbor (Georgia) (LC)
professional pilots from Savannah conducted a series of runs for the purpose of validating the simulation.

The simulations consisted of existing and planned conditions. Inbound and outbound runs were performed in opposing currents from an extreme tidal range of 10.5 ft. A total of 42 runs were made, 10 outbound runs in the existing channel, 10 outbound runs in the planned channel, 11 inbound runs in the existing channel, and 11 inbound runs in the planned channel. Professional pilots from the Savannah Pilots Association conned the ship during the tests. Study results were based on a basic statistical analysis in which the means and standard deviations of the following maneuvering parameters in the existing and planned channels were compared: rudder angle, rate of turn, heading, revolutions per minute, speed, and clearances to the channel edge. Results of this analysis showed a small but consistent improvement in navigation in the planned channel.

Appendix A presents plots of the current model meshes for both the existing and planned channels. Appendix B shows plots of the current vectors from the finite element model. Appendix C shows all pilot track-lines plotted simultaneously for each test condition. Appendix D presents the pilots' ratings of the simulator and of the proposed channel widening and tabulates these comments.
This investigation was performed by the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) for the US Army Engineer District, Savannah (SAS). The study was conducted at the WES research ship simulator. The essential information for channel, radar, and visual scene data base development was provided by SAS. The current data base was developed by the authors with verification prototype data being obtained by the Hydraulics Laboratory Estuaries Division field crew. The study was conducted during the period June 1985-May 1986.

The investigation was conducted and the report written by Mr. J. Christopher Hewlett and Dr. Larry L. Daggett of the Math Modeling Group, Hydraulic Analysis Division, and Mr. Samuel B. Heltzel of the Estuaries Division, under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory, M. B. Boyd, Chief of the Hydraulic Analysis Division, and W. H. McAnally, Jr., Chief of the Estuaries Division. Acknowledgement is made to Dr. Billy Johnson of the Math Modeling Group, who conducted the Savannah Comprehensive Study. The numerical model of the entire Savannah estuary system developed during that study provided boundary conditions for the numerical current model developed as part of the simulator study. This report was edited by Mrs. Marsha C. Gay, Information Technology Laboratory.

Messrs. Dennis L. Brandon, statistician, and Donald L. Robey, Chief of the Ecosystem Research and Simulation Division, WES Environmental Laboratory, generated the statistical data for the study results and provided assistance in the analysis of these data.

Thanks go to Mr. John Meyer, SAS, manager for the Savannah Harbor Widening Project, for his assistance and interest during the study. Thanks should also go to the shipping agents, ship captains, and pilots for access to transiting commercial ships for the purpose of gathering data for the simulation, and to Mr. Chris Brett, naval architect, United States Lines, Inc., for providing information and data on the New York Class containership used in this study. Special thanks go to pilots of the Savannah Pilots Association, Messrs. Ken Stanford, Rick Wesley, George Henry, Mike Foran, William Stegin, Spencer Edleman, William Brown, Jr., and William Brown, Sr., for their expertise during the simulator tests.
COL Allen F. Grum, USA, was the previous Director of WES. COL Dwayne G. Lee, CE, is the present Commander and Director. Dr. Robert W. Whalin is Technical Director.
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PART I: INTRODUCTION

Savannah Harbor

Physical description

1. Savannah Harbor (Figure 1) comprises the lower 21.3 miles* of the Savannah River in Chatham County, Georgia. In general, the harbor channel is a narrow, winding river subject to both freshwater inflow and tidal action. Industrial development starts around mile 10.0 on the south bank and extends to the end of the harbor. Major development includes the city of Savannah, petroleum terminals, container terminals, chemical plants, paper mills, sugar refineries, cement plants, and many smaller industrial activities. On the north bank exist more oil terminals, the operations yard for the US Army Engineer District (USAED), Savannah, a large pulp mill effluent aeration lagoon, and numerous dredged material disposal sites. Despite this development, the major portion of the north bank remains fairly open ground consisting of brushlands and saltwater marsh. Because of the large amount of industrial activity in the harbor, the Port of Savannah recently recorded a larger increase in total tonnage than most other harbors in the United States.

2. The Savannah River is one of the largest rivers in the southeast United States with an average freshwater inflow at the boundary of the present study area of 7,000-8,000 cfs. The river is subject to mean tidal ranges on the order of 7 to 8 ft that produce current speeds through the study area of around 2.5 to 3.0 knots on the ebbing tide. The flooding tide usually produces currents a little smaller than those in the ebbing tide. One of the main controlling factors of this strong ebb tide is the tide gate structure located on the north side of Hutchinson Island in the Back River (Figure 1). This structure was constructed by the US Army Corps of Engineers to aid in sediment flushing through the main shipping channel in the Front River.

*A table of factors for converting non-SI units of measurements to metric (SI) units is found on page 4.
During the flooding tide, the tide gate remains open, allowing the sediment to settle in the trap downstream where it is dredged and disposed. When the tide begins to ebb, the gate is closed, allowing the entire flow of the estuarine network upstream to pass through the Front River, flushing sediment as it goes.

3. The main features of the present channel are

a. A bar channel 8.2 miles long, 40 ft deep, and 600 ft wide and a bar channel 2.6 miles long, 38 ft deep, and 500 ft wide ending at the inner harbor entrance at Fort Pulaski on Cockspur Island.

b. A channel 38 ft deep and 500 ft wide to mile 13.3 at the upstream end of Fig Island Turning Basin.

c. A channel 38 ft deep and 400 ft wide to mile 18.9 and a channel 36 ft deep and 400 ft wide to mile 19.9 near Kings Island Turning Basin.

d. A channel 30 ft deep and 200 ft wide from mile 19.9 to the end of the harbor project at mile 21.3.

The proposed widening is confined to the portion of the Front River from Fig Island to Kings Island turning basins, that part of the channel listed in paragraph 3c, the extent of which is shown in Figure 1. Within this area, two emergency bend widenings were constructed during the period September 1984 to February 1985 to alleviate the maneuvering problems being experienced by the new 950-ft-long containerships which began to call at Savannah during the same period (USAED, Savannah, 1985b). These emergency widenings are not shown in Figure 1, but were considered part of the existing condition in the simulation.

Navigation problems

4. Navigation problems in the study area stem mainly from the strong tidal currents, the narrowness of the channel, and the large amount of development adjacent to transiting ships. Savannah pilots recognize no time window for ship transits, meaning that if there is a ship requesting arrival or departure at any stage of the tide, the pilots will accommodate as long as the ship will clear the bottom and the bridge. This practice subjects the ships and pilots to a wide range of conditions causing unique difficulties. Within the study area the primary piloting concerns are as follows:

a. The turn just above the Fig Island Turning Basin at the point where the widening begins. Pilots seem to drift toward the south bank partly out of habit and partly because of the change of direction of the current.

b. The turn at city front just below the bridge. The sharpness of the turn makes timing of the turn very important to keep the bow into the current on opposing tide and to minimize drift on
following tide. Also, the dense development along River Street in Savannah causes controllability in this area to be crucial.

c. The transit through Marsh Island Turning Basin is difficult because of the Amoco petroleum dock upstream of Union Camp Corporation's pulp mill. This dock lies only 60 ft off the channel boundary, which forces 100-ft-beam ships to extend into the channel 40 ft. This protrusion causes the pilots to steer into the turning basin to avoid passing too close to the ships at anchor there, which forces more maneuvering to line up with the channel on the other side of the turning basin. The problem is more noticeable during outbound transits.

d. The narrow area between Marsh Island Turning Basin and Kings Island Turning Basin causes problems because of the proximity of ships on the south bank and because the steeper slope on the north bank causes bank suction.

These problems were determined partly by witnessing them firsthand from a ship navigating the harbor and partly by analyzing track-lines from actual testing by pilots on the simulator. Another navigation problem that exists but could not be tested on the simulator involves the availability of convenient passing areas since the heavy traffic of the harbor forces passing situations frequently. Although the channel is not designed for two-way traffic, it is hoped that the proposed widening will enhance safety when these situations occur.

Proposed channel improvements

5. A proposed plan for navigation improvement in the Savannah Harbor was recommended by USAED, Savannah (Georgia House of Representatives 1983). Figure 1 shows the proposed channel modifications as recommended by the General Design Memorandum (USAED, Savannah, 1985b). The proposed widening is to involve the 5.6-mile section between the upstream end of Fig Island Turning Basin and the downstream end of Kings Island Turning Basin. Presently, the channel is maintained at a depth of 38 ft and width of 400 ft. The proposed improvement would widen the north side of the channel to 500 ft, except for the area through the Eugene Talmadge Memorial Bridge, which would remain at 400 ft because of the position of the piers. Also, the proposal calls for a slight channel realignment in the Talmadge Bridge to Fig Island channel reach. No change is planned for the project depth, which will remain at 38 ft. Above the bridge the widening will require removing small amounts of upland to maintain the channel side slope. Below the bridge, however, large portions of developed land on the north bank including the Savannah District operations yard and other old docking areas will require removal. USAED,
Savannah, requested that the US Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory conduct a ship simulation study concerning the effect of the proposed improvements on navigation.

**Purpose of Investigation**

6. The objective of the simulator investigation was to compare the existing and the planned (proposed) channels to determine any change in ship controllability and operational safety.

**Data Required**

7. Required data included channel geometry, bottom topography, currents for both the existing channel and the planned channel, a numerical model of a ship, and photographs of the scene along the riverbanks. The Annual Survey (USAED, Savannah, 1985a) was used for the existing channel data, and the planned channel was modeled as proposed. A numerical hydrodynamic model was generated using the TABS-2 RMA-2V program to generate the channel currents. Prototype data were used for boundary conditions and verification of the model of the existing channel. Boundary conditions for the planned channel were obtained from the laterally averaged numerical model generated for the sediment and salinity intrusion study being conducted by the WES Hydraulics Laboratory (Johnson, Trawle, Kee 1986). A reconnaissance trip was carried out to observe an inbound and outbound transit through the study area to obtain some familiarity with prototype conditions. Video recordings and still photographs were taken during the transits to aid in generation of the simulated visual scene. A 950-ft-long containership was chosen as the test ship because it is the largest vessel operating in the Savannah Harbor. A numerical model of the ship was developed through a contract with Tracor Hydronautics (Ankudinov 1986).

**Scope of Investigation**

8. Originally, this investigation was to run simulations using a number of different ship numerical models including three containerships, two LASH ships, two bulk carriers, and a liquid tanker. Because of limited time, it
was desirable to test only worst-case conditions; therefore, the scope of the testing was restricted to the new United States Lines, Inc., 950-ft New York Class containerships. This particular ship was determined to be the best design case for the following reasons:

a. It is the largest ship in Savannah Harbor. Although, according to comments made by the pilots, the 950's have better mechanical response than do many smaller ships, the length of the ship causes greater control problems in opposing currents due to large moments created by forces on the bow.

b. Discussions with the pilots who agreed that the 950's caused them the most stress.

c. Actual simulator testing by pilots and simulator employees using a few models of smaller ships. These ships were observed to cause no greater difficulties than did the 950's.

In keeping with the objective of testing only the worst case, it was also decided to run the simulation in spring tide conditions and, in so doing, subject the ship to extreme currents. The tidal range used to generate these currents was approximately 10.5 ft. From this tidal cycle, the maximum flooding currents and maximum ebbing currents along with the currents coinciding with minimum depth at ebb tide were extracted. With testing it was quickly determined that the shallow-water effects present in the minimum depth case were less a navigation problem than were the maximum currents. Also, through discussions with pilots and through testing it was determined that ships passing through opposing currents were more difficult to control than were ships running with the current. These reasons along with time requirements were used as the basis for restricting the simulator testing to two conditions in both the existing and planned channel: outbound with maximum flooding tide and inbound with maximum ebbing tide.

9. This report presents descriptions of the existing channel, the navigation problems in the study area, and the proposed channel modifications. Sections on data base creation and hydrodynamic modeling are included. The verification and testing procedures are outlined and the statistical results are presented. Finally, the study conclusions and recommendations are summarized.
10. To run a simulation study for a given channel, five input data types are required:

a. A "test" file, which contains initial conditions for the simulation and x- and y-coordinates for the channel. These coordinates represent opposite sides of the channel at each of around 50-60 cross sections chosen to best describe the changes in direction and magnitude of the current in the study area. This file also contains data to define the conditions of the banks adjacent to the channel, including slope angle and overdepth which are used in the hydrodynamic program to calculate bank suction forces on the ship. Finally the data file contains the definition of the autopilot track-line and commands which enable the autopilot.

b. A "scene" file, which actually represents a collection of separate programs and files containing geometrical information enabling the graphics computer to generate the simulated visual scene of the local area on the large television screen.

c. A "radar" file, which contains a list of coordinates defining the border between land and water. These data are used by another graphics computer that connects the coordinates with straight lines and displays them on a terminal as the simulated radar for use by the pilots. The file also contains coordinates for any major physical feature deemed important such as bridges or docked ships.

d. A "ship" file, which contains characteristics and hydrodynamic coefficients for the test vessel. These data are used by the main hydrodynamic program to calculate forces on the ship at each time step.

e. A "current" file, which contains current magnitude and direction at eight points across the channel at each of the cross sections defined in the test file.

In the following paragraphs the methods for compiling these data for the Savannah Harbor project are described.

**Test File**

11. The information used for development of the channel data base was obtained from USAED, Savannah (1985a). This was the latest information available concerning depths and dimensions of the channel and bank line. State plane coordinates as shown on the Annual Survey were used for definition of the data. The only feature included in the simulation that was not present in the survey was the docking lagoon constructed by Gulf Oil Corporation across

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from the Savannah Electric Power Station. The dimensions of this feature were estimated from notes and photographs taken during reconnaissance trips to Savannah.

12. In general, the simulator channel cross sections were placed at each one of the bends in the channel, and the remainder were fairly evenly spaced between these. Closer spacing was used in areas of crucial navigation such as through the bridge and along city front. Figure 2 shows an outline of the existing channel along with the defined cross sections. For the proposed channel, also shown in Figure 2, the locations of only a few of the cross sections were changed; however, many were lengthened to include the proposed widening.

13. Bottom depths were used as they appear on the survey for the current modeling of the existing channel. For simulator cross sections between survey transits, interpolation was used. For the proposed channel, a uniform depth of 39.5 ft was used so that the bottom of the 950-ft containership would barely clear. This depth is actually less than that used in the model of the existing channel, but it was felt that this would be justified because the shallower depth would force the calculated proposed currents to be on the conservative high side. The reader is referred to the section, "Current File," for more information on bottom conditions. Also, side slopes along the edge of the channel were obtained from the survey for use in the main program for calculating bank suction forces. These slopes were used in the simulation of both the existing channel and proposed channel, except that in the latter, a slope of 1V on 3H was used in areas requiring cuts on the north bank.

14. In a narrow channel as in the Savannah River, the bank suction force calculated in the simulator hydrodynamic program becomes important, especially in the area just below Kings Island Turning Basin. Basically, the bank suction force comes into play when a large-beam ship travels close to one of the banks through a restricted channel. The small area through which the water flows between the ship's hull and the bank creates an increase in velocity and a coincident decrease in pressure. The higher pressure on the other side of the ship pushes the vessel toward the bank. Because the ship is not longitudinally symmetrical, this force creates a moment about the center of gravity (CG), typically rotating the stern toward the bank and the bow away from the bank. The pilot has to control this movement with counteracting rudder, depicted in Figure 3. The main variables in the formulation of the bank
Figure 2. Simulator cross sections
suction force and moment are distance to the bank, steepness of the bank, depth of the water, and draft of the vessel. For more details see Ankudinov and Barr (1980). Because the hull of a permanently moored ship is rather similar to a vertical bank, the effect on the test ship of docked ships present in the simulation was considered the same as a bank effect.

15. The practice of simulating these effects is very subjective, comprised mainly of a trial and error procedure with the main objective being to tune the effect until the ship "feels right." This procedure is complicated by the fact that most pilots are not completely aware of these forces. The reader is referred to Part III, "Validation Tests," in which a tuning process is described whereby the bank forces were necessarily lowered following comments by Savannah pilots.

Scene File

16. The visual scene is second only to the current model in time and effort required for generation. The graphics hardware used for the Savannah project is a stand-alone computer which is connected with the main computer from which certain information for the scene updating is passed. This information includes parameters such as heading, rate of turn of the vessel, and position. Also, the viewing angle is passed to the graphics computer for the look-around feature on the simulator console. This feature enables the pilots to look at objects outside of the straight-ahead view, which encompasses only
about a 40- to 50-deg arc. This feature compensates to a degree for the pilot's inability to turn his head to see an object.

17. The basic data used for scene generation were obtained from two sources. The first was the Annual Survey (USAED, Savannah, 1985a), which is printed on aerial photographs made in February 1983. These photos were an excellent source of coordinates for physical features in the area and provided assistance in determining which of these features were most prominent. Still photographs, video recordings, and pilot comments, all obtained aboard actual transiting ships during the reconnaissance trips to Savannah, constituted a second source of information for the scene. These allowed weeding out of the many insignificant physical features present and also helped determine which, if any, features the pilots themselves use for ranges and sightings.

18. Some of the main buildings in the city of Savannah such as city hall, a few of the largest churches, a bank building, and the row buildings along River Street were included in the simulated scene. Numerous warehouses along the industrialized sections were included along with a number of oil tank farms. Main industrial features included the Union Camp pulp mill, the Atlantic Cement Company facility, and the Georgia Port Authority container terminal near Kings Island. The Talmadge Memorial Bridge was simulated along with some of the docks located adjacent to the channel. Part III lists some objects added after the first pilots tested the simulation and made comments. Figures 4, 5, and 6 show the simulator appearance and setup. Figure 4 shows the overall setup, with a man operating the deep-draft ship console. In this figure, the large television screen shows part of the Savannah scene. The larger console directly in front of the screen is used for shallow-draft push boats which operate in inland rivers. The two terminals to the man's left are the radar scene on the bottom and the precision navigation digital readout on top. The latter gives information every 10 sec which includes water depth, longitudinal and lateral speed, and heading. Figure 5 shows a close-up of a section of the simulator scene in Kings Island Turning Basin. The simulated cranes at the Georgia Port Authority container terminal are directly ahead of the ship's bow. Figure 6 shows the bow of a prototype 950-ft containership and a part of the river just downstream of Kings Island Turning Basin. The Georgia Port Authority cranes are on the port side of the river in this photograph.
Figure 4. WES simulator overall setup

Figure 5. Visual simulator scene of Savannah Harbor
Figure 6. Savannah Harbor

**Radar File**

19. The radar file was the simplest data base to generate. It consisted of coordinates of the border between land and water obtained from the 1985 Annual Survey (USAED, Savannah, 1985a). In short, these data defined what the pilot would actually see on shipboard radar, including ships docked alongside the channel, the bridge, and aids to navigation. Three different scales were programmed so that the pilot could choose which one he preferred. The display was simulated in the sense that the coordinates were connected with straight lines and it did not appear just like an actual radar with sweeping circular motion; however, all the important information obtainable on ship's radar was present. Figure 7 shows how the section just above the Tal-madge Bridge appears in the simulated radar.

**Ship File**

20. This data file was obtained through a contract with Tracor Hydronautics (Ankudinov 1986). The file consisted of the characteristics and coefficients used in the hydrodynamic program for calculating forces on the 950-ft
containership. Data on the ship were obtained from United States Lines, Inc.,* which is the shipping company that operates the new 950-ft New York Class containerships. The ship itself is 950 ft long overall with a length between perpendicul ars of 915 ft. The beam at midships is 106 ft. In the Savannah River, the pilots try to maintain a draft of 36 ft on flood tide and 34 ft on ebb tide, which are the conditions tested in the simulator study. In the scene that the pilot would see from the bridge, the bow of the ship would be visible. Included in the collection of files in the scene file was a file containing the ship's bow defined as a geometrical object. After the Hydronautics data were received, the ship model was tested in a few defined maneuvers on the simulator computer using its fast time capability. These maneuvers included turns and crash stops. The results from the testing showed

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* Personal Communication, Chris Brett, Naval Architect, United States Lines, Inc., Newark, N. J.
close agreement between the simulator computer and the Hydronautics computer. Figures 5 and 6 show the simulated bow and the actual bow, respectively.

**Current File**

21. The current file is the simulator's source of information concerning current speed, current direction, and water depth. Values for these three parameters are required at eight equally spaced points across each of the cross sections shown in Figure 2. To obtain these values, a finite element model of the area of the Savannah River shown in Figure 1 was developed. This procedure is discussed in Thomas and McAnally (1985). The following paragraphs discuss the development of boundary conditions and the verification of the model using prototype data.

22. Appendix A contains plots of the current model meshes for both the existing and planned channels. The mesh consists of 720 elements and 850 corner nodes. The mesh is refined to provide adequate detail across and along the river. The model bottom definition was derived from the latest available hydrographic survey (USAED, Savannah, 1985a), which was modified to reflect dredging for the proposed planned channel. Four sets of boundary data were developed for the current model used in this study: an adjustment data set, another for verification using a 7.5-ft tidal range in the existing channel, and an existing and planned condition using a 10.5-ft tidal range for actual testing. Three boundaries required hourly updates: a head boundary (watersurface elevation) at the downstream end of the model near Fort Jackson and two velocity boundaries, one at the junction of the Middle and Back rivers and the other upstream of this junction in the Front River. These boundaries are located in Figure A1.

23. For the model adjustment boundary conditions, WES conducted a field study in the Savannah estuary in April 1985. Tides, velocities, salinities, and suspended sediment concentrations were recorded at several locations along the estuary from its mouth to the upstream end of tidal intrusion. The tidal and velocity measurements in the vicinity of the numerical model mesh provided the data necessary to develop boundary conditions and to ensure that the model was reproducing tidal velocity conditions within the mesh in a reasonable manner.

24. The tidal data could be used directly with only adjustments for reference conditions. The velocity data had to be averaged to obtain a
vertically integrated value that could be compared with the numerical model results or used as boundary conditions. The integrated velocity was assigned to the numerical model node closest to it at the upstream boundaries. These data then formed the information for developing the dynamic boundary conditions necessary to run the numerical model for a complete tidal cycle.

25. Prototype data and model results were compared at two different cross sections in the existing channel model. One of these cross sections was immediately downstream of the Savannah District operations yard, and the other was upstream of the Talmadge Bridge at the location of the Diamond Construction Company's dock on the north bank, sta R-5 and R-6 in Figure 8. Figure 9 compares the field data and the numerical model results. Figures 9f, 9g, and 9h represent the north side, center, and south side of the channel, respectively, at the upstream adjustment cross section (sta R-6 in Figure 8). As can be seen, agreement is close at all three points, the only exception being at hour 4 at the center of the channel. A possible explanation of this exception is that the field data here represent a small-scale phenomenon such as an eddy or a passing vessel which caused the velocity to drop. At the other adjustment cross section (sta R-5), agreement is reasonable at the center and south edges (Figures 9d and 9e) of the channel although the model seems to calculate somewhat low on the south edge. At the north side of the channel, the field data were taken "at the edge of the channel"; however, this was one of the areas where an emergency bend widening was constructed and an exact location is not available. The numerical model flow exhibits a strong lateral gradient here as can be seen by comparing Figures 9c, 9b, and 9a, which represent model nodes starting near the center of the channel and moving out toward the north side. The field data agree best with the node approximately 100 ft north of the center, and agreement decreases as the nodes approach the north bank. Adjustment of bottom roughness and other energy loss coefficients in the finite element model seemed to have no effect on these results. Various integration approaches also seemed to have little effect on the results. Two explanations are possible. Since the exact location of the measurement is unknown and since the measurement agrees closely with the computed value at the channel edge prior to the emergency construction, it is likely that the location of the field data is at this point. Another possibility would be some local flow pattern that is caused by local geometry conditions not included in the model.

20
Figure 8. Prototype measurement locations for Savannah Harbor ship simulation study
Figure 9. Comparison of field data and numerical model results (Sheet 1 of 4)

b. Near north side of channel, sta R-5
c. Center of channel, sta R-5

d. Near center of channel, sta R-5

Figure 9. (Sheet 2 of 4)
e. South side of channel, sta R-5

f. North side of channel, sta R-6

Figure 9. (Sheet 3 of 4)
g. Center of channel, sta R-6

h. South side of channel, sta R-6

Figure 9. (Sheet 4 of 4)
26. The boundary conditions for existing and planned channel testing were generated using LAEM, a laterally averaged estuary numerical model which was modified to handle sediment computations along with flow, temperature, and salinity computations. A bed model that allows for multiple layers when sediment is cohesive has been incorporated to simulate the exchange of sediment between the bed and the water column. The resulting model is called LAEMSED. This model was used by Johnson, Trawle, and Kee (1986) to assess the impact of channel deepening on salinity intrusion and shoaling in the navigation channel.

27. The LAEMSED model produced discharge values at cross sections and water-surface elevations at points between the cross sections for a complete tidal cycle with a range of 10.5 ft. These data were used to develop an average hourly cross-sectional velocity at the two upstream boundaries of the simulator current model and hourly water-surface elevations at the downstream end. The velocity values were computed by taking the cross-sectional area of the upstream boundaries and modifying it by the surface elevation change. This value was then divided into the discharge calculated by LAEMSED to get an average cross-sectional velocity which was assigned to each node, including midside nodes, across the cross section. Plots of the current vectors from the finite element model are shown in Appendix B. These plots depict maximum flooding and maximum ebbing tide in both the existing and planned channels, which are the conditions actually run in the simulator. The dynamic output from the finite element model was further used for the interpolation of the current speed and direction for the eight-point simulator cross sections.
PART III: VALIDATION TESTS

28. To validate the simulation of the Savannah Harbor, two pilots from the Savannah Pilots Association visited the ship simulator prior to actual testing. Their experience and familiarity with the area were used to fine-tune model parameters such as bank effects, ship hydrodynamic coefficients, and objects in the visual scene.

29. These validation tests were conducted on the model for the existing channel to avoid giving prior experience to the pilots on the simulation of the planned channel. Maximum flood and ebb currents were used from two separate tidal ranges of approximately 7.5 and 10.5 feet. This allowed four different current conditions in the channel. These four conditions with inbound and outbound directions created eight specific simulated conditions available for testing.

30. After a briefing with the pilots concerning the simulator and the Savannah project in general, tests were begun. The first test included the effects of banks and currents from the lower tidal range. The pilot experienced difficulty in controlling the ship during this run. Two more runs were made with different initial conditions for the ship with no more success than on the first. It was decided that the ship model should be tested in deep water with no effects of wind, banks, or currents to determine whether the ship model was operating correctly. During this deepwater run, the pilot remarked that the ship handled just as he would expect. The next trial changed the water depth from 500 feet to 43 feet to determine whether the shallow-water corrections in the ship model were causing the problem. With this condition, the pilot experienced no problems handling the ship. Current and actual water depth were added for the next step; and while the pilot indeed felt the effect of the moving water, the ship handled normally. When the bank effects were added during the next step, the pilot again experienced difficulty in control. A number of runs were then made with adjustments to the bank conditions until the pilot felt the ship handled properly. In addition to the adjustments to the channel model, the pilots requested that a few more objects be added to the visual scene for aid in navigation such as the radio towers on Oatland Island and the channel markers. Also, docked ships were added at three locations along the harbor where, according to the pilots, ships would normally be located.

31. Testing was conducted with six professional pilots from the Savannah
Pilots Association who came two at a time on three different weeks. All of these were long-time Savannah pilots with the minimum length of experience being about 7 years. Typically, they arrived at the simulator during midafternoon and were introduced to the equipment, after which they conducted a couple of warmup runs in the simulated existing channel. The next day the pilots started the actual testing. To avoid fatigue the pilots alternated driving the simulator as each run required approximately 1 hour to complete. The first run performed by a pilot was usually in the existing channel followed by a run in the planned channel with the same conditions. The second full day of testing proceeded as the first with the number of runs per day averaging 7, a total of 42 over 6 days. There were 10 runs each for the existing and planned channels outbound with flooding tide and 11 runs each for the existing and planned channels inbound with ebbing tide. All pilots did not complete the same number of runs; however, each run in the existing channel had a counterpart by the same pilot in the planned channel.

32. The pilots were asked to perform the simulation in as realistic a manner as possible, meaning, most importantly, to maintain the speed of the ship at a level acceptable in the prototype. They were asked to consider the effect of the ship on moored vessels along the channel as they normally would. While the pilots warmed up to the simulator at different rates, all had positive comments on its realism by the end of their test periods.
33. The warm-up runs performed by the pilots were not included in the analysis. Many of the runs for pilots 6 and 7 were conducted with a 15-knot wind from the northeast. Subsequent statistical comparison using analysis of variance showed that there was no significant difference in pilot performance in runs with this wind and runs without this wind; therefore, the 15-knot wind was ignored as a specific condition. During each run the characteristic parameters of the ship were automatically recorded every 10 sec. These parameters included position, speed, revolutions per minute (rpm) of the engine, drift angle, rate of turn, heading, port and starboard clearance, and rudder angle. Since the simulator performances of nearly 50 percent of the active pilots in Savannah were recorded during the testing, it was decided analysis could be based on parameter means rather than concentrating on individual runs. Appendix C shows all pilot track-lines plotted simultaneously for each test condition. These figures represent different regions of Savannah Harbor for the purpose of isolating specific areas. These regions are identified on Figure 2. The results of the statistical analysis are presented for these same regions.

34. The results are presented for each of the recorded parameters listed in paragraph 33 except position which is reflected in the clearance values. Bar charts comparing the mean of means and the mean of standard deviations for the existing and planned channels are presented for each parameter. For the standard deviations, the closer the parameter clusters about its mean, the less maneuvering is going on. A generalization cannot be made about the means because the results are parameter dependent; e.g., more clearance is desirable but less rudder is desirable.

Clearance

Outbound runs

35. Figures 10a and 10b show the standard deviations and means for south and north bank clearance, respectively, from all 10 outbound runs. The bar charts show the values of the existing and planned channels side by side for each area. The values in area A (Figure 10b) are much larger than in the other areas because the outbound ships had an initial position in the Kings
Figure 10. Standard deviations and means, outbound runs, bank clearance

a. South bank clearance

b. North bank clearance
Island Turning Basin with large clearances on both sides. In areas A and B, the mean north bank clearance shows a large increase in the planned channel and the standard deviation shows a decrease. For the mean south bank clearance in the same areas, a much smaller increase is evident in the planned channel while the standard deviations still decrease. This pattern is somewhat reversed in areas C and D where the mean south bank clearance shows a marked increase in area D. In area C little change is evident, which indeed should be the case because the channel is restricted to 400 ft through the bridge and the small differences in clearance are due to the approaches. The mean north bank clearance shows little change in these two areas between the two channel scenarios. However, the standard deviations in C and D show a small increase in the planned channel.

36. The reason for this difference between the upper and lower parts of the river can be attributed to pilot unfamiliarity with the planned channel. In areas A and B above the bridge, very little change will be made in the existing bank line when the widening is implemented. In the simulation there is essentially no difference here between the existing and planned scenes and radar; therefore, the pilots did not change their paths or strategy. Apparently, their paths were easier to follow in the planned channel in these areas as evidenced by the lower standard deviations. In area D there will be a significant change in the widened bank line on the north side. The pilots realized this in the simulation and adjusted their paths accordingly, causing the south bank clearance to increase greatly in the planned condition. The slightly higher deviations could be a result of these adjustments when the pilots steered through areas C and D.

37. Another way to consider clearance is to look at the minimum values rather than the mean values. When the mean minimums are calculated, including groundings becomes a problem. Clearances are recorded as the closest distance from any point on the ship to the boundary of the channel unless the boundary is passed, for which a negative distance signifies a grounding. In Figures 11a and 11b the mean minimum clearances for all the outbound runs are shown with any groundings (read negative clearances) included as a zero clearance. Practically the same pattern exists here as for the mean clearances discussed previously. The planned channel improved navigation conditions significantly in areas A, B, and D with little change in area C.
Figure 11. Mean minimum clearances for all outbound runs

a. Minimum south bank clearance

b. Minimum north bank clearance
Inbound runs

38. For the 11 inbound runs, Figures 12a and 12b show the means and standard deviations. The same pattern as described for the outbound runs exists here with the mean south bank clearance in the two channel scenarios showing almost no change in areas A, B, and C and with a more significant increase in area D. The standard deviations again decrease in A and B and remain generally unchanged in C and D except for the south bank in C. These results indicate that the pilots will recognize and, with familiarity, use the widened portion of the channel, even though on the simulation they tended to keep to their accustomed paths.

39. Figures 13a and 13b show the mean minimum clearances for all the inbound runs. For the planned channel, little increase is seen in areas A and B for the south bank minimum clearance. All the increased clearance is on the north side for these areas. In areas C and D, south bank minimum clearance is improved. These observations agree with the discussion of the mean clearances.

Groundings

40. The following tabulation summarizes all the groundings recorded during the ship simulator study:

<table>
<thead>
<tr>
<th>Run</th>
<th>Area A</th>
<th>Area B</th>
<th>Area C</th>
<th>Area D</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>outbound</td>
<td>4</td>
<td>6</td>
<td>0</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>Planned</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Existing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>inbound</td>
<td>8</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>13</td>
</tr>
<tr>
<td>Planned</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>16</td>
<td>9</td>
<td>1</td>
<td>14</td>
<td></td>
</tr>
</tbody>
</table>

There was a total of 30 groundings for the existing condition and a total of 10 for the planned condition. It is to be noted that a grounding in the simulator sense does not necessarily mean that a physical grounding would have occurred; rather, it means some part of the ship strayed beyond the boundary of the channel as defined in the Annual Survey (USAED, Savannah, 1985a). The majority of the groundings in both scenarios occurred in areas A and D. One of the main features that caused these groundings was the narrowness of the channel between Kings Island and Marsh Island turning basins with fairly steep
Figure 12. Standard deviations and means, inbound runs, bank clearance

a. South bank clearance

b. North bank clearance
Legend

- Existing Channel Mean
- Planned Channel Mean

Figure 13. Mean minimum clearances for all inbound runs

a. Minimum south bank clearance

b. Minimum north bank clearance
banks on the north side. The bank suction caused by these banks makes passing ships difficult to control; therefore, pilots must be careful not to approach too closely. Also, extreme care must be taken to keep clear of the south edge of the channel in this area because of moored ships directly alongside. These two hindrances combine to reduce the effective width of the channel. The planned widening improved conditions in the simulator significantly, causing much fewer groundings; however, any additional widening in this area would allow the pilots to clear the channel boundaries even more.

41. Another group of groundings occurred in the transitional region of areas A and B. These occurred mainly during outbound transits where the pilot steered the simulated ship into Marsh Island Turning Basin to avoid the Amoco dock upstream of Union Camp. After the ship moves into the basin, much maneuvering is required to get lined up for the passage downstream. This problem is compounded by the narrowing of the channel below the turning basin which forces the bow of the ship to get caught in flooding currents, slowing the turn to port and causing a drift toward the south edge of the channel. The planned condition runs still registered a few groundings in this area; however, the track-lines in Appendix C for this scenario show that these are actually boundary groundings and that much channel is left to the north for improvement when the pilots become accustomed to the widening.

42. The other area which exhibited a large number of groundings is on the south bank in area D just upstream of the Fig Island Turning Basin. In the simulator runs, the groundings occurred mainly in the existing condition (Figure C7a). However, the scenario track-lines demonstrate that there still were groundings in the planned condition runs (Figure C7b). A number of these groundings in both channels would not have been physical groundings; as a matter of fact, the pilots stated that they steer toward the south bank habitually because they know that there is plenty of water there. This practice leaves much of the channel to the north unused. A change in the planned channel at this location, described in the study recommendations, would encourage the pilots to stay further to the north in the channel, thus receiving more benefits from the channel widening.

Drift Angle

43. The drift angle is the angle off the heading of a ship toward which
the center of gravity of that ship is traveling. Pilots call this movement "set." It usually is on the order of 1-2 deg either port or starboard. Set typically occurs when a ship is not traveling parallel to the current, or it can be caused by high winds. In the Savannah River the predominant region where a ship is subject to large drift angles is in area D along city front. 

Outbound runs

...It is in the outbound runs on strong flooding tides in front of River Street that drift angle becomes most critical to pilots. The sharp bend to the north below the Talmadge Bridge creates a navigation problem when the bow of the ship sticks out into current. This bend causes difficulty in initiating the rotation of the ship and creates a large drift angle which tends to force the ship directly toward the Hyatt Regency Hotel. Relief of this problem would improve navigation in this area. Figure 14a shows the means and standard deviations of the drift angle for the outbound simulator runs. In areas A, B, and C, little change in the means between the planned and existing channels is noted. The drift angles themselves are very small in these areas. However, in area D the drift angle in the existing channel approaches a mean of 1 deg to starboard. A large variability is present also, but this is probably a result of there being one large bend in the area followed by fairly straight stretches. Nonetheless, the standard deviation exhibits a drop in the planned channel runs, and the mean shows a drop of around 30 percent. These results tend to indicate that the widening would create a less severe change in direction of the currents and that the pilots would be able to start turning the ship earlier into the bend, lessening the danger of the set.

Inbound runs

...Where in the outbound runs the large drift angles were confined to one area, in the inbound runs against a stronger ebbing tide, larger sets are evident through the whole transit. Area D still exhibits the largest drift angles (Figure 14b) with no change between the existing and planned runs. The variability in the planned channel does show a significant drop here. The mean drift angle in area C is lower in the plan, probably as a result of the widened approaches to the bridge creating conditions for earlier turns. In areas A and B, less variability is evident in the planned channel; however, the mean drift angle shows very little change.
Figure 14. Standard deviations and means, drift angle
Heading

46. Figures 15a and 15b show the standard deviations of the heading for the outbound and inbound runs, respectively. The means of the heading are not plotted because they do not change in the planned channel. No conclusions can be drawn on the basis of the variability of the heading. The variability exhibits either no change or very little change in both outbound and inbound runs. The only exception to this pattern is in area C in the outbound runs. A small increase is seen here in the planned channel, probably because the pilots make the turn into the city front bend earlier than in the existing channel, causing the change in heading to occur in area C rather than area D.

Rate of Turn

47. The rate of turn is a measure of how fast the ship is rotating about its center of gravity. Considering the huge mass of a ship, it behooves the pilots to keep the rate of turn to a minimum to avoid momentum getting out of control. Figure 16 shows the variabilities and means for the rate of turn. Obviously, the simulated planned channel does very little to lower the rates of turn. Almost no difference in the means and standard deviations can be seen in any of the areas for either the inbound or outbound runs. The exception is in area C for inbound runs, where the mean is significantly higher in the planned channel. Closer inspection of the individual rates of turn from all the inbound runs in this area reveals that in the existing channel the values varied around zero and in the planned channel they were all positive. These results make it appear that ships in the existing channel exhibit lower rates of turn than in the planned channel; however, the ranges and variabilities are approximately the same. The conclusion is that the pilots followed a more consistent path with less uncertainty in the planned channel through this area. This conclusion is supported by the track-lines for the inbound runs (Figure C6) where a tighter grouping is noted in the planned scenario below the bridge in area C.

Revolutions Per Minute

48. Figure 17 compares the recorded rpm in the existing and planned
Figure 15. Standard deviation of heading

a. Outbound

b. Inbound
Figure 16. Standard deviations and means, rate of turn
Figure 17. Standard deviations and means, rpm
channels. In most areas the means and standard deviations do not change appreciably between the two simulated channels. As a matter of fact, rpm seemed to be way down on the pilots' list of priorities during the simulator runs. Most of the pilots set the rpm at the preferred level and changed it very little during the run, as can be seen by the low values of the standard deviations. This practice also means that the standard deviation and mean are very sensitive to a short-duration change in the rpm such as would be made for a kick turn. This could explain many of the small differences seen in these figures for the two channels. It is hard to determine whether more rpm or less rpm is preferable; therefore, at this point no conclusions can be drawn as to the effect of the planned widening on the rpm of transiting ships. Because rpm in conjunction with the rudder angle determines the amount of maneuvering power that a ship has, the following discussions on rudder angle and the "maneuvering factor" will try to extract some meaning from these results on rpm.

Rudder Angle

49. In contrast to the vague results for rpm, the rudder angle is very definitive as to preferable settings: less rudder action is better.

Outbound

50. Figure 18a shows the standard deviation and mean of the pilots' rudder positions during the recorded runs. For these outbound runs, the variability shows very little change in all areas, although what change exists constitutes a drop in the planned channel values. The mean rudder position is very near zero through the straight regions in areas A and B, as would be expected. In area C little difference is seen between the existing and planned positions. However, in area D a small increase is seen in the mean rudder position for the planned channel. The difference is small enough to be insignificant and is probably a result of the pilots' following a slightly more consistent path through this area, which can be noticed in the track-line plots in Appendix C.

Inbound

51. Figure 18b shows the rudder angle statistical comparison for the inbound runs. Areas A, B, and D show slight improvements in the planned channel with lower variabilities and means. In area C through the bridge,
Figure 18. Standard deviations and means, rudder angle
slightly higher variability and mean in the planned channel are evident. This result goes along with the increased rate of turn through this area discussed earlier. Observation of the inbound track-lines in Figures C6a and C6b reveals a more consistent path in the approach below the bridge. It is this section of area C that appears to cause this reversal of trends in the inbound runs. Possibly the widened channel creates conditions which allow the pilots to approach the turn below the bridge in a more consistent manner; in any case, no adverse impact can be detected on the passage through the bridge.

Maneuvering Factor

52. To determine if there was any lessening in actual maneuvers in the recorded runs for the planned channel, a "maneuvering factor" was created whereby the rpm at every time-step was multiplied by the rudder angle at the same time-step. This creates a purely comparative measure of the amount of maneuvering going on. Figures 19a and 19b show the variabilities and means of this factor for the outbound and inbound runs, respectively. No improvement or slight improvement for the planned channel is seen in all areas except in area D in the outbound runs and area C in the inbound runs. These two exceptions have been dealt with in the preceding discussions on rpm and rudder angle. Basically, what these results appear to show is that the simulated planned channel had the most effect on maneuvering in the city front bend. First observations seem to show less desirable characteristics in the planned channel in this area; however, closer inspection suggests that the differences exist because the pilots felt more comfortable with the planned channel and demonstrated this by following a more consistent path through the bend.

Speed

53. Figures 20a and 20b show the statistical comparison for speed in the different scenarios. Because speed seems to be more pilot dependent than channel dependent, no conclusions can be made as to the effect of the planned channel. At the beginning of the tests, each pilot was asked to maintain a fairly realistic speed while driving the simulator. According to the pilots, on the river they usually maintain a speed of between 5 and 7 knots. On the simulator runs, the speed generally varied between 6 and 8 knots; therefore,
Figure 19. Standard deviations and means, rpm x rudder angle
LEGEND
- STANDARD DEVIATION, EXISTING CHANNEL
- STANDARD DEVIATION, PLANNED CHANNEL
- MEAN, EXISTING CHANNEL
- MEAN, PLANNED CHANNEL

Figure 20. Standard deviations and means, speed
it seems the pilots went about 1 knot faster than they would normally go in the river.

**Pilot Ratings**

54. To determine what the pilots themselves thought about the simulator in general and the proposed channel widening, two questionnaires were drawn up to document their comments (Appendix D). The first one was given to the pilots after each run; the second was given after the pilot's 2-day test period. The realism ratings are not plotted; however, the average for the simulation in general was about 6 on a scale of 1 to 10, 10 being just like the real thing. The pilots rated the ship handling and the bank force realism generally higher than the docked ship realism. Many of the pilots did not acknowledge that they had ever felt any effect caused by docked ships alongside the channel while piloting actual ships. However, most of the pilots did acknowledge bank effects. In the simulator, the docked ships were treated the same as steep banks. In any event, this misunderstanding concerning docked ship effects is considered the reason why the realism ratings were not higher, because the pilots had many good comments concerning realism on their final questionnaire. See Appendix D for tabulation of these comments.

55. Figure 21a shows the mean pilot ratings for the overall run difficulty and attention required. As suspected, the inbound run was considered a little more difficult than the outbound run. In both instances the simulated planned channel showed up as an improvement according to the pilots. Figures 21b through 21e show the results of the last four area-specific questions asked of the pilots. The areas dividing the river here are a little more general than in the previous discussion on run results. In Figure 21d the ratings for the danger of ramming an object are presented. The largest rating drop for the planned channel was in the FITB to TB and the MITB to KITB areas. These areas comprise areas C and D for the former and area A for the latter in the run results. These results show that the pilots really felt that the increase in south bank clearance created a less dangerous passage. The same pattern is seen in Figure 21c for the danger of grounding and also in Figure 21e for vessel controllability. In all three areas the pilots rated the planned channel as an improvement for all factors rated.
a. Overall run evaluation

b. Severity of environmental conditions

Figure 21. Mean pilot ratings of simulator
(Sheet 1 of 3)
c. Danger of running aground

d. Danger of ramming an object

Figure 21 (Sheet 2 of 3)
e. Controllability of vessel

Figure 21 (Sheet 3 of 3)
PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

56. Results of the Savannah Harbor ship simulation study reveal these conclusions:

a. A slight but consistent improvement was noted in vessel controllability in the planned channel.

b. Passage through the immediate vicinity of the bridge appears to be unaffected by the plan.

c. A significant improvement was evident in the mean south bank clearance in the planned channel, especially in the city front area.

d. The area between Marsh Island Turning Basin and Kings Island Turning Basin is a potential area for an accident, exhibited by the high incidence of groundings in the simulator runs.

e. In their comments and questionnaire ratings, the pilots consistently judged the planned channel as an improvement.

f. A common comment made by the pilots was that the planned channel would afford them safer passing zones, especially in the straight reach between Talmadge Bridge and Marsh Island. This is a possible advantage of the planned channel that the simulator did not test.

g. The study also quantified another problem in the Marsh Island area: ships docked at the Amoco dock upstream of Union Camp Corporation. All the pilots voiced apprehension about approaching too close to this dock.

57. The finding of a small improvement in vessel controllability was based on a basic statistical analysis of the parameters recorded during the simulator runs: port and starboard clearance, drift angle, rudder angle, speed, heading, rate of turn, and rpm. In addition, another parameter was created by multiplying the rudder angle by the rpm for a comparative measure of degree of maneuvering. The hypothesis was that the closer these parameters clustered about their respective means, exhibited by the standard deviation, the more the ship was under control. In the large majority of comparisons for both inbound and outbound runs, the mean standard deviation for these parameters dropped in the simulation of the planned channel. In addition to the standard deviation, the means of the recorded parameters were compared. Here again, in nearly all instances this comparison came out in favor of the planned channel.
58. In a few instances in the area through Talmadge Bridge the statistical comparison came out in favor of the existing channel; however, it was concluded the statistical differences are due to the fact that the area includes the approaches 1,000 ft above and below the bridge. The track-lines show that the differences occurred mainly in the approaches, and no conclusion can be made that additional danger exists for the bridge.

59. Both north bank and south bank clearance improved significantly in the planned channel. The improvement in the south bank clearance is considered more important for two reasons: (a) most of the development is on the south bank, and (b) since the widening would take place on the north bank the clearance there would naturally be expected to be greater. An important point to make is that the large increase in north bank clearance indicates that the pilots did not change their paths as much as they could have in the planned channel. This suggests that as the pilots become familiar and comfortable with the widened channel, they could move further north and the important south bank clearance could increase even more.

60. The most surprising result was the high incidence of groundings in the Marsh Island to Kings Island area. The planned channel runs exhibited a marked drop in groundings; however, groundings still occurred. Any additional widening possible in this area would be advisable.

61. The pilot ratings are presented only as a documentation that the pilots themselves are enthusiastic about the widening and think that it will prove to be a benefit. The ratings results are consistent with the quantitative results.

62. Based on the track-lines and pilots' comments, the simulator study has documented a problem that exists in Marsh Island Turning Basin. Because of their apprehension concerning the Amoco dock, the pilots consistently steer into the turning basin. This forces more maneuvering in this area than would be necessary in the event the dock were not present. The dock itself is approximately 60 ft from the south edge of the defined channel. In the event a petroleum tanker is docked here with a beam of 100 ft, the ship extends into the channel 40 ft.

**Recommendations**

63. Because of the accident potential as noted in paragraph 56d,
additional widening of the channel in the area just below Kings Island Turning Basin would make the channel safer by allowing transiting ships more south bank clearance, and, hence, more room to clear moored vessels.

64. At the upper end of Fig Island Turning Basin between beacons 60 and 62, the channel should be trimmed back on the north side at the point where the channel opens into the turning basin. As shown on the track-lines, the pilots always drifted to the south edge of the channel here. This occurrence was verified by pilot comments that this pattern is usually what happens in a real transit. This pattern did not change with the simulated widened channel. If this point were moved back and beacon 62 were relocated to mark it, the pilots would be able to move north and take advantage of an area of water which is not presently being used.

65. Consideration should be given to relocating the Amoco dock at Marsh Island Turning Basin further from the channel. As presently constructed, ships moored at this dock extend into the navigation channel. Pilots maneuver into the Marsh Island Turning Basin, which causes extra maneuvering above and below the dock with increased potential for navigation hazards. An alternative to this relocation would be to cut back the lower corner of the Marsh Island Turning Basin to ease the transition back into the navigation channel for outbound ships.
REFERENCES


a. Upper river section

b. Lower river section

Figure A1. Existing channel mesh
a. Upper river section

b. Lower river section

Figure A2. Planned channel mesh
APPENDIX B: CURRENT VECTOR PLOTS
Figure B1. Maximum flood velocities, existing channel, 10.5-ft tidal range
a. Upper river section

b. Middle river section

c. Lower river section

Figure B2. Maximum ebb velocities, existing channel, 10.5-ft tidal range
Figure B3. Maximum flood velocities, planned channel, 10.5-ft tidal range
a. Upper river section

b. Middle river section

c. Lower river section

Figure B4. Maximum ebb velocities, planned channel, 10.5-ft tidal range
APPENDIX C: PILOT TRACK-LINE PLOTS
a. Existing channel

b. Planned channel

Figure C1. Outbound, area A
a. Existing channel

b. Planned channel

Figure C2. Inbound, area A
Figure C3. Outbound, area B

a. Existing channel

b. Planned channel
a. Existing channel

b. Planned channel

Figure C4. Inbound, area B
a. Existing channel

b. Planned channel

Figure C5. Outbound, area C
a. Existing channel

b. Planned channel

Figure C6. Inbound, area C
Figure C7. Outbound, area D

a. Existing channel

b. Planned channel
a. Existing channel

b. Planned channel

Figure C8. Inbound, area D
APPENDIX D: PILOT QUESTIONNAIRES AND COMMENTS
The purpose of this questionnaire is to document your comments and observations concerning the simulator run you just completed. The first section involves rating different aspects of the simulator run for the channel as a whole. Each aspect should be rated on the accompanying scale by circling your selected rating. Feel free to make comments.

**DIFFICULTY OF THE RUN**

very simple difficult

1 2 3 4 5 6 7 8 9 10

**AMOUNT OF ATTENTION REQUIRED**

very low high

1 2 3 4 5 6 7 8 9 10

**REALISM OF THE HANDLING OF THE SIMULATOR SHIP IN COMPARISON TO AN ACTUAL SHIP**
The second section involves the same rating method; however, these questions are intended to be area or site specific. Please provide a rating of these aspects for the following areas.

**AREA A**: Fig Island Turning Basin to Talmadge Bridge
**AREA B**: Talmadge Bridge to Marsh Island Turning Basin
**AREA C**: Marsh Island Turning Basin to Kings Island Turning Basin

Please note on the attached track-line plot of your run [not included in this report], the reasons for the particular ratings you give. Please indicate by arrows or lines at what point the notes pertain.
very easy  very difficult

AREA A

AREA B

AREA C

CONTROLLABILITY OF THE VESSEL

low danger  high danger

AREA A

AREA B

AREA C

DANGER OF RUNNING AGROUND

low danger  high danger

AREA A

AREA B

AREA C

DANGER OF RAMMING AN OBJECT

D5
The purpose of this questionnaire is to get your thoughts about the possible effect of widening Savannah Harbor based on the simulation runs you have made. For this purpose we ask that you answer the following question for each of the areas listed. Also, please answer the question at the bottom.

Question: In your opinion, based on the simulator runs, how would the widening of the harbor between Fig Island Turning Basin and Kings Island Turning Basin affect ship maneuverability and safety in this area?

Fig Island Turning Basin to Talmadge Bridge

Talmadge Bridge

Talmadge Bridge to Marsh Island Turning Basin

Marsh Island Turning Basin to Kings Island Turning Basin

In your opinion is there any way for the simulation to be improved? Think about currents, bank forces, console equipment, visual scene, radar, vessel behavior, shallow water effects, etc.

Pilot: __________________________
Date: __________________________
Pilots' Comments on Final Questionnaire

Fig Island Turning Basin to Talmadge Bridge

Pilot #4:
More room for two-way traffic plus better maneuverability when passing.
More room for maneuverability in the turn.

Pilot #5:
Allows for the use of less rudder to make turns and control the vessel once it is on a straight course.

Pilot #6:
On city front channel this is especially helpful in meeting two vessels and adds to the safety of the port. The turn on to city front is much easier.

Pilot #7:
Widening would give vessels more "breathing" room in meeting situations.

Pilot #8:
The turn at #62 is a very tricky one, but the widening of the bend helped a great deal with passing, bank effects and the current effect.

Pilot #9:
It would give more room for making approach to city front channel, thus having better control of vessel.

Talmadge Bridge

Pilot #4:
More room and water approaching turn - outbound also when ships alongside of Berths 1 and 2.

Pilot #5:
Widening again allows for better control of vessel.

Pilot #6:
Didn't notice any difference.

Pilot #7:
Just widening overall will help to make the port of Savannah a safer one.
Pilot #8:
The bridge is in the way so in order to get the full effect, should remove the bridge.

Pilot #9:
This is one of the main areas, in my opinion, that needs widening, particularly making the bend approaching Talmadge Bridge. This seems to be an area where ships hesitate as they make the bend to Talmadge Bridge.

Talmadge Bridge to Marsh Island Turning Basin

Pilot #4:
Better passing area.

Pilot #5:
Widening would allow a vessel more clearance from vessels moored at Ocean Terminals, Colonial Oil #1 and #2.

Pilot #6:
Much the same as before—perhaps less damage to docked vessels from ships' suction.

Pilot #7:
This stretch is one of our most popular for meeting. Widening here would give vessels a tremendous advantage for two-way traffic.

Pilot #8:
When 2 vessels pass in this area, there is great bank effects. The widening would help in a great way.

Pilot #9:
In this area it would give ships much more room for maneuvering especially in passing situations.

Marsh Island Turning Basin to Kings Island Turning Basin

Pilot #4:
New passing area which may not exist now.

Pilot #5:
Widenings would allow more clearance from vessels moored on the south side of this area.
Pilot #6:
Much easier to meet in upper harbor and easier to turn out of Kings Island with slower speeds.

Pilot #7:
The widening here is definitely needed. More often once vessels have to meet here through no other choice. It is really narrow when two vessels meet with other vessels moored at the docks. If nowhere else, this stretch needs widening.

Pilot #8:
When 2 vessels pass in this area, there are great bank effects. The widening would help in a great way.

Pilot #9:
It would cause ships not to be affected so much by bank effect on this reach, particularly on stretch just before reaching King's Island Basin.

Response to last question

Pilot #4:
Greater degree of visual. Not so much shallow water effects.

Pilot #5:
Allow for wider view of ships' bow and sides (open degree of peripheral)

Pilot #6:
Add more vessels alongside docks, perhaps two-way traffic.

Pilot #7:
The simulator is quite a good comparison in the actual handling of ships. I found that if you handle the simulator in the city (speed), as you would ships, it is very realistic. You can actually feel the effect of currents when handling the simulator.

Pilot #8:
The wheel response is too fast, but overall simulation was good.

Pilot #9:
Overall simulator seems to be fairly representative. Currents seem to affect our turns a little more than simulation shows.