Channel Design and Vessel Maneuverability - Next Steps[1]
"WHEN SHIPS GET TOO BIG FOR THEIR DITCHES" - GRAY[2]

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Several tugs assisting a vessel grounded just outside of a navigation channel.

A recent workshop on Channel Design and Vessel Maneuverability brought together channel designers, naval architects, pilots, and ship operators to review and share design approaches and standards that affect safety of operations. The desire was to develop policy recommendations that can be implemented both in the way channels are laid out and enlarged and how ships of various types using them should be designed and handled. Resulting recommendations based on the discussions promise to improve overall safety of ship operations in restricted waterways.

INTRODUCTION

Most Americans are blithely unaware that international commerce is rapidly approaching 20 percent of our gross domestic product (GDP), which is the world's largest, and that 95 percent of U.S. foreign commerce is transported by ship. This figure is expected to double by 2020. And many Americans don't know, or care, that this marine trade involves not only desirable consumer goods, but also much of our food and over 60 percent of the petroleum we consume. So why should Americans care whether our nation's channels can accommodate the ships that carry so much of the trade that fuels the U.S.-economy? If ships unexpectedly could no longer transit our waterways, the nation would experience shortages of power, heat and food in days or weeks at the outside.

These facts have become slightly better known because of INTERTANKO's 1996 Port and Terminal Safety Study [1], which led to the Marine Transportation System (MTS) Report to Congress, in 1999 [2]. Both reports observed that in the United States we have for many years been putting bigger and bigger ships (and more of them) into the same old ditches. It is only a slight stretch to state that since WW II, 57 years ago, this nation has created only one new purpose built offshore port during a period when tanker size grew 25 fold, and container ships over 1,000 feet long took the place of freighters carrying ten fold that of their 500' predecessors. All we have really done is to dredge deeper and deeper, but seldom wider, and it's harder and harder to do. So who cares, and what are the risks and remedies?

The significance of these trends is that more, larger ships will continue to use the nation's waterways for the foreseeable future. Concerned mariners and pilots do a superb job of safely and efficiently handling these ever-larger ships in the same old ditches. However, somewhere, there must be limits on the size ship that a channel can accommodate, or means of determining when special measures must be imposed on harder to handle ships in order to ensure the continued safe, efficient, and environmentally responsible use of the U.S. Marine Transportation System. It is incumbent upon the users and managers of our nation's waterways to evaluate and address the risks associated with ships that have become too big for their ditches.

MAY 2001 INTERNATIONAL WORKSHOP

These issues were the subject of the "International Workshop on Channel Design and Vessel Maneuverabil-

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[1] Presented before the New York Metropolitan Section of the Society of Naval Architects and Marine Engineers on January 9, 2002
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ity" held in Norfolk, Virginia on May 3-4, 2001, (See program in Appendix A). The workshop was intended to provide an opportunity for channel designers, naval architects, ship masters and pilots, and waterway managers from the US, Europe, and Asia to share information and address all aspects of these issues. The goal was to develop policy recommendations addressing the way channels are laid out and enlarged and how ships of various types using them should be designed and handled.

For example, the International Maritime Organization (IMO) has for years provided guidance criteria for the maneuverability of ships operating at sea-speed in open water. But these are only guidelines with which many ships don't comply. And they may not help ensure that a ship is maneuverable at slow speed in narrow channels where bank effects and squat, which increases at approximately the square of the ship's speed, are crucial. All agreed something better is needed, and soon.

Figure 1 Congestion in modern waterways.

The pilots, mariners, naval architects, and channel designers at the Workshop came up with some fresh and practical approaches for addressing these complex issues. Their ideas could have an important bearing on decisions that this country's port authorities and marine safety agencies – U.S. Coast Guard (USCG), U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA), and the Maritime Administration (MARAD) – will have to make in coming years. This is critically important if the two to three fold increase in US maritime commerce that is expected to occur over the next 20 years [2] is to be efficiently and safely handled.

SHIPPING TRENDS

At the Norfolk workshop, several speakers (Vickerman [3], de Jong, and Hensen [4]) presented data on the explosion in the size of container ships that has occurred since the first "Post-Panamax" vessels (ships exceeding the Panama Canal limits of length (L), beam (B) and draft (H) of roughly 840'x 106'x 36' (256m x 32.2m x 11m) appeared a few years ago.

Table 1 provides a sample of principal dimensions for container ships now sailing and building up to a size of about 7,500 TEU. It also includes probable dimensions of projected designs out to 18,000 TEU. Whether or when container ships of these sizes will be built is not known, however, no one doubts that building such ships is well within the present technological capability.

Table 1 Container Ship Trends [Adapted from 4]

TEU	DWT	Length (m)	Width (m)	Depth (m)	Draft (m)	Speed (kts)
2,000		242				32.0
6,600	104,750	347	42.8	24.1	14.50	24.0
6,690	88,669	300	42.8	24.4	14.00	24.5
7,400						
7,500	100,000	320	42.8	24.5	14.50	
8,850		348	45.3	27.0	14.00	25.0
9,000						
11,989	157,935	400	50.0	30.0	17.04	25.0
12,000		380	54.5		14.00	
12,500	123,125	381	57.0		14.70	25.0
18,154	242,800	400	60.0	35.0	21.00	25.0

Some relevant points to note about container ships as well as car carriers regarding their controllability in constricted waters are:

- Unlike tankers which can lighter to smaller drafts, accommodating fully-loaded container ships is vital for ports wanting to serve long haul routes, i.e., as load centers;
- Container ships have large windage that can complicate ship controllability in narrow channels as well as during slow speed maneuvering;
- Direct-drive diesel ships with high installed power to achieve design service speeds can, in some cases, have a minimum bare steerage speed of about 8 knots — quite a high speed in confined waters; and,
- Twin screws may be installed on larger container ships to meet design service speed requirements. Although twin screws do improve slow speed controllability, any gains will be more than offset if these ships are equipped with a single rudder rather than twin rudders.

Like container ships and car carriers, cruise ships are also increasingly becoming larger and have significant windage areas (See Fig. 2). However, since controllability in restricted waters is a more important criterion than open water speed for cruise ships, they are being fitted with azipods, as well as multiple thrusters coupled through a dynamic positioning system.

Figure 2 U.S. Capital and GRAND PRINCESS shown to scale (Princess Cruise Lines)

Tankers and dry bulkers are also increasing in size. While the largest tankers, 300,000 dwt VLCCs and 400,000 - 500,000 dwt ULCCs, seldom enter this nation's ports due to draft restrictions, it does not mean the trend toward "bigger ships in the same old ditches" is not relevant for tankers calling at US-ports. It is, and some examples of tanker size and handling problems include:

- In Houston Texas, the main ship channel, which was designed and constructed in the 1950s, is 400 feet wide by 40 feet deep. The "project ship" L x B x H for that channel was 800' x 85' x 35'. In contrast, tankers over 900' long with beams of 140' and at times even 160', now routinely transit this channel. And, under-keel clearance (UKC) has become very small. Houston is now being dredged to 530' by 45' to handle even larger ships.
- In New York the largest tankers for years were about 80,000 dwt (~ 800' x 125'), but recently 110,000 dwt has become common and up to 160,000 dwt is not unusual. But few changes have been made to the waterways they traverse. In fact, the topography of channels like the Arthur Kill and the Kill Van Kull may make it extremely difficult, if not prohibitively expensive, to make the modifications necessary to accommodate these larger ships without imposing appropriate operational controls.
- Design features, including twin screws and rudders, that are intended to reduce the risk of marine casualties on some new tankers have the additional benefit of improving slow speed maneuverability. However, some new single screw tankers and bulkers being built at minimum cost with low power / tonnage ratios and small rudders do not incorporate these features and pose significant maneuvering challenges in shallow and confined waters.

Fortunately most tankers and bulkers handle quite well at very slow speeds, i.e., 3-4 knots. However, a few of the newest designs are being built at minimum cost. These ships have very low power relative to their dwt as well as rather small rudders. This poses handling problems, especially in ballast when the windage area of these types of vessels is greatest.

WORKSHOP FORMAT

The Workshop program (Appendix A) featured an opening plenary session with presentations on Shipping Trends, Channel Design Criteria, Ship Maneuverability, Ship Controllability, and Use of Simulators in Channel Studies. A key purpose of the workshop was to gather channel designers and ship designers together with ship pilots to better understand current design and operational practices and collectively determine how to make needed improvements. Five questions were posed to help frame the participants' discussion:

- What is the current situation?
- What is the desired situation?
- Why is there a difference between the current and the desired situation?
- What are the impediments to change?
- How can these impediments be most effectively addressed?

Three breakout sessions were then held in parallel to permit those present to work on the issues:

- Channel Design Criteria
- Ship Controllability in Dredged Channels, and
- Ship Maneuverability as a Consideration in the Design Process.

Each breakout session was held twice to provide Workshop participants the opportunity to attend and participate in the discussion of two of the three subject areas. This is where the real dialogue took place between experts from the various disciplines. The closing plenary session heard summaries from the breakouts and then closing comments from the sponsoring organizations.

This paper presents results from the workshop organized by the three breakout sessions and then follows with conclusions and recommendations of next steps.

CHANNEL DESIGN CRITERIA

Overview

In the plenary session Dand [5] described the Permanent International Association of Navigation Congresses (PIANC) approach to channel design and Denis Webb from the Waterways Experiment Station described the approach used by the U.S. Army Corps of Engineers (USACE). In general, the PIANC approach is more documented and deterministic than the USACE approach but results are very similar [6, 7, 8]. A Guide for Design [9] provides the basic assumptions and guides of PIANC and the USACE has for many years held a yearly Channel Design workshop to bring together those involved in the

US and address good channel design practice [10]. A 1978 Symposium also provides many significant articles addressing aspects of navigability of "constraint" waterways [11].

The breakout discussions on the topic of channel design criteria discussed and deliberated issues ranging from technical and maintenance to policy and regulatory. Most of the participants were from the US and many specific issues and case studies discussed were US-related. However, it was noted and reinforced by the international participants that many of the concerns are global in nature. It was well-recognized by those present that the USACE is the principal organization in the US responsible for navigation channel design guidance, maintenance, and operations, and PIANC is the recognized analogous authority internationally. In practice, it is common for both US and non-US channel designers to consult guidance published by both USACE and PIANC.

The two sessions of the breakout each had strikingly different central themes – the first group centered around technical design issues while the second focused on policy and governmental issues. However, despite the differences between the discussions both groups raised many similar concerns and issues. Some of the key points from these exchanges of ideas and opinions are summarized here.

Port Utilization

The first breakout session began by deliberating the effect that channel design has on port operations. Many factors exist that are critical to assessing a channel's effect on port utilization or level of vessel activity, with channel configuration factors comprising the emphasis of the group's discussion. Although channels are designed to accommodate both the type of vessels and the level of vessel traffic that are forecasted to use a given channel, there are no guarantees that the forecast will accurately predict actual usage. As a result, vessels with much different characteristics than the "design vessel" used during the *channel* design process are likely to eventually transit the channel. Exacerbating the problem is that the length of the process to modify a channel is extremely long; and the vessel fleet may change significantly between when the channel is planned and when it is actually constructed.

The reality is that the vessels actually transiting the channel are frequently much larger than those for which the channel was designed. At some point, a channel becomes unsafe, unreliable and inefficient for larger and larger vessels. However, it was pointed out that there is no recognized measure or point at which a channel is identifiably "substandard." Channel improvements should ideally keep up with traffic so that a channel never becomes substandard. Yet while channel improvements continue to occur, they typically are not accomplished in a proactive manner, but rather in a reactive manner.

Risk and Uncertainty in Channel Design

The channel design process is moving from a deterministic process toward a more probabilistic and managed approach with the increased appreciation of risk assessment processes [12]. For example, a standard clearance allowance or "safety factor" used to be applied to different channel dimensions based on the size of the design vessel along with other factors, such as prevailing winds or currents. However, now those margins and clearances are often reduced, partly due to observations of vessels transiting channels with lower clearances. It is assumed that the lower clearance is acceptable if the associated negative effects (e.g., the likelihood of an accident) are not significantly increased. However, few tools are currently available for channel designers to complete this type of assessment. In order to identify and/or assess safety concerns, channel designers usually depend on ship simulation to provide information regarding problematic areas of a proposed channel.

Role of Ship Simulation in Channel Design

Ship simulation was formerly used primarily as a training tool for mariners seeking to gain experience and to exercise maneuvers in a controlled "virtual" environment. While simulation continues to be used as a training tool for operators (see discussion in later Ship Controllability section), ship simulation (physical and/or numerical) is now widely used as a navigation channel design tool [13]. Both the USACE and PIANC recommend using ship simulation to perform final (USACE) or detailed (PIANC) design. In the guidance for both organizations, ship simulation is used to test or verify a conceptual design that has been developed using more conventional "on paper" design procedures. In this process, engineers (e.g., from a Corps district in the U.S.) propose a channel design based on use of design manuals and local experience; ship simulators are then used to verify that ships can safely navigate the proposed channel. The results of the simulation are typically used as a "pass-fail" check for a design, and to suggest incremental improvements through such modifications as altering a proposed channel width or altering the proposed turn configuration.

There are two basic types of ship simulators: physical scale models and computer-based models. In the first type, a small-scale physical model of a particular channel or harbor bathymetry is constructed. Small-scale ship models are then piloted through the model-scale channels, usually by a person on shore via remote control (e.g., as with studies conducted by the Army Corps of Engineers' Waterways Experiment Station in Vicksburg, MS), or alternatively by a person onboard the model vessel (as with Port Revel Ship Handling Training Center located near Lyon, France). Physical simulators are used relatively infrequently for channel design, but they have certain advantages in that they provide a realistic representation of complicated hydrodynamic effects such as bank suction effects, shallow water maneuvering, and interactions between vessels. While some technical disadvantages exist, such as the inability to properly scale all phenomena (fluid friction or viscosity effects) and the compression of time scales, most ship operators have a very high level of confidence in the feedback obtained from physical simulation – particularly the manned model simulators.

Computer-based simulators have been used more extensively than physical simulators in recent years, both for the training of merchant mariners and for the refinement of navigation channel design. Numerically-based simulators used for navigation studies generally have less sophisticated and less realistic visual displays and bridge mock-ups than those used in training exercises, but often have more complex and robust computer models that better simulate such external effects as tidal currents and winds. However, even the state-of-the-art computer simulators used in channel design today still have considerable limitations and can only model hydrodynamic phenomena that the programmer has been able to model and code into the simulator. Many workshop participants therefore underscored the need for more full-scale physical data to help calibrate, validate and improve existing and future numerical models.

In a typical simulation application (either physical or numerical), ship pilots from the local study area who are familiar with the existing channel and the ships that use it operate the simulator. The pilots initially operate the simulator in a present-day or "as-is" channel configuration and provide recommendations to fine-tune the ship simulation code or setup. Then the proposed channel modifications are applied and the pilots carry out subsequent runs. Feedback obtained from simulation includes ship tracks through the channel and pilot responses to a set of post-simulation questions. Simulations are usually carried out using several pilots in order to assess a range of individual piloting styles.

The outcomes of simulation are often significantly helpful to channel designers but are still quite subjective in nature. It is easy to identify problem areas if, say, all five or six pilots run aground in a particular area during their simulations. It is not so easy to ensure that just because all five or six pilots satisfactorily transited a channel during simulation that the channel should be deemed safe. The number of runs should be rather large so that there are enough results to perform a meaningful statistical analysis as well as a risk and uncertainty analysis. This has not yet been practically feasible in channel design due to the time and expense associated with simulation studies.

Channel Characteristics: Is Width The New Critical Factor?

The key characteristics of a channel may be grouped into one of two general categories:

- Channel Layout (i.e., plan view path characteristics such as straight and curved sections)
- Channel Cross-Section (hydrodynamic characteristics such as depth, width, and side-slopes)

Many factors feed into the determination of the dimensions and specifications of channel characteristics, including: vessel traffic characteristics (e.g., traffic mix and density; length, beam, draft, air draft, etc. of vessels); environmental factors (e.g., tide, wind, waves, currents); and location and characteristics of features such as bridges, and economics, along with many others.

There were a few characteristics and factors that participants identified as increasingly problematic or requiring more attention. Bridge height (see Fig. 3) is often a critical factor in a channel's efficiency and requires increased coordination between agencies. Definition of channel toe or side-slope intercept with the channel bottom is often not given much attention, but is an important issue when installing aids to navigation (ATON). Some of the difficulty in defining this channel toe location after dredging exists because of common dredging techniques: for example, often a box cut is performed to deepen a channel (creating a locally vertical "notch" in the channel) and the side slopes are allowed to slough off into a stable condition. Depending on when an ATON is installed, it may or may not be at the true final or equilibrium toe of the channel. Similar to this issue is the consideration of operations and maintenance issues during channel design, i.e., is there a way to design a channel so that the required maintenance dredging is reduced?

Figure 3 A container ship navigating the Kill Van Kull passing under the Bayonne Bridge. (USACE photo)

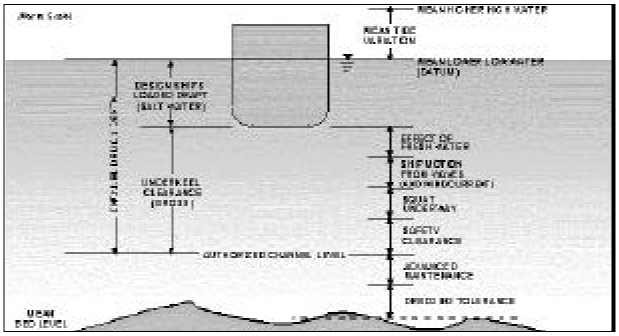

Figure 4 Schematic of factors included in determination of channel depth. (Based on USACE)

Historically, channel depth has secured the most attention by channel designers, economists and mariners alike. Both USACE and PIANC have detailed guidance for determining channel depth based on a number of factors, as illustrated in Fig. 4. Although channel width is treated somewhat similarly by PIANC, the USACE does not provide nearly the level of detail and attention to channel width as it does channel depth.

The quote "depth is for productivity, width is for safety" – although not embraced by all – illustrates a mindset that sees width as a more fluid channel characteristic. In fact, recently, there have been more than a few cases where the designed width of a navigation project has been reduced in order to cut costs. The significance of this mindset and this trend in channel design is that channel width may potentially be reduced to a point where certain vessels may not even be able to transit a channel based solely on width – similar to the present-day limitation of channel depth. Other more immediate impacts include one-way vs. two-way limitations, as well as reduced vessel speed (and therefore reduced efficiency and perhaps maneuverability) in channels due to increased blockage factors.

Agency Coordination Issues

Intense coordination between various agencies is essential for a successful navigation project. Specifically in the US, some of the key federal agencies involved in a typical navigation project include: USACE, which designs, constructs and maintains the channels; USCG, which is responsible for vessel traffic management, including ATON, and port safety; NOAA, which is responsible for charting; the EPA, which is involved in environmental issues; and MARAD which is responsible for having a healthy US merchant marine industry to meet national transportation and emergency needs. The more seamless the linkages are between the involved agencies, the better the channel design, construction, and usage will be. However, even between sister federal agencies there is lack of compatibility between databases and information systems. This hindrance is only the beginning of the many technical, procedural and regulatory difficulties involved in channel design in the US.

Local interests such as port authorities, pilot associations, shipping companies, and local/state/regional governmental agencies must also be included in the channel design process. Participants agreed that incorporating all of the involved parties requires a great deal of effort but is essential to a good design and an accepted design. However, on a related issue, some noted that the segmentation of navigation projects into the federal project and non-federal berths is often tricky and adds to difficulties in the project's process. In order for the full depth of a navigation project to be realized and utilized, port berths must also be deepened to accommodate the larger vessels traveling through the channels.

Environmental Issues

The term "environmental issues" usually implies one of two interpretations:

1. Wind, waves, tides, sediment characteristics and/or other environmental factors involved in channel design and usage, or
2. Environmental protection in the sense of reducing the negative impact on water quality or aquatic and coastal habitat quality.

In the first sense of the term, participants agreed that methods for predicting and reporting environmental conditions have greatly improved. There are numerous historic as well as recent and predictive datasets available. In fact, several locations around the US have established a system entitled "PORTS," the Physical Oceanographic Real-Time System. PORTS is a program of the National Ocean Service of NOAA that provides real-time information about water levels, currents, and other oceanographic and meteorological data from bays and harbors. Also, PORTS provides "nowcasts" and predictions of these parameters with the use of numerical circulation models. In certain locations this information is very important to track because changes to the bathymetry (due to dredging or otherwise) have resulted in changes in water currents or other oceanographic effects. Participants indicated that the PORTS system enhances the safety and reliability of navigation channels in which it is installed.

In the second interpretation of the term "environmental issues," participants commented on the difficulty in finding suitable dredged material disposal sites. Nearly all commented that access (or lack of access) to an easily available, economical disposal site can make (or not make) a project economically feasible. On the other hand, participants also commented on the need to incorporate positive environmental aspects into channel design instead of just digging a bigger ditch and hauling the sediment out of the site. Some typical environmentally beneficial uses of dredged material include wetland creations or improvements, beach fills and/or shore protection.

Concluding Remarks on Channel Design

The U.S. Army Corps navigation mission is "to provide safe, reliable, efficient, and environmentally sustainable waterborne transportation systems (channels, harbors, & waterways) for movement of commerce, national security needs, and recreation." However, there seem to be some fundamental difficulties in achieving this mission. Most notably is that there are no recognized standards for safety, reliability, efficiency or environmental sustainability relative to navigation channel design promulgated by either USACE or PIANC.

Risk and uncertainty analysis of channel design and usage is desperately needed – to incorporate vessel transit data, accident data, as well as other factors into an assessment of channel safety, reliability and efficiency. However, it is a challenge to even define "risk" in terms of channel design due to the varying independent, dependent, and coupled factors involved. The role of simulation in the design process is valuable and significant, but simulation technology needs to be supplemented with other tools for assessing total risk and uncertainty.

Perhaps the most important issue identified in the discussions is that channel design is often done in a purely reactive manner. There is an acute need for a proactive process to look at improving channels to meet larger vessels, as well as to meet the significant changes in the nature of maritime shipping. Future vessel designs and design trends could be regularly tracked and incorporated into planning processes. There also seems to be little assessment of projects post-construction: i.e., typically how does actual traffic compare with predicted traffic?

And finally, the participants concluded that there is a need to educate the public and make all aware of the personal, regional and national value of shipping. Internationally, there seems to be more of an appreciation of shipping because of the general proximity of major shipping ports to large population areas. However, in the US, most Americans are completely unaware of the existence of maritime shipping industry and cannot even begin to realize the impact it has on our daily lives and our quality of life.

SHIP CONTROLABILLITY IN DREDGED CHANNELS

Overview

Captain Richard Owen of the Maryland Pilots' Association introduced the present state of ship controllability in dredged channels during the plenary session. The perspective of pilots is particularly important since they must work with the channel and the ship as they have been designed and maintained to provide for the continued flow of the nation's waterborne commerce without compromising the safety of navigation and protection of the marine environment. Capt. Owen pointed out that the capabilities of ships do vary, and that some have very poor maneuvering characteristics for the channels they must transit.

The discussions of ship controllability in dredged channels during the breakout sessions centered on the practical aspects of controlling a ship in a dredged channel. The controllability of a given ship in a given channel is a function of numerous decisions made during two independent design processes – the design of the channel and the design of the ship. Although ship controllability in a dredged channel is directly influenced by the multitude of decisions made in these independent processes, ship controllability is not a primary measure for evaluating the acceptability of a particular design – either of the channel or of the ship. Therefore, the intent of these breakout sessions was to highlight characteristics of the channel and of the ship that should receive greater attention during the respective design processes in order to assure the controllability of ships in dredged channels. The discussion also focused on two other areas related to ship controllability in dredged channels: information needs and waterway management issues.

The Channel

Participants were asked to identify physical characteristics of channels that contribute to the controllability of ships. There was general agreement that channel width should receive as much attention in the design process as channel depth. This is particularly important as ships' beams increasingly expand whereas channel width is not. This necessitates maneuvers such as the "Texas Chicken" so large ships can meet in some channels (see Fig. 5). The Texas Chicken is a maneuver where ships meeting in a straight, narrow channel make synergistic use of bank cushion and bank suction effects so that they can pass each other without going aground on the channel's outer edges. Pilots operating in the Houston Ship Channel have perfected this maneuver and have established strict protocols to minimize the risk of collision or grounding.

Figure 5 Ships meeting in the Houston Ship Channel.

It was also agreed that in addition to beam the designed width of a channel must also account for windage so that ships encountering cross winds can crab as necessary to avoid being set out of the channel or into the path of other ships. This is particularly important for ports frequented by ships with large windage areas, i.e., container ships, car carriers, and cruise ships.

Another physical dimension considered important for ship controllability is the radius of turns. Turns must be sized to not only physically accommodate the ships using the channel, but to also accommodate the larger turning diameters of ships when operating in shallow water. The radius of turns is directly related to navigation safety and protection of the marine environment. Small radius turns require large rudder angles and higher rates of turn to execute. Checking a ship's swing when exiting a small radius turn also requires large rudder angles. Because large rudder angles are needed to navigate small radius turns, there is less rudder angle in reserve for making corrections or reacting to unexpected situations. In contrast, larger radius turns can be executed with smaller rudder angles, which provides for more positive ship control by reducing the rate of turn [14]. Slower turns generally also require less opposite rudder to check. Additionally, being able to use smaller rudder angles to execute turns also helps ensure that enough extra rudder is available if needed.

A practice criticized by several pilots that has been used to reduce the cost of channel construction is to dredge one half of the channel deeper than the other. This design practice can be used when there is a significant difference between the drafts of inbound and outbound ships. Although asymmetric channels reduce construction costs, they also create what is essentially a continuous passing situation due to the asymmetric hydrodynamic forces acting on the ships transiting the deeper side of the channel. Asymmetric channels also effectively cut in half the width of the channel available to ships required to remain in the deeper side.

There was general support for design features that facilitate vessel traffic movement. These features include auxiliary channels to separate vessels with different maneuvering characteristics, e.g. deep-draft ships and tugs with tows; turning basins so that ships can maneuver without obstructing the main channel; and passing lanes, or spots, so that faster ships can overtake slower ones without having to alter course. Although not directly related to the design of the channel *per se*, it was suggested that how a waterfront facility might impact vessel traffic should receive careful consideration before permits are issued for construction or modifications. For example, vessels moored at a facility may encroach on a channel, or in the case of a ferry terminal, vessels using the facility may alter existing traffic patterns. Some facilities, such as marinas or boat launches, may modify the mix of vessels using a channel.

Aids to Navigation / Navigation Information

There was some discussion about how navigation systems, both short-range aids, such as buoys and ranges, and systems providing real-time tide and current data such as NOAA's PORTS system and electronic systems for monitoring under keel clearance [15, 16] contribute to ship controllability. Although the linkage between the information provided by these systems and ship controllability was not expressly established during the Workshop, there was agreement that they must be understood as vital components of the channel that directly contribute to the safe navigation of ships in dredged channels. The implication is that these systems should be incorporated into the channel design (and funding) process.

The Ship

Participants were asked to identify the characteristics of the ship that influence its controllability. Factors considered particularly important for ship controllability included:

- Length/beam (L/B) ratio;
- Rudder size;
- Power/tonnage ratio;
- Minimum bare steerage speed; and,
- Windage.

Without reference to any particular ship type, it was noted that length/beam ratios are becoming lower as naval architects increase ships' beams as a means of multiplying cargo capacity without increasing draft. Increasing beam reduces directional stability and hence makes it easier to initiate a turn. However, it also makes it more difficult to check a turn and therefore is of concern to masters and pilots since it can compromise a ship's controllability.

The rudder is a ship's most important control surface [17]. Insofar as the performance of a rudder is directly related to its surface area and the speed of the water passing over it and, it is not surprising that participants highlighted rudder size as a particularly important factor influencing ship controllability.

Several participants observed that the rudders of many newer ships are becoming smaller relative to increases in length (L), breadth (B) and draft (T) – in other words, rudder size is becoming smaller relative to increases in overall ship size. This is because rudder area is most commonly expressed as a percentage (values between 1.75 and 2% are common) [17] of a vessel's submerged lateral plane, or L x T, which is an indicator of a vessel's resistance to turning [20]. It was noted that while the trend toward smaller rudders relative to overall ship size may not adversely impact controllability at sea speed in deep water, it is having an adverse impact on controllability at slower speeds in narrow channels and in shallow water. This point is illustrated by one pilot's observation that whereas loaded tankers in dredged channels may require 10 degrees of rudder to initiate a turn, at least 20 degrees of rudder is needed to check a turn. Although rudders sized as a percentage of L x T may have sufficient area to generate the force necessary to initiate a turn, it does not necessarily follow that they will have adequate area to generate the force necessary to check a turn since it does not account for the ship's displacement. Lastly, it should again be noted that as larger rudder angles are needed to check a turn, there is less reserve rudder available. The importance of reserve rudder cannot be underestimated; it can be the difference between a near miss and a collision, allision, or grounding.

There was general agreement that rudders should be sized to ensure ships are controllable at slow speeds in shallow water. Several suggestions were offered regarding factors that should be considered when establishing a minimum rudder size. These included:

- Length/beam ratio;
- Displacement;
- Wetted surface area;
- Sail area; and,
- Power/tonnage ratio.

Due to the time available, it was not possible to engage in a discussion of the relative merits of each of these factors as a potential basis for determining rudder size.

Although rudder size is important, there are other factors influencing rudder effectiveness that were not discussed but which must also be considered by the naval architect when evaluating whether a particular rudder will provide adequate controllability at slow speed in shallow water. These include: rudder shape, e.g., horn, spade, or balanced rudder with shoe; the foil shape; the rudder's angular rate of turn; and the shape of the hull just forward of the rudder [17, 18, 19]. Another factor that must be considered is the number of rudders as well as the location of the rudder(s) relative to the propeller(s).

Vessel masters and pilots noted that power/tonnage ratios are becoming lower and as a result some ships are becoming increasingly underpowered and difficult to control in shallow or confined waters at slow speeds. This is because low powered ships lack enough reserve power to provide sufficient "kick" when the engine is ordered half- or full-ahead just long enough during a turn to increase the speed of the water flowing over the rudder in order to enhance its performance.

Another propulsion related factor of interest to several participants is that the difference between bare steerage speeds (the speed at which the rudder is effective) and "dead slow ahead" speeds (the minimum speed a vessel will make through still water with its propulsion continuously engaged) have been increasing as ships design service speeds have gotten higher. This is particularly a problem for container ships and car carriers. Both bare steerage and dead slow ahead speeds have typically ranged between 3 and 5 knots. Although bare steerage speeds have not increased, dead slow ahead speeds in excess of 5 – 6 knots are becoming increasingly common. In fact, one pilot cited a ship he had recently been on that had a dead slow speed ahead of 8 knots. Also of concern is that there can be a significant difference between dead slow ahead speed and the speed at which an astern bell can be ordered. For example, on the ship cited above, the dead slow ahead speed was 8 knots but an astern bell could not be ordered unless the vessel's speed was less than 3 knots.

It was noted that the apparently ever-increasing windage area of many cruise ships, car carriers, and container ships can simply exacerbate a less than desirable situation for ships that have less than adequate slow-speed / shallow-water controllability. There was also a comment that the controllability of ships in ballast can be compromised, although this is more of problem when a ship is stopped or maneuvering alongside then when transiting a dredged channel – provided the channel is wide enough to accommodate the required crab angle. Although ships must have sufficient ballast tank capacity to submerge the propeller and rudder, the location of the ballast tanks can result in excessive trim by the stern.[7] Trim by the stern shifts the pivot point aft and can create significant windage forward. The result is a ship that under even moderate wind conditions can be very difficult to control.

Shallow / Restricted Water Maneuvering Standard

There was general consensus that a design standard for shallow- and restricted-water maneuvering capability should be established. Although the technical challenges of developing a shallow/restricted water maneuvering standard were acknowledged, there was agreement that such a standard is important for navigation safety. In addition to ensuring that ships can be controlled when operating in shallow-water, such a standard could also be used to improve the safety of navigation and protection of the marine environment. Although ships may spend 90 – 98 percent of their operational lives underway at sea speed in deep water, it is during the mandatory beginning and end of every voyage when the risk of collisions, allisions, and groundings are highest. Ensuring the ability to maintain complete and positive control of a ship's movement during these segments of a voyage is absolutely vital if that risk is to be reduced. The current practice of not positively addressing shallow-water, slow speed controllability during the design process is not unlike assuming that an airplane will be able to takeoff and land if its inflight controllability is adequate.

Information needs

Ships operating on the navigable waters of the United States are currently required by 33 C.F.R. § 164.35(g) to

[7] The design limit for trim by the stern for a tanker is 0.015L in accordance with Regulation 13 of MARPOL 73/78, Annex I. This requirement does not apply to other vessels.

have maneuvering information posted on the bridge. This information, which is based on tests conducted in deep-water, includes a turning circle diagram as well as tables showing time and distance to stop the vessel from full- and half-speed. IMO Resolution A601(15), which was adopted in 1987, contains recommendations for ensuring maneuvering information is available on board ship. The recommendations specify information that should be included: on a pilot card, which can be used during the master-pilot exchange;[8] a maneuvering poster, which contains much of the information presented on the poster required by U.S.-regulations; and, a maneuvering book. Although this information is useful, it does not communicate the maneuverability of a ship since it does not provide a means of directly comparing the maneuvering characteristics of a given ship against an established standard.

Pilots currently fill this void by informally comparing the maneuverability of different ships amongst themselves. While these informal comparisons provide pilots with information that they need, it is after the fact information. In other words, it is information that can only be gained by actually handling the ship in a restricted channel and potentially hazarding the safety of navigation or protection of the marine environment. It should also be noted that this information is generally not shared between pilot associations. Since this information is generally based on a subjective comparison, its usefulness to the USCG for making operational decisions, the USACE for evaluating a channel design, or the naval architect for developing a better ship design is limited. Being able to communicate the maneuverability of a ship relative to an objective standard would make it possible for masters, pilots, and the Coast Guard to make better decisions regarding a ship's movement and imposing operational controls. It may also contribute to improving the channel design process.

Participants also noted that the maneuvering information available on board ships, e.g., maneuvering diagram, pilot cards, or maneuvering booklet, also does not make it possible to determine whether a given ship exceeds the channel's design limits, a point that has also been made by the National Research Council [21]. While computer-based or scale models can be used to determine whether a ship meets or exceeds a particular channel's design criteria, such modeling is not routinely conducted.

[8] The 1995 Seafarers' Training, Certification and Watchkeeping Code, Section A-VIII/2 part 3-1, article 49 requires the master and pilot to "exchange information regarding navigation procedures, local conditions and the ship's characteristics." There is an ongoing effort at IMO to, among other things, establish best practices that can be used as a model for this exchange and to improve to improve operational safety and prevent misinterpretation of information or intentions when maneuvering.

The skill and ability of a master or pilot to maneuver a given ship through a particular channel and make a safe passage remains a basic safeguard of safe navigation and protection of the marine environment in confined waters. Masters and pilots are increasingly utilizing ship simulation training to hone these skills. Shipmasters and mates also are receiving such training to help with the process of coordinated bridge operations as an effective and knowledgeable team. A Marine Board study [22] assessed the use of numerical simulation technology to train mariners and concluded that while modeling accuracy is sufficient for deep-water operations, modeling requires refinement to provide the accuracy needed for shallow and restricted water operations. Both trainers and trainees must also be aware of how the limitations and assumptions upon which the simulator is based influence the results [18, 23].

Ships' masters and pilots commonly use physical models to enhance their knowledge of slow-speed maneuvering in shallow water [21]. This type of training is available at a limited number of facilities around the world, including Port Revel, the Warsash Maritime Centre in the United Kingdom, and the Massachusetts Maritime Academy's Center of Maritime Training. While model facilities cannot reproduce currents and wind gusts accurately, their simulation of bottom and bank effects are as close to reality as one can get short of handling a ship in a narrow waterway. Because of model scaling, actions occur roughly five times faster than in real life so they provide rapid feedback with respect to how hydrodynamic phenomena affect ship trajectories.

Management

Based on comments made by speakers during the plenary session and by participants in the breakout sessions, it became apparent that channels should be managed as a system. This is in contrast to the current regime, which is focused on individual components, e.g. the channel, ATON, or a particular navigation information system, e.g. PORTS. In other words, the channel is seen as a compilation of components rather than as an integrated whole. Integrated management is needed to optimize the various components that comprise the channel.

Integrated management also requires closer coordination between *all* of the agencies and parties that have an interest in the channel. These include the USACE, the USCG, NOAA, the local project sponsor, ship operators, and the local pilots' association. Closer coordination is needed to ensure that channel management is not overly focused on one particular aspect, e.g. channel depth, but is instead as holistic as possible. It was suggested that forums such as harbor safety committees could contribute to improved channel management by providing a venue that promotes this type of coordination.

A number of participants noted that the USACE does not have the authority to initiate reviews of navigation projects without first receiving congressional authorization. The result is that project reviews are not always as timely as they should be – either in advance of or following some change, i.e. a significant increase or decrease in cargo, a terminal expansion project, or projected increase in ship size. Because of this, our channels are frequently not optimized to safely accommodate the ships that will be using them.

SHIP MANEUVERABILITY AS A CONSIDERATION IN THE DESIGN PROCESS

Overview

Ship design discussions at the workshop reviewed how vessels are designed, what design criteria and standards exist, and what more needs to be done to ensure adequate vessel maneuverability perhaps better matching of vessel, channel, and operational practices.

In general, naval architects and marine engineers are educated and equipped with knowledge, skills, and design processes that permit continuous checking and balancing of constraints and design tradeoffs of vessel capabilities as the design progresses. The intended result of the process is the best design given the basic requirements of speed, payload, and endurance [24]. Focus is not placed on how the channels and waterways are designed. Perhaps even more importantly, there is a general lack of understanding of the operational scenario regarding piloting of vessels in constrained waterways. Only recently has there been a real attempt to fully integrate human operational practices with vessel design. The involvement of human beings onboard vessels both extends and restricts the inherent vessel maneuvering capabilities vastly complicating the necessary methodology for assuring safe and efficient operations.

Including restricted waterway maneuverability as an important spoke in the ship design spiral would seem a necessary step to enabling proper tradeoffs in vessel design (see Fig. x). The reality is that maneuverability is still not an important consideration in ship design of many merchant ships. The result is that design decisions that can compromise maneuverability are decided in favor of other factors. As an example, one notorious LNG vessel was known to initiate major turns (up to 180^o) without warning while underway at sea. Concern for vibrations during design had resulted in a cutaway stern with very fine flow lines and little transverse restraint to provide needed horizontal stability (Fig. 161 in [19]). Only with consideration of the full range of channel design and human factors relationships affecting maneuverability will we be able to produce an efficient and safe marine transportation system.

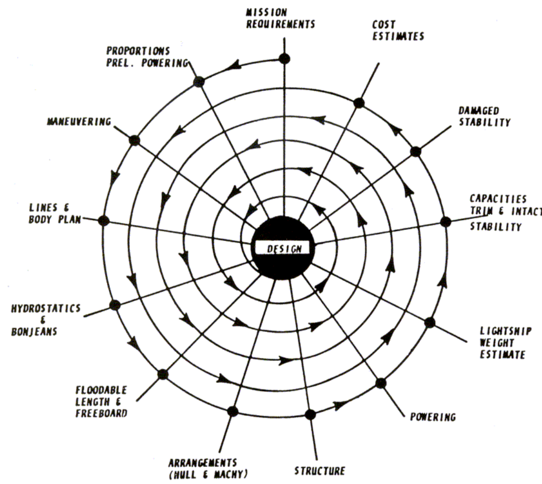

Figure 6 Maneuverability should be an important spoke in the "Ship Design Spiral." [25]

There are several reasons maneuverability is not considered particularly important during the design process, including:

- Owners generally do not include maneuverability requirements as part of the design specification;
- There are not any established international or domestic requirements for ship maneuverability other than the minimum required rudder swing rate[9] as well as that a ship have adequate horsepower and a means of generating reverse propulsion; and,
- There is difficulty in specifying what constitutes adequate maneuverability.

Even though participants agreed that maneuverability should receive more attention during the design process, their comments also suggested that elevating the importance of the maneuverability will require that this issue be highlighted by regulatory bodies. They also indicated that while the design tools currently available may be adequate for design issues related to maneuverability at sea-speeds in deep-water, more work (and data) is needed before they can be used reliably for making design decisions for maneuverability at slow speeds as well as in shallow- or restricted-waters.

Vessel Design Standards Development

The maneuverability of ships began to receive the attention of the international maritime community in the 1960's and 1970's as the size of tankers began to increase more and more rapidly. Although maneuverability has been of concern, agreeing on maneuvering criteria and standards, as well as a methodology for implementing those standards, has been an elusive goal [26].

In 1971, IMO adopted Resolution A.209(VII) establishing recommendations regarding posting maneuvering

[9] Regulation II-1/29.3.2 of SOLAS requires rudder movement from 35^o on either side to 30^o on the other to occur in 28 seconds or less.

information onboard so that it would be available to ships' officers and pilots. Resolution A.601(15) in 1987 superseded A.209(VII) and established recommendations for ensuring maneuvering information was available in standard formats to ships' officers and pilots.

SNAME's Panel H-10 (Ship Controllability), in partnership with MARAD, and the USCG focused a great deal of effort on identifying vessel maneuverability needs and assessing the design tools available to properly identify both inherent and piloted maneuverability characteristics of ships [24, 27, 28]. The Panel documented the state of the art vis-à-vis design tools and methodologies available for ensuring that the maneuverability of a ship would be adequate in [24]. Based, at least in part, on this effort, IMO approved circular MSC/Circ.389 in 1985 establishing interim guidelines for estimating the maneuverability of ships. Although Circ.389 addressed the problem of defining maneuvering characteristics and how they should be estimated during the design process, it did not discuss specific performance standards.

In 1993 IMO finally adopted Resolution A.751(18), which established interim standards for ship maneuverability. The minimum basic maneuvering qualities to be delivered by the standards were:

- Turning ability – tightness of turn
- Initial turning ability – quickness in initiating
- Course keeping ability – ability to keep a steady course
- Yaw checking ability – ability to check a turning motion
- Stopping ability – ability to come to a stop.

The guidelines call for ships to be designed to meet the interim standards and that their actual performance should be measured after construction to check to see if they meet the requirements. The resolution also recommended that each member country work with the interim standards for five years and report the results to IMO in a format that was detailed in circular MSC/Circ.644. The circular also provides detailed guidance for meeting the interim standards. The data collected by IMO is intended to allow examination of the feasibility of these minimum deepwater performance requirements and the practicality of applying them. The interim standards were then to be reviewed after five years to determine needed changes. Since the IMO interim criteria and standards are only recommendations, many ships do not comply and not much data has been reported during the trial period. IMO is now in the process of reviewing the available results with a meeting planned for March 2002 to consider changes and implementation of the criteria and guideline standards as requirements.

Practical considerations, of course, limited the extent of trials specified to verify maneuverability under the IMO criteria. The trials include only those that can be run in parallel with the normal first-of-a-class powering and endurance trials in order to not require additional trials time. The recommended criteria are thus based on vessel characteristics at normal trial drafts in deep water and at full speed.

What about maneuverability capabilities in shallow and restricted waters where banks and ship-to-ship interactions are present? Can the IMO criteria and standards assure safe operations in these close conditions (See Fig. 6) where speeds are slow, water shallow, channels narrow, and where bank effects and vessel squat performance are so crucial to safe operations?

Figure 7 Ships passing in a narrow channel. (USCG)

A good maneuvering ship in deep water can infer good maneuverability under close in situations but performance does vary considerably with many particulars of the design. Unfortunately, developing standards to assure minimum capabilities under these conditions is not practical with current design tools and testing for performance under these tight conditions is not safe or economical.

Assuring adequate minimum maneuverability for these critical situations may need to await improvements in numerical modeling capabilities. With such improvements, determining capabilities in close in situations could be based on deepwater full speed trial predictions. Even so, adopting the 1993 deepwater criteria and standards as requirements rather than guidelines, however, is a very important step as it causes maneuverability to become a real consideration in the many trade offs that occur during the ship design process.

There are also a number of other design elements important to providing adequate vessel maneuverability. Some of these are noted here and discussed in this or other sections of this paper:

- Rudder size and effectiveness
- Ability to transit at slow forward speed
- Propulsion and propeller characteristics
- Number of available engine reversals
- Adequate horsepower for control
- Extra reserve rudder angle needed to allow for ship crabbing from wind forces or moored ship suction
- Visibility from bridge and bridge arrangement
- Hull form squat (trim and sinkage) characteristics and effect of bank forces on moorings and passing ships

- Air draft
- Emergency anchoring ability
- Amount of tow line leads and line access

Few of these elements are addressed properly in regulations or classification society standards from the viewpoint of maneuverability.

SHIP DESIGN TOOLS

While naval architects continue to rely upon experience and good marine practice when addressing maneuverability issues during the design process, they do have analytical tools and methodologies to assist with this purpose [19, 24, 25, 28]. Current mathematical models based on ship model testing and full-scale trials validation provide accurate tools for analyzing ship trajectory prediction and behavior in deep water. Although the existing models do require modification when addressing the controllability of unusual hull forms, the solutions they provide are adequate for predicting a ship's maneuverability in deepwater. The IMO vessel performance guidelines, indeed, have evolved based on these good deepwater modeling abilities and validation experiences.

Existing analytical tools can provide relatively consistent and reliable design comparisons for the purposes of evaluating compliance with the existing deep-water maneuvering guidelines. They are not, however, completely up to this task. The necessity of being able to accurately predict and validate a ship's maneuverability during the design process becomes particularly meaningful when it is remembered that checking whether the ship's maneuverability is adequate is accomplished through tests performed after the ship is constructed – when corrections are difficult or economically impossible to perform.

In addition, although maneuverability has been of concern since the 1960's, the existing IMO maneuvering criteria and standards guidelines are based on deepwater modeling and are not necessarily appropriate for ensuring that the maneuverability of a ship in shallow-water is adequate. Therefore, existing design tools cannot, at least with any degree of reliability, be used to design a vessel and ensure it will have adequate maneuverability in shallow or restricted waters. In part this is because of the extreme non-linearity of hull and propulsion characteristics under these conditions. It is also due to the fact that very few full-scale measurements have been performed to gather the data necessary to validate existing models so that they can be used to reliably evaluate a ship's maneuverability in shallow- and restricted-waters.

Therefore, more accurate design maneuverability prediction tools are needed. Without such tools, the ability to reliably make design tradeoffs that ensure maneuverability is not possible in the situations that are important. Current mathematical models are not sufficiently accurate for simulating shallow water, hull and bank interactions and powering effects because it has not been previously possible to accurately measure the full-scale forces and movements.

It should be noted that these full-scale measurements and better modeling are needed not only for ship design purposes, but also for improved training of mariners through simulators using these same models and for channel design where these ship operational models are similarly used.

Recent Developments

A number of promising developments exist and many were discussed at the workshop. Kutsuro Kijima [29] showed a modeling approach that permitted analysis of passing situations that would help set procedural standards for safe passing. Wei-Yuan Hwang described analyses in a study of the Norfolk harbor area that are utilizing computational fluid dynamics (CFD) to make accurate predictions where current mathematical models are unable. Ian Dand [5] reported on the development of models for ship squat that have shown very good accuracy over the years. They are limited in their ability to adequately predict trim, however, which is a governing parameter of interest due to its effect on UKC.

Larry Daggett [30] described the advent of dual frequency dgps receivers and their role in gathering full-scale ship trial data. In addition to the excellent horizontal accuracy of the normal dgps receiver, these receivers provide vertical location with an accuracy measured in centimeters. This accuracy is a vast improvement over the crude means of measurement available up until now. Although these receivers are somewhat expensive and currently only used in research situations, data acquired will enable making significant refinements in numerical trajectory models. With accurate full scale data to model from, models will be able to predict vessel trajectory, sinkage, and trim in shallow and restricted water operations as well as in meeting, passing, and bank suction situations.

The summer 2001 data gathering activities reported at the Workshop by Daggett [30] promise to provide accurate vertical data on ship squat needed in the process of beginning to develop sufficiently accurate models for design purposes

Terry O'Brien's [31] modeling of UKC incorporating weather, current, tidal, and squat characteristics as part of a real time advisory system for ships coming into several ports in Australia was also described. The system has achieved great success with more cargo carried through deeper draft operations with increased safety during port entry or departure. As prices of dual frequency receivers decrease one can also anticipate that all ships may be so instrumented so they will know where they are vertically. With this equipment they will also be able to gather useful data for further understanding of the principles and improvements to the prediction capability.

All of these and other related efforts show that the opportunity now exists to make great progress in mathematical modeling in the coming years. The possible improvements can significantly increase the accuracy in analysis tools past their deep-water capabilities. This will not only allow setting standards for appropriate criteria but will permit accurate analysis of the ability of designs to meet the standards earlier in the ship's design spiral and before construction of the vessel and trials.

The Desired Situation

There was general agreement amongst the participants that firm deep- and shallow/restricted-water maneuvering standards that can be applied during the design process should be established. There was also agreement that such standards could only be successfully implemented if compliance is mandated and that the tools needed to accurately analyze and validate vessel capabilities during the design process are developed. Several participants note that shallow-water maneuvering standards were required to ensure that ships and channels are better matched and thereby avoid the situation we are in currently where ships are too big for their ditches.

We are not currently at the desired situation primarily because of the expense and the great difficulty in the past (at any cost) of gathering the needed data for modeling analysis. Recent developments in both theory and practice when coupled with the tremendous advancements in our ability to gather data during full-scale tests in shallow-water provide the opportunity now to develop the tools that are necessary. These new opportunities permit overcoming many of the difficulties encountered in past attempts to develop complete criteria and standards.

Next Steps for Ship Maneuverability Design and Modeling

Ship operations in shallow and restricted waters are not well understood because of very limited gathering and analysis of full-scale data needed for modeling of sufficient accuracy to validate a design before it is constructed. Collection of data using dual frequency dgps receivers and proper analysis needs to be supported to enable unlocking our understanding of restricted water operations. Improvements in modeling can then permit usable criteria and standards to be established and design tools developed to ensure that the maneuverability of ships in shallow-water is adequate to permit the continued safe and efficient operation of the MTS.

Although recent developments have significant promise for addressing many of the technical obstacles to establishing viable deep- and shallow-water maneuvering standards, there are some other problems, some technical and some institutional, that must also be addressed if maneuverability is going to become a critical element during the design spiral. These include:

- Many shipowners, as well as other stakeholders, are not familiar with the risks to navigation safety and protection of the marine environment associated with ship maneuverability;
- It is difficult to gain access to the data that does exist either because it is proprietary or because of liability concerns;
- The predictive tools that do exist require additional development and full-scale validation;
- There is not sufficient data currently available to develop and validate the design models needed to accurately evaluate a ship's shallow and restricted-water maneuvering characteristics during the design process;
- The current cost of conducting needed systematic model tests of different hull forms and full-scale trials in shallow-and restricted-waters is still expensive;
- The current knowledge of ship maneuverability in shallow-water as a result is not sufficient to make informed decisions.

Summary

Establishing maneuverability criteria and standards remains elusive. However, there are indications that IMO will adopt mandatory maneuvering standards based on deep-water criteria in the near future. Deep-water criteria and standards based on definitive trial maneuvers are practical and reasonably accurate modeling capabilities to assure this performance capability are present.

Although the science of designing ships for adequate maneuverability still contains much art, the advent of dual frequency dgps receivers and the improved ability to conduct full-scale testing promises to erase many of the unknowns regarding ship maneuverability in shallow and restricted waters. It is reasonable to expect in the near term that this will permit the development of criteria and standards and the design tools that will assist naval architects and marine engineers as they make decisions throughout the design process to ensure that maneuverability is not compromised as the design is optimized for other factors, e.g., cargo capacity.

RECOMMENDATIONS

A goal of the workshop was to generate specific, actionable recommendations for improving the safety of navigation and protection of the marine environment by enhancing the controllability of ships in dredged channels. Recommendations generated by participants include:

- The international maritime community must treat channel design and ship controllability as a significant safety and environmental protection issue that must be addressed in order to ensure that the U.S.-MTS continues to operate safely and efficiently.
- The Water Resources Development Act should be amended to give the USACE authority to perform periodic reviews of navigation projects without having to wait for specific authorization. This authority is needed to ensure that channel improvements keep pace

with changes in ship size and capabilities. Triggers that could prompt a review include: changes in traffic or cargo volume, changing ship size, terminal expansion, etc.
- Ensure that both the USACE and PIANC channel design guidelines provide as much attention to channel width and radius of turns as is currently given to channel depth.
- IMO should adopt mandatory maneuvering standards based on deep-water criteria while also initiating the development of shallow-water maneuvering standards.
- MARAD, the USCG and the USACE, in partnership with SNAME and the maritime industry, should initiate a comprehensive research effort to develop slow-speed, shallow- and restricted-water maneuvering standards that could be used by ship owners, pilots, and the USCG to evaluate whether a particular ship can be safely accommodated by a particular channel as well as to guide the design of channels. In addition, the US should encourage IMO to initiate a project for establishing shallow-water maneuvering standards.
- The USCG's ATON system and NOAA's navigation information systems (i.e. air gap monitoring, PORTS, surveys/charting) should continue to be supported and improved.
- Communication between different agencies and interests involved in channel design and waterway management must continually improve so that channels can be managed as a system. Particularly, database correlation is still a challenge between even sister federal agencies and should be standardized for ease of use and correlation.

As noted in various places throughout this paper, implementing these recommendations will require coordination amongst the various Federal agencies responsible for managing the different components of a waterway, as well as local project sponsors, naval architects, ship operators, and ships' pilots. Although ensuring the safety of navigation and protection of the marine environment in our nation's waterways is a Port State concern, successfully addressing issues such as the development of a shallow water / slow speed maneuvering standard will require close coordination with other Port States as well as Flag States at the IMO. Implementing these recommendations will also require ensuring that the design of channels and of ships is optimized for safe navigation as well as economic viability.

However, as several participants noted, without a major accident that can be attributed to a flagrant controllability problem - the classic impetus necessary to make improvements to safety and environmental protection - it may be difficult to generate sufficient interest within the international maritime community to implement these recommendations.

SUMMARY

Many valuable points were made in the closing session. Several participants noted that it was particularly valuable that the workshop was attended by experts representing a broad mix of disciplines (pilots, regulators, channel designers, simulator experts and ship operators) and that they were given plenty of time to talk with each other about the various issues associated with channel design and ship controllability. Many indicated that this was a unique experience that should periodically be repeated. The value of this event can be summed up in a remark made by a senior channel designer: "I learned more about ship handling and ship behavior in the last two days than I had in the previous 35 years in this business."

In addition to the specific recommendations, some of the more technical observations and conclusions included:
- Whereas there are differences in the approaches to channel design used by USACE and PIANC, the results from both are quite similar, but
- Some of the more fundamental "Rules of Thumb" for channel design are often violated in practice – both in the US and abroad. For example, the general rule that the width of one-way channels should be between 4 - 5 times the maximum beam of ships expected to use it is seldom followed.
- Some valid criteria that were raised, but not resolved include issues like nature of the bottom, sensitivity of area, degrees of hazard for various ship types etc.
- The issue of UKC and the effect of heel on UKC needs more attention. For example one degree of heel increases draft of a 100' beam ship about a foot.
- Naval architects and ship handlers alike stressed the importance (and difficulty) of the passing maneuver in restricted waters. While greater speed means greater control, it also means much bigger forces to overcome.
- Vessel owners are intensely aware of the economies of scale and are continually looking to increase the cargo-carrying capacity (and thus size) of their vessels. Typically, a larger vessel requires a larger navigation channel. Interestingly, it has been observed that vessel beam has been increasing faster than other dimensions (length and draft). Perhaps this is due to the impatience of vessel owners to increase cargo throughput through a channel; that is, if the channel deepening is too slow, a vessel with a wider beam may accommodate more cargo without waiting for a channel modification project to be completed. This change in vessel characteristics and aspect ratio (wider and fuller) can potentially add to maneuvering difficulties in restricted waterways.

Participants throughout the workshop emphasized two especially important issues having to do with ship handling and behavior:

- Far more full-scale data is needed to help naval architects and channel designers better improve their understanding of how ships of various types and hull forms behave in restricted waters. It is more than 20 years since the ESSO OSAKA shallow-water maneuvering trials [32] were conducted; however, the results from these trials are still some of the best correlative data available. The best recent work is that done by Waterway Simulation Technology in the Panama Canal in 1999 [33] and in the Houston Ship Channel in 2001 [30]; however, more full-scale trials are still needed.
- Most workshop participants familiar with the vessel maneuverability standards in IMO Resolution A.751(15) agreed that these voluntary criteria for ships operating as sea-speed in deep-water are of relatively little value for assessing ship handling performance at low speeds in restricted waters. They recommended that the world's hydrodynamic community develop alternative criteria for the slow speed restricted water cases and that eventually these become part of an IMO standard. Such criteria should deal with turning, checking, stopping and course keeping.

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APPENDIX A

International Workshop on Channel Design & Vessel Maneuverability

Thursday-Friday, 3-4 May 2001

Norfolk Waterside Marriott Hotel
Norfolk, Virginia 23510 USA

Day One – Thursday, May 3	9:00 – 11:45 AM	**Plenary Session** • Introduction / workshop overview: Mr. Bill Gray • Shipping Trends – What are the implications of shipping trends for channel design? Mr. John Vickerman • Channel Design Criteria – A comparison of PIANC and USACE design criteria : Dr. Ian Dand and Mr. Dennis Webb • Ship controllability in dredged channels: Dr. Katsuro Kijima • Ship maneuverability as a design consideration: Capt J. Cook and Capt Mike Watson	
	12:00 – 12:45 PM	**Lunch**	
	1:00 – 1:30 PM	**Afternoon Session:** Use of Simulators in Channel Studies: Dr. Johan deJong	
	1:30 – 3:00 PM	**First Breakout Session** (choose one) • Channel design criteria • Ship controllability in dredged channels • Ship maneuverability as a consideration in the design process	*These breakout sessions are intended to provide a forum for an open discussion of the three highlighted areas. Participants are encouraged to focus on the following questions:* • What is the current situation? • What is the desired situation? • Why is there a difference between the current situation and the desired situation? • What are the impediments to change? • How can these impediments be most effectively addressed?
	3:15 – 4:45 PM	**Second Breakout Session** (choose one) • Channel design criteria • Ship controllability in dredged channels • Ship maneuverability as a consideration in the design process	
	5:15 – 6:30 PM	**Reception**	

Day Two – Fri, May 4	9:00 – 11:30 AM	**Policy Discussion**
		• Reports from breakout session moderators
		• Open discussion with representatives from
		  o USACE
		  o USCG
		  o MARAD
		  o APA
		  o AAPA, and
		  o SNAME (moderator)	