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ERDC Convenes Vessel Effects Workshop

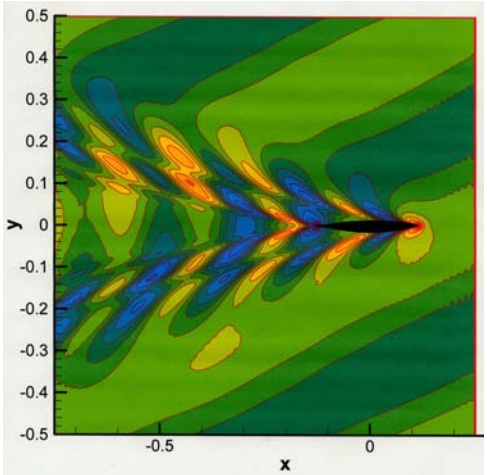
Purpose of the Workshop

The U.S. Army Engineer Research and Development Center (ERDC) convened a navigation vessel effects workshop on 29-30 October 2002 in Gulfport, MS, timed to conclude the day before Ports Symposium 2002 began at the same location, for the convenience of those attendees wishing to attend both gatherings. Dr. Sandra Knight, ERDC Technical Director for Navigation and organizer of the workshop, said the purpose of the workshop was to provide a forum for interagency discussion of the effects of passing navigation vessels on safety, engineering design, and ecological impacts.

Objectives of the workshop were to (a) provide status of current activities based on case study presentations, (b) define problems and issues, (c) discuss state-of-the-art methodologies, models, and measurement techniques, and (d) define research gaps, areas of collaboration and stakeholders. The workshop also was used to help refine goals of a newly established Permanent International Association of Navigation Congresses (PIANC) working group, and conduct advance planning for a workshop at the annual PIANC U.S. Section meeting to be held in Portland, OR, 29 April-01 May 2003 (http://www.iwr.usace.army.mil/PIANC/Presentations/brochure4.pdf). Workshop participants included representatives from the U.S Army (ERDC; and Corps of Engineers, St. Louis District), U.S. Navy (David Taylor Model Basin; and Naval Facilities Engineering Service Center), U.S. Merchant Marine Academy, and the U.S. Coast Guard.

Current Activities and Case Studies

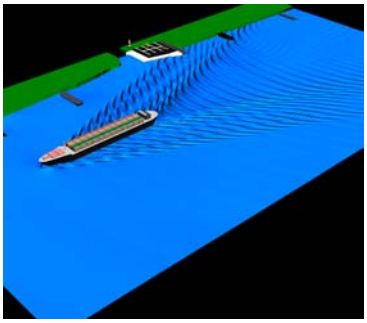
The workshop participants discussed their respective state-of-the-art methodologies, numerical simulation and physical models, and prototype and physical model measurement techniques.



The U.S. Navy has an inherent interest in the interaction between ship waves and surface gravity waves in shallow coastal waters. Dr. Ray-Qing Lin, U.S. Navy, David Taylor Model Basin, Carderock, MD, discussed a newly-developed spectral wave model, and it's application to such interactions. Nonlinear wave-wave interactions increase significantly as water depth decreases. Incoming long waves grow significantly faster in shallow water by interacting with local wind waves. The significantly longer waves may strongly impact ship stability. It was necessary to develop a fully nonlinear ship motion model to study wave-wave interactions between the ship and surface waves. All existing models could study at most only weakly nonlinear wave-wave interactions. A strongly nonlinear model should have nonlinear terms equal to or even greater than the linear terms. Nonlinear ship wave/surface wave interactions can significantly alter the ship wave patterns and the ship wave energy distribution, especially for high Froude numbers (fast moving ships). The new spectral wave model is very efficient, being several orders of magnitude faster than traditional Green function models.

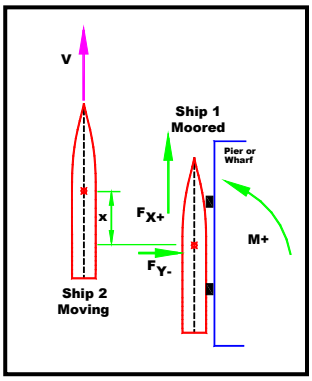
Dr. Zeki Demirbilek, U.S. Army, ERDC, Vicksburg, MS, discussed Boussinesq modeling of ship wave generation. New-generation vessels are larger with lengths on the order of 1,000 ft, beams on the order of (150 ft) and drafts on the order of 50 ft. Many are high-speed vessels with speeds of 35-50 knots compared to 10-15 knots for conventional vessels. Simple methods previously used become less reliable

for estimating wave fields, underkeel clearance, squat, maneuvering, and motions of such vessels. Vessel-induced effects include extreme water level drawdown and return currents in confined channels, surge waves on shallow banks, higher risk of ship transit in confined waterways and shallow estuaries, and disturbance to tranquility and accessibility of marinas, ports, and harbors. Previous model algorithms utilized a shallow water depth-average technique for solving the Navier Stokes equations. The Boussinesq model allows for the non-hydrostatic pressure distribution, and is able to deal with shorter-period dispersive waves. Non-linear wave effects can be included, as well as wave breaking, wave-induced currents, runup, and overtopping.

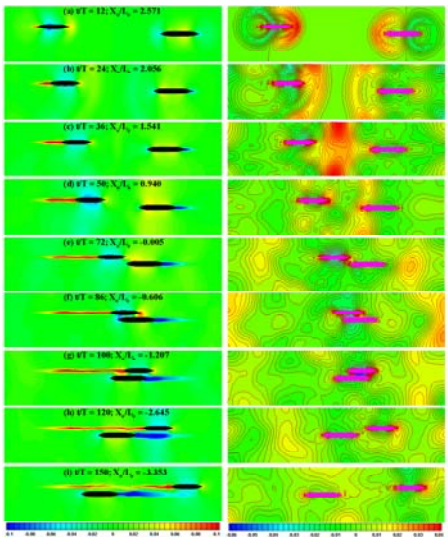


Ship effects in navigation channels were discussed by both Dr. Stephen Maynord-1, ERDC, and LCDR Alan Blume, U.S. Coast Guard Headquarters, Washington DC, from the standpoint of bank erosion and safety. Dr. Maynord addressed the issue of transverse stern waves in restricted waterways where the channel may be confined on both sides or open on one side and confined on the other. Typical features include shallow berms adjacent to the navigation channel. Long period ship effects at the bankline include drawdown, surge, transverse stern waves, and return velocity. Short period ship effects include secondary waves at the bow and stern, surge waves, and propeller jet. Ship speed is critical in confined channels. Ship effects increase rapidly with speed, and most ships generally operate at 70-90 percent of limiting speed. Surge waves result from drawdown effects in channels with shallow (1-2 m deep) berms. Surge waves increase as shallow water depth decreases over berms, with increased ship speed, and with increased drawdown. LCDR Blume was concerned with high-speed vessel wake wash and its effects pertaining to safety of bathers on shore and small craft operating near shore. Empirical evidence indicates that speed limits for vessels like high-speed ferries are not necessarily the answer. It is not possible to establish a "one size fits all" standard. Controls must be appropriate for the location. Factors that must be considered include vessel hull form, displacement, trim, speed, length, and course changing. Waterway factors to consider include depth of channel, physical configuration, character of shoreline and nearshore, and character of wake waves where impact occurs.

Dr. Bill Seelig, U.S. Navy, Naval Facilities Engineering Service Center, Washington DC, and Dr. Wei-Yuan Hwang, U.S. Merchant Marine Academy, Kings Point, NY, each discussed forces generated by passing ships. Dr. Seelig was concerned with ship wave and pressure forces generated by a moving ship on a moored vessel, and passing speed limitations concerns of ships moored at the terminal. As the ship moves past, the forces and moments on the moored ship undergo a reversal in direction, with a rotating moment about the pier mooring points. Sensitivity tests have been conducted to ascertain the dynamic effects of vessel size and speed on mooring line tension for different tide elevations. Dr. Hwang conducted Reynolds Averaged Navier Stokes (RANS) computational fluid dynamic (CFD) studies of both mooring line forces and interacting forces created by passing ships, either overtaking or meeting. Motivations for using RANS CFD arise because generic ship-ship interaction models based on towing tank test are not sufficient for studying a moored ship system. Ship-ship interaction models based on potential theory also are not sufficient for real-time applications due to assumptions made during problem formulation, such as rigid water surface, non-viscous fluid, simple



bottom and bank geometry, and parallel course without drifting. RANS CFD utilizes far less assumptions, simplifications, and restrictions on geometry and test conditions. More comprehensive data are available for analysis, and a deeper insight into the dynamic physical processes can be gleaned although the method is computer time consuming. It was determined that passing speed affects both the phasing and magnitude of the peak force and moment. The maximum sway forces do not always scale with the velocity squared. The crab angle introduces additional interaction forces and moments depending on the traffic ship speed and crabbing driection. Previous adjustments multiplied the parallel course testing data with the cosine of the crabbing angle. CFD findings do not support this approach. For moored ships, wharf distance comparisons show phase and peak force variations with the extended wharf distance. As the wharf distance increased, Bernoulli effects become less dominant, although long-reaching mechanisms such as vortex shedding may come into play.

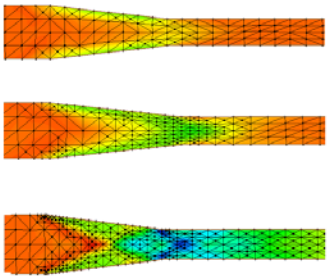


Mooring forces on barge tows during filling and emptying of locks were discussed by Dr. Richard Stockstill, U.S. Army, ERDC, Vicksburg, MS. Hydrodynamic forces on barges during navigation lock operations were determined by both a physical model (1:25 scale) and a numerical model (LOCKSIM). During filling and emptying of the lock chambers, low pressures exist at critical locations inside culvert bends and downstream of valves. Mooring system (hawser) forces become significant as the water level in the chamber rises and falls. In the physical model, pressures were measured with pressure cells, and hawser forces were measured by hawser ring strain gages. LOCKSIM determined pressures and velocities throughout the system, and hawser forces were computed in a post-processing manner. Added mass for barge tows in lock chambers was found to be 0.50. Damping coefficient varies with the lock chamber size. Calculations bases solely on water surface slope are not necessarily conservative in computing maximum hawser forces.

Fishery impact assessment studies resulting from vessel wave effects, including larval fish and adult mortality, were discussed by Dr. Tom Keevin, U.S. Army, Corps of Engineers, St. Louis District. The effects of pressure changes induced by commercial navigation traffic on mortality of early life stages of fish were determined. Stranding potential of young fishes subjected to simulated vessel induced drawdown also was evaluated. Littoral zone species are less susceptible to stranding than main channel species. Barge avoidance and lock mortality studies were conducted. Results were minimal for all occasions and species evaluated.

Dr. Charles Berger, U.S. Army, ERDC, Vicksburg, MS, discussed shallow water modeling of vessel hydrodynamics by using High Velocity 2D (HIVEL2D) and Adaptive Hydrodynamics (ADH). Vessel effects can be modeled by the Navier Stokes equations (air/water 3D and single phase 3D), shallow water equations (Boussinesq and St. Venant), and the Shijf equation (Bernoulli 1D). The models

produce current and water surface knowledge such as drawdown and transverse stern waves. HIVEL2D uses an unstructured static grid where the vessel is simulated by a moving pressure field. Two vessels can be run at the same time. Vessel features must be added to the ADH code, and sedimentation processes associated with vessel entrainment must also be incorporated. Also, a moving pressure field should be added to ADH, and there are stabilization questions to be resolved. The standard shallow water wave equations are appropriate for drawdown and transverse stern wave estimates. These codes represent strong bores and jumps correctly, but they treat undular bores and weak jumps as if they also were strong.

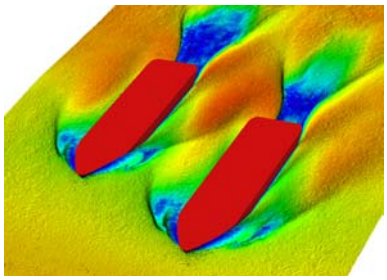


Analytical approaches to quantifying the physical effects of shallow draft navigation by the use of numerical models Navigation Effects (NAVEFF) and Navigation Sedimentation (NAVSED) were discussed by Dr. Stephen Maynord-2, U.S. Army, ERDC, Vicksburg, MS. These models are used over long river reaches, and the output from both is used in ecological assessment of impacts. They were developed under the Upper Mississippi River-Illinois Waterway System Navigation Study that is evaluating the impact on the environment of traffic increases resulting from navigation improvements. Ecological concerns include larval and adult fish, plants, mussels and other macroinvertebrates, sedimentation of side channels and backwaters, and bank erosion. Ecological application of NAVEFF results include plants breaking from tow waves/currents, stranding of larval fish in nearshore shallows due to drawdown, defining areas providing suitable fish spawning habitat that is not disrupted by navigation effects, and defining discharge thru propeller jets for larval fish mortality. Ecological application of NAVSED results include light extinction to plants from resuspended sediments, and deposition in side channels and backwaters from tow induced resuspension.

Dr. Jeffrey Melby, U.S. Army, ERDC, Vicksburg, MS, discussed bank erosion and structure stability under the combined effects of ship and wind waves. Ship wave challenges include ship-induced wave modeling, ship wave and wind wave interactions, and bank stability. Wind waves are irregular and are analyzed by statistical representation. They are assumed to have a continuous history for each storm. Ship waves are regular episodic events and are studied with a wave-by-wave analysis. Water levels can change dramatically during a single event. Bank stability is complicated by water level changes, life cycle loading, and frequency of occurrence of combined ship and wind waves. Rubble-mound coastal and riverine structure damage is progressive. Risk analysis to such structures is studied by STORM-CSHORE, a life-cycle simulation tool. STORM-CSHORE predicts storms at the coast, total water depth (wave setup, storm surge, tide), and wave height at any location. This model predicts mean damage and variability, and overtopping of structures, but does not include ship wakes and there is presently no ongoing research to develop these tools. Combined wind waves and ship wakes are complex. The simplest solution would be to superpose the number of ship-induced waves at a given height and period with the wind waves. It is then necessary to know about the probability of occurrence of ship wakes, which is a function of ship type, speed, draft, frequency, proximity to the coastal or inland structure, etc.

Dr. Melby also discussed a Navier Stokes-based model developed by Clark-Atlanta University hydrodynamicists for complex wave and flow phenomenon. The model is capable of modeling combined wind-induced surface gravity waves and ship wakes and the resulting flow forcing on structures. In addition, the model has linear and non-linear moorings and wave generation and absorption capabilities. Dr. Melby showed examples of ship wake modeling and wind-induced wave modeling such as wind

waves around ships interacting with wakes, breaking waves, wave runup on structures, and overtopping. Although computationally intensive, these models have the capability to solve complex hydrodynamic problems with few assumptions and are therefore ideal for looking at specific complex problems that cannot be accurately solved with other models such as ship-ship interaction, moored ship response, and ship-structure interaction.



Problems and Issues

Presenters next discussed several deficiencies in the numerical simulation modeling efforts from the standpoint of passing navigation vessels on safety, engineering design, and ecological impacts that were evident from the case study presentations by all of the agencies participating in the workshop. It was apparent that many of the phenomena of interest (ship wave generation, wave-wave interaction, wave effects on shorelines and marinas) occur in intermediate-to-shallow water depths. Research and development needs to be directed to the following several areas.

a. Adaptation and/or interfaces to connect the near-field to the far-field should be enhanced.
b. There is a need between shallow water and deep water to describe the wave field that will dissipate wave energy or modify a strong hydraulic jump to describe an undular jump which is more representative of bore dissipation and wave breaking.
c. Analytical tools and numerical simulation models should be better validated with more precise laboratory physical model data and prototype field investigations. These data should be acquired through collaborative agency data collection protocols for precision, reduction, storage, and sharing to eliminate duplication of effort and reduce exceedingly high costs for obtaining synoptic field data.
d. There should be acceptable end points to the computational discreteness, depending upon the specific phenomena of interest.
e. Cross-shore and along-shore transport of non-cohesive materials for wind waves is moderately-well understood; however, there exists essentially no research pertaining to the interaction and superposition of wind waves and ship waves which simultaneously impact shorelines of restricted waterways and beaches.
f. Bank erosion models should be integrated with the hydrodynamics of coasts and rivers to better understand both cohesive and non-cohesive sediment transport. There exists great uncertainties in the modeling of mixed sediment transport which constitutes a large percentage of bay and estuary material movement.
g. Vessel effects pertaining to forces resulting from ship-ship wave generation should be more comprehensively investigated. Coupling of interacting ship waves with wind-generated surface gravity waves is not well understood, and the mechanisms of both bottom sediment initiation and stresses on moored vessels is significantly impacts by these interactions.
h. There should be a standardized development for better technology transfer through web-based knowledge management and e-learning.
i. There is an immediate need for obtaining better mooring criteria for lock approach walls, and for getting those criteria transferred expediently to field operating offices.

Methodologies, Models, and Measurement Techniques

As vessels become longer (O(1,000 ft) and wider (O(150 ft), with deeper-drafts (O(50 ft) and higher-speeds (O(50 knot), simple methods become less reliable for estimating wave field, underkeel

clearance, squat, maneuvering, and motions of such vessels. More comprehensive solution techniques for ship-generated waves include (a) shallow water equations, (b) Boussinesq equations, (c) boundary-integral methods, and (d) Navier-Stokes equations. HIVEL2D and ADH can be used for modeling vessel effects such as drawdown and the transverse stern wave, and can simulate far-field long reaches. The quantification of the physical effects of shallow draft navigation can be investigated by the application of NAVEFF and NAVSED. All of these numerical simulation modeling tools are applicable at various levels of sophistication as management tools for estimating shoreline impact of vessel waves on both beaches and armoring coastal or harbor structures

a. **Shallow water equations** utilize a hydrostatic pressure field and generate nondispersive waves. These equations are better suited for estimating longer period drawdown and return periods. They are not valid in regions with slope discontinuities.
b. **Boussinesq equations** utilize non-hydrostatic pressure fields and are able to deal with shorter-period dispersive waves. They also are able to handle nonlinear wave effects, wave breaking, wave-induced currents, runup, and overtopping. However, they provide a poor description of flow fields around ships when compared to boundary-integral methods.
c. **Boundary-integral methods** provide an accurate description of the flow field around ships. However, they are exceedingly computationally intense for large areas where it is necessary to discretize the seabed in addition to the ship body and free water surface.
d. **Navier-Stokes equations** are able to deal with viscous effects and provide an accurate description of flow around the ships with boundary-fitted grids. Again, these equations are computationally intense for large areas and are limited to only a couple of ship lengths.
e. **HIVEL2D** is an unstructured, static grid model of hydrodynamics. Vessels are simulated by moving pressure fields. The conservative form of the equations captures shocks and bores. Two vessels can be computationally described at the same time.
f. **ADH** is an unstructured, adaptive grid, parallel model of hydrodynamics and sedimentation. The ADH computational engine can handle unsaturated groundwater equations, shallow water equations, and Navier-Stokes equations. A moving pressure field should be added to the code, as well as a method for estimating sediment entrainment under the vessel.
g. **NAVEFF** is used to determine the physical effects produced by shallow draft navigation (barge tows). Propeller jet near-bed velocity and bed shear lateral and longitudinal distribution are determined by empirical methods. NAVEFF is a screening tool for covering large systems.
h. **NAVSED** is used to determine sediment resuspension resulting from the physical effects determined in NAVEFF. NAVSED output is a cell-by-cell time history of sediment concentration.

Areas for Collaborative Research between ERDC and Others

Vessel-induced effects include extreme water level drawdown and return currents in confined channels. Surge waves are generated on shallow banks. There exists a higher risk of ship transit in confined waterways and shallow estuaries, and there is disturbance to tranquility and accessibility of marinas, ports, and harbors. Ship-generated waves can adversely affect bank stability and result in shoreline erosion. There is potential impact on marine life in coastal wetlands. There is greater risk for swimmer safety and for smaller boats using the waterways. Berthing and mooring difficulties arise for cargo vessels in inland ports as they onload and offload. There are also hazards to both recreational and commercial boat marinas.

All of the agencies that participated in the vessel effects workshop (U.S. Army Engineer Research and Development Center; U.S. Army Engineer District, St. Louis; U.S. Navy, David Taylor Model Basin; U.S. Navy, Naval Facilities Engineering Service Center; U.S. Merchant Marine Academy; and the U.S.

Coast Guard) agreed that great opportunity exists for conducting collaborative research in many areas of mutual interest between ERDC and others. Specific examples include the following.

a. **ESTuarine EXperimental (ESTEX) Facility**: ESTEX is located at ERDC, Vicksburg, MS. It is a large-scale facility for research in unsteady non-uniform flow and transport research in all hydrographic zones. ESTEX has two main parallel components: (a) a 480-ft-long x 60-ft-wide x 4-ft-deep flume with a 60-ft-long section at one end being 10 ft deep, and (b) a 480-ft-long x 10-ft-wide x 4-ft-deep flume. (The 60-ft-long x 60-ft-wide x 10-ft-deep section at one end of the 60-ft-wide flume can actually be used as a third component.) ESTEX is equipped with circulating pumps capable of producing 125 cfs maximum flow, and also has tide generation capabilities. ESTEX is essentially free of sidewall, endwall, and entrance effects over large distances, a characteristic available nowhere else. It will provide high Reynolds Number flows that escape the usual limits of scale effects in other flumes presently available. ESTEX provides sufficient length of flume to rigorously define sediment transport processes to substantially improve riverine and estuary sediment transport models. Typical collaborative studies which can be performed in ESTEX include (a) dredging research, (b) sediment deposition under stratified flow conditions, (c) flocculation under turbulent flows, (d) fluid mud and mud flows, (e) calibration of numerical studies, and (f) wetland modeling. Large-scale physical model navigation studies such as propeller effects on bottom sediments, vessel behavior, and vessel safety effects on waterways can be conducted to any desired scale in ESTEX.

b. **Ship/Tow Simulator for Navigation Research and Training**: ERDC maintains the Corps' only ship/tow simulator. It provides engineers, licensed pilots, and others studying navigability in federal channels with the ability to design and evaluate proposed modifications for improvements to commercial or military navigation. This computerized simulator uses real-time piloted evaluations; that is, realistic events require the same amount of time on the simulator as they do in real life. Realistic sights, sounds, and conditions for maneuvering ships and tows make the pilots feel as if they are in their actual surroundings. It can simulate ports, harbors, inland waterways, and any other maritime environment. The simulator accurately portrays currents, wind and wave conditions, shallow-water effects, bank forces, ship handling (rudder angle, propeller revolution, and bow and stern thrustes), ship-to-ship interaction (in meeting and passing or overtaking and passing situations), fender forces, anchor forces, and tug assistance. The 220-deg field of view can be rotated 360 deg horizontally, and 180 deg vertically, equivalent to the effect of turning one's head and/or tilting it in real life. The simulator has Electronic Chart Display and Information System (ECDIS) displays. The radar is comparable to that found on a typical ship. The heart of the ERDC Ship/Tow Simulator is the Virtual Ship Model, developed by Computer Sciences Corporation Advanced Marine Training Technologies, and used to calculate ship or tow response to the variety of forces that can be exerted upon a vessel. Results from the simulations provide significant navigation channel construction cost savings with inherent safety implications, and navigation changes can be adjusted to avoid conflict with environmentally sensitive areas. The ERDC Ship/Tow Simulator is available for collaborative research and/or training between the Corps and/or other agencies with similar areas of responsibility.

c. **Berthing and Mooring Operations**: Mooring of large ships in some major ports and harbors entails accounting for great sway forces when long period waves are able to propagate into the harbor with such lateral forces that they may tear the moorings from the wharves. At other locations where ships are moored adjacent to the navigation channels, effects of waves and currents generated by passing ships may create detrimental forces and moments on moorings. At inland locks, the forces on a barge tow moored in a lock chamber are exceedingly complex, being a function of the tow characteristics and the filling and emptying characteristics of the lock system. The Corps is intimately involved with each of these scenarios, from evaluation of sway forces on commercial and Navy ships in the Ports of Los Angeles and Long Beach, to passing ships effects on moored commercial and Navy ships at Norfolk Harbor, to lock operations on the inland river systems. ERDC maintains physical model experimental

facilities adequate to conduct collaborative comprehensive studies and evaluations for solutions of most hydrodynamic force problems associated with each of these different berthing and mooring configurations.

d. **Numerical Simulation Modeling**: ERDC and other agencies with responsibilities in the hydrodynamic modeling arena have made significant advances in numerical simulation modeling from resources within their own organizations. However, collaborative research allows for a more comprehensive effort and thus increases the possibility of obtaining funding. Duplication of effort is also avoided, and collaboration encourages knowledge exchange and technology transfer with a much wider use of the research results. Practical needs that should be addressed include ship operations in channels and ports, channel and port design, and mooring line configuration guidance. Areas of cooperative initiatives in such numerical simulation modeling include studies of shallow water effects, channels, locks, banks, and passing ship effects. Results from these research investigations are applicable to engineering design, operational procedures, preventive maintenance, risk analysis, and modularized course material for education and training. It is important that the Boussinesq technique be incorporated into the modeling of waves in shallow water and the ADH structure. Near-field models should be coupled to in-transit ship motion models, and maneuvering models should be developed to consider multiple vessel interactions. Wall suction effects should be incorporated into model revisions. An integrated system should be developed that includes waves, vessel hydrodynamics, sediment, and shoreline effects (runup, overtopping, mooring, and design loads for different protective structures and systems).

e. **Ship Effects and Safety**: In confined channels, ship speed is critical in defining bank effects, which increase rapidly with increased speed. Ships generally operate at 70-90 percent of limiting speed. Surge waves increase with increased speed and increased drawdown. However, the worst-case scenario may actually be an intermediate speed around a critical Froude Number of 1 where the largest undulations occur. Of interest to the Corps, in addition to the specific vessel wake waves where impact with a shoreline or other structural measure occurs, are the specific waterway features such as (a) depth of channel, (b) physical configuration of the channel, and (c) character of the shoreline and nearshore. Of interest to the Coast Guard is the ability to predict high-speed ship wake generation in bays, estuaries, and sounds, and distinguishing this wake from other ship waves, barge waves, or wind waves. Political implications pertain to what agency regulates with respect to safety and environmental concerns, as there may be overlapping federal, state, and local regulations in the coastal zone. Similar concerns exist pertaining to safety of navigation and human life to both the Corps and others. ERDC researchers are well suited from the standpoint of estimating ship effects and associated safety aspects for performing collaborative investigations into these phenomena.

f. **Environmental Effects of Navaigation**: Analytical tools (NAVEFF and NAVSED) for quantifying the physical effects of shallow draft navigation have been developed by ERDC to evaluate physical effects and sediment resuspension by vessel tow fleets over long river reaches for ecological assessment. Studies on the Upper Mississippi River have evaluated larval fish mortality due to shear stress along the hull of barges, or the drawdown decay at the mouth of side channels and backwaters. This provides knowledge pertaining to suitable fish spawning habitat that is not disrupted by navigation effects. NAVEFF also can be used to define discharge through propeller jets for larval fish mortality. NAVSED uses the output from NAVEFF for evaluating nearshore shallow water habitat where vessel wave resuspension is a dominant mechanism. The manner in which wind waves and vessel waves should be superposed is not entirely clear. Collaborative studies should be performed in this area of mutual interest among the Corps and other watercraft users, as well as further investigations into the effects of vessels on sedimentation resuspension and resulting ecological impacts.