Further Perspectives on Operator Guidance and Training for Heavy Weather Shiphandling

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ABSTRACT

Historically, mariners have received minimal formal training in heavy weather shiphandling, relying on mentoring and hands on experience to develop shiphandling skills for dangerous environmental conditions. Maritime organizations are increasingly turning to technology to reduce the inherent risks of heavy weather, including operator guidance systems and simulation to train watch personnel. Shiphandling simulators are on the cusp of extending training capabilities from simple maneuvering situations to highly realistic heavy weather scenarios, resulting in vastly improved training effectiveness. This is especially critical as actual time spent afloat may represent proportionately less of a mariner's total career.

KEYWORDS

Shiphandling simulation; heavy weather training; operator guidance

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Note: The opinions expressed in this paper are those of the authors and not necessarily those of the Naval Sea Systems Command or the United States Navy.

INTRODUCTION

Heavy weather presents mariners with significant risk of structural damage, loss of cargo, crew injury, and the potential for environmental damage (e.g., oil spills). Damage from heavy weather incurs significant costs to the maritime industry, both in property and environmental damage. In most cases, ships try to avoid heavy weather if possible, but some storms cannot be avoided, or prove to be worse than originally forecasted, leaving shiphandlers to deal with seas and winds for which they may have received little formal training.

All ships can be at risk of capsizing in extreme seas, and that risk can be exacerbated by poor shiphandling decisions. Current heavy weather training follows two basic precepts: avoid extreme weather, and if the weather cannot be avoided, adhere to "rule of thumb" procedures and techniques to assist in safely riding out the storm. Advances in meteorological technology have significantly enhanced the ability to avoid severe weather by providing concise, real time understanding of the current and predicted weather environments, as well as storm mapping. However, on occasion, seamen must face the elements. It is at this point that correct and time-sensitive shiphandling decisions must be made, often in a high-stress environment that increases the potential for human error, and heavy weather training becomes critical.

SHIPHANDLING TRAINING

Historically, shiphandling training has focused on building skill sets for normal seaway and restricted maneuvering situations, such as entering and exiting ports and special evolutions at sea. The focus has been on understanding basic shiphandling characteristics and techniques as bounded by a ship's size, propulsion, ship control, and steering capabilities. Mariners have received minimal formal training in heavy weather shiphandling, relying instead on personal mentoring and hands on experience in specific ship types or classes with known handling characteristics to impart the ability to cope with difficult and dangerous environmental conditions. The reality of shiphandling in heavy weather is that normally only the most experienced shiphandlers are engaged in ship control in severe weather, so junior officers get little actual hands-on experience. Because heavy weather is normally avoided, even the most seasoned mariners may have only limited experience in higher sea states. This training gap in appropriate shiphandling procedures in heavy seas contributes to a higher risk of damage and loss when heavy weather is encountered.

Heavy Weather Shiphandling Training Objectives

In addition to the paucity of actual heavy weather shiphandling experience facing many of today's mariners, the advent of a variety of new hull forms makes it increasingly important to educate shiphandlers on the unique handling characteristics of these designs, particularly in higher sea states. In some cases, traditional shiphandling methods may not be appropriate for some of the more innovative designs, so relying on traditional responses in emergency situations may in fact exacerbate the danger. This is an important consideration in the training solution, as care must be taken to mitigate the possibility of negative transfer between traditional shiphandling techniques and those required for non-traditional hull forms. Shiphandling training, and in particular, heavy weather shiphandling training, should focus on providing tools that complement existing training and focus on ensuring the safety of ship and crew.

Regardless of the hull form, mariners must have a practical knowledge of sea characteristics and the ability to "read" and predict conditions based on clues ascertained from the surrounding environment. This type of information can be covered through classroom training, is currently included in most shiphandling training programs, and provides the foundation for heavy weather operations. Higher sea states, however, require separate skills outside of the scope of shiphandling in calm seas. Certain standard operating procedures can improve the likelihood that at-sea maneuvering events do not result in catastrophic loss or damage. To effectively train for heavy weather, the shiphandler must learn to correctly interpret several basic elements of dynamic information (presented either by display or visual/physical recognition):

- Own ship stability data
- Wave direction, length, height, and periodicity
- Wind speed and direction
- Ship motions (roll, pitch, yaw, surge, sway, and heave)
- The combined dangers/effects of all of the above (slamming, pounding, pooping, surf-riding, broaching, and ultimately, capsizing)
- Appropriate mitigation techniques
- Casualty situations (structural damage, flooding, loss of power/steering, etc.)

Each hull form has its own unique stability characteristics. Factors such as list, trim, displacement, ballasting, KG, and GZ are all important for the shiphandler to know and understand in order to successfully maneuver in heavy weather. Paramount for the shiphandler is the ability to understand the combined effects of environmental conditions and how they impact the unique shiphandling characteristics of the ship. A dynamic capsize can seem to be the result of unrelated events, but in reality, it is comprised of a cascading series of events and conditions that must be understood in order to properly interrupt the sequence and avoid catastrophic consequences.

There are basic tenets of good shiphandling that hold true in any situation, such as maintaining power, buoyancy, and stability; avoiding beam seas; and adjusting course and/or speed to minimize pitch and slam. However, once in heavy weather, understanding the combined effects of wind and waves on the specific hull form is critical (Alman, P. R., Minnick, P. V., Sheinberg, R., Thomas, W. L. III; 1999). Simple classroom training can provide a basic understanding of these effects, but the best form of instruction is simulation, through which the trainee can practice decision-making skills and experience the results of both correct and incorrect actions. These aerodynamic and hydrodynamic effects were heretofore difficult to simulate, but modern advances in physics-based ship motion software coding are now providing critical enhanced capability. This opens up the potential for rigorous hands-on training in a simulated environment, allowing routine training in the most dangerous of sea conditions, without jeopardizing personnel or ships.

Heavy weather training curricula should also include instruction on the use of basic calculations for estimating wave encounter period. This can be a useful tool during heavy sea states when technology is unreliable and/or unavailable. When simulation opportunities are added to this type of training, they allow the operator to effectively test his/her understanding of the principles, and to practice mitigation strategies appropriate for the ship type. This type of training helps solidify appropriate reactions when faced with time-sensitive decisions in actual heavy weather situations. There are basic mitigation strategies, or "rules of thumb," to assist the operator in maintaining a stable ship environment, such as the International Maritime Organization's "Revised Guidance to the Master for Avoiding Dangerous Conditions in Heavy Seas." [1] Guidance of this nature is useful, but should directly relate to the specific characteristics of the ship in question. For instance, some of the newer container ships appear to be susceptible to head sea parametric rolling, something not historically noted as a shiphandling concern. The magnitude of risk of a stability failure or capsize event can vary significantly between ship designs, as can the mode of failure. Consequently, the criticality of being able to recognize potentially severe conditions and make the correct judgment call with respect to the shiphandling decisions needed to mitigate risks assumes a degree of importance that cannot be underestimated.

The shiphandler should be trained to recognize 'cues' or precursors leading to an imminent dynamic stability event such as wave capture, bow plunging, or broaching to name a few, and understand the correct action necessary to get the ship out of danger in these situations. Ship motions are multi-dimensional, and shiphandlers need to thoroughly understand the implications of their ship's response to heavy weather (i.e., its motions), the dangers certain combinations present, and how to correct for them. For many ships, the arrangement of hull and superstructure create significant windage and there may be large differences across various load conditions. The lateral distribution of windage can create lee/weather helm characteristics similar to that of a vessel under sail. A ship trying to ride out a storm in head seas may need sufficient headway to maintain controllability, but at the same time, may suffer significant or dangerous structural damage as a result of wave impact, making it necessary to come about into stern

[1] *Revised Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions*. Ref. T1/2.04 (11 January 2007). MSC.1/Circ. 1228.

seas. A ship with insufficient power may get caught "in irons" if trying to steer thorough head seas and come around to a new course. Multiple factors are in play at any given time, and maneuvering decisions need to be balanced against handling capabilities accordingly. The shiphandler must weigh the amount and rate of turn to minimize slamming or pounding when turning into the wind, and rolling when turning away from the wind. Each ship motion imparts key information to the shiphandler. For instance, a long-hanging roll implies a loss of stability in following seas, but might be interpreted by an inexperienced shiphandler as an improvement on how the ship is riding. Avoiding a roll event may be as simple as altering course to ensure the period of encounter is as different as possible from the ship's natural roll period, while in the same situation, changing speed alone will not correct for roll occurrence. [2] Here again, the opportunity to test these skills in a simulator allows the shiphandler to hone his "seaman's eye" and get an accurate assessment of what can and cannot be done safely, so that when faced with an actual emergency, appropriate decisions can be made.

Over the past several years, the authors have worked with the Operator Guidance and Training Working Group (OGTWG), part of Cooperative Research Navies (CRNAV), to help define heavy weather shiphandling training objectives for the Naval Watch Officer. In addition to basic shiphandling objectives already routinely contained in shiphandling curricula, the following recommended additions have been identified: better meteorological training; training on available decision aids; enhanced static, dynamic, and damaged stability training (including how to avoid/escape from hazardous situations, recognizing and understanding non-survivable conditions, and consequences of damage or system failures in heavy weather); and discussions/assignments on heavy weather stability. Several workshops have been held over the years using full mission bridge simulators with heavy weather simulation capability. During these workshops, a number of simulator scenarios were tested to help develop these recommendations. Additional benefit can also be gained by using a full-mission shiphandling simulator with enhanced heavy weather rendering and ship capsize modeling, and (if possible) by incorporating a classroom physics-based model simulator with an interface that can support changing factors such as course, speed, KG, wave height, etc.

One key advantage of adding simulator training is that it allows a scenario to be replayed (multiple times if desired) and the operator to practice different mitigation techniques as environmental conditions change. If a "bad" decision is made, the consequences should be clearly apparent, and the operator can try again and experience the results from a different set of shiphandling maneuvers. Repetition can progressively enhance the degree of training transfer, while the risk of transfer failure is reduced (Foxon, M.; 1993). The trainee can also dissect the actions taken to better understand when naval architectural limits are reached and resulting damage can be anticipated. This type of training experience can provide lasting impressions on trainees, and can also facilitate development of a shiphandling "fault tree" specific to each ship type.

Training Proficiency

One of the main issues with any type of proficiency is the rate at which it decays when it is not used. Higher order cognitive skills and team behaviors (such as shiphandling in heavy weather) are extremely perishable (Cannon-Bowers, J. A., Burns, J. J., Salas, E., and Pruitt, J. S.; 1998). The infrequency with which most shiphandlers have to face severe weather puts them at risk of having a much lower proficiency level than would be desired when

[2] *Revised Guidance to the Master for Avoiding Dangerous Situations in Adverse Weather and Sea Conditions*. Ref. T1/2.04 (11 January 2007). MSC.1/Circ. 1228.

confronted by those conditions. Today, maritime organizations (including navies) are increasingly turning to simulation tools as a means of providing required training to watch officer and bridge personnel in order to meet qualification requirements.

The effectiveness of training transfer is directly linked to how well training devices duplicate the actual environment (e.g., simulation fidelity).[3] Simulators have long been used in the aviation world as a principal (and economical) form of training. Airlines have been able to amortize the cost of a simulator in less than two years. For instance, Boeing 767 aircraft full flight simulator training costs approximately $400 per hour, while actual aircraft training time costs between $7000 and $8000 per hour (Thompson, T. N.; Carroll, M. B.; and Deaton, J. E.; 2009). Simulator use has also increased significantly over the past 20+ years for shiphandling, though primarily for such tasks as open water and harbor maneuvering, man overboard practice, and for naval vessels, steaming in formation, and special evolutions. Shiphandling simulation also has to incorporate the element of motion in a seaway, which is difficult to accurately model in higher sea state conditions. Recent improvements in software coding capabilities are redefining the limits of shiphandling training possibilities. Shiphandling simulators are beginning to have the technical capacity to extend their training capabilities from providing traditional calm water/low sea state and restricted waters maneuvering to presenting highly realistic heavy weather scenarios, resulting in improved knowledge and effectiveness under the most severe circumstances. This is especially critical as, in many contemporary instances, actual time afloat may represent proportionately less of a mariner’s total career. Consequently, the integration of a heavy weather shiphandling training capability into an overall maritime training program should be approached carefully, with a structured set of goals.

Simulator Fidelity

Simulation quality and human capabilities are critical factors in training effectiveness and efficiency. Simulator fidelity is potentially the most important aspect of simulator quality, and is also a critical factor in the cost effectiveness of simulation device design. It is normally understood to mean the degree to which the simulation replicates the actual environment, and there is a strong link between it and transfer of training (Liu, D., Macchiarella, N. D., and Vincenzi, D. A.; 2009). There are two principal aspects of simulator fidelity – physical fidelity (the replication of sights, sounds, and the “feel” of the actual environment), and psychological or cognitive fidelity (the replication of such things as communication, situational awareness, etc.), and these aspects have subsets which are not mutually exclusive, but rather, have a large degree of overlap. These include: visual and auditory fidelity (how well the simulation replicates known visual and auditory stimuli of the actual environment); equipment fidelity (how well the simulator replicates the actual equipment/systems the operator is expected to use); motion fidelity (how well motion cues experienced in the actual environment are replicated); task fidelity (the tasks and maneuvers executed by the user); and functional fidelity (how the device functions and provides realistic stimuli in the simulated environment). All of these must be considered in the overall simulation solution equation.

Shiphandling simulators have become quite good at representing most of these aspects of simulation. Technology has significantly enhanced visual fidelity in recent years. For instance, harbors now used in simulators are extremely realistic, with recognizable structures, piers, buoys, lights, navigational aids, etc. Environmental factors such as fog, low light levels, rain, lightning, thunder, and

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[3] Allen, (1986); Alessi, (1988); Hays and Singer, (1989); Gross, et al, (1999).

other characteristics can be added into the simulation, as can other vessels, numerous types of aircraft, small boats, and even birds and people in the water. Ship sounds, such as whistles and alarms, and communications equipment have been accurately replicated. Equipment fidelity, the extent to which a simulator can emulate or replicate the equipment being used, which includes all the software and hardware components of the system (Zhang, B.; 1993), can prove to be more of an issue for some ship classes that have unique bridge or engineering equipments, but most bridge equipments are of sufficient similarity to provide adequate training transfer for routine evolutions. However, portraying realistic sea conditions in higher sea states has proven to be a challenge.

Heavy Weather Simulator Models

To provide accurate seaway representations, a heavy weather shiphandling simulator must be driven by a physics-based hydrodynamics model (such as FREDYN) which is capable of providing non-linear, six degree of freedom motion in the large amplitude motions resulting from exposure in a severe seaway. A principal requirement for the hydrodynamics model is that it should be executable in time domain at a time scale that is at least as fast as real time and validated for use in training. Development of numeric codes providing this capability is an evolving science. The non-linearities associated with seakeeping computations are associated with viscosity, pressure, free surface, and body geometry. Currently, fully non-linear codes are not suitable for integration into the simulator environment because excessively long execution times are in excess of real time. Some codes have adopted short cuts by blending linear and non-linear theories. These blended codes are significantly faster and are capable of engineering accuracy (Beck, R. F., and Reed, A. M.; 2001). The code used also must be capable of fidelity that can replicate behavior characteristics for specific ship classes in the heavy weather environment. These general characteristics are a functional requirement of the previously identified training objectives.

Numerous commercial shiphandling simulation tools are available. Determination of the appropriateness of any simulator should include the verification, validation, and accreditation (VV&A) of the model used to run the simulation. The VV&A of the model is a necessity, and should include conceptual validation, design verification, code verification, results validation, and accreditation, which must be specific for the application. Specific intended uses of the tool should be clearly defined as part of this process. This will help ensure that desired training transfer can actually be achieved by the simulator.

OPERATOR GUIDANCE

There are several commercially available systems designed to provide operator guidance on ship motions and limitations, give warnings of impending difficulties, and serve as decision aids in situations such as extreme roll motions/parametric rolling, bow impact, green seas on deck, and broaching. These are real-time systems that display the ship's position in relation to pre-calculated sea-keeping operational risk limits. Some can also be interfaced with weather routing systems to predict ship motions based on forecasted weather under different motion parameters, and define the operational limits for route planning, as well as recommend tracks that avoid areas with forecasted excessive motion.

The emergence of these new operator guidance systems also supports the inclusion of heavy weather shiphandling into training curricula. These capabilities offer shiphandlers a tool that can automatically calculate safe operating environments and provide course and speed options to minimize hazards based on real-time wind and sea data. This can improve operational safety and provide an enhanced capability to continue a ship's mission in certain situations. More importantly, these operator guidance tools can incorporate actual hull form data for unique ship types and help prevent catastrophic consequences for an operator who does not have a significant experiential base in that platform. When coupled with physics-based ship motion simulator training opportunities, this decision aid can significantly enhance the overall training experience, allowing the operator to test the limits of the ship and "experience" the consequences of erroneous shiphandling decisions, even taking the ship to the point of capsizing to better understand the dynamics of each shiphandling decision.

CONCLUSION

Current technology advances are beginning to offer the ability to integrate multiple simulators, which create even greater "virtual reality" potential for heavy weather training. Simulation of various casualties can provide shiphandlers with training opportunities to better prepare them for decision-making under duress. Decision aids in the form of operator guidance capabilities are becoming more refined, and combining these capabilities with heavy weather shiphandling training could significantly reduce the incidence of mishaps in heavy weather.

As we look to the future, the potential for heavy weather simulator training is extremely encouraging, and this valuable resource should be a standard part of all shiphandling training. Simulators are on the cusp of providing highly realistic heavy weather scenarios, resulting in vastly improved knowledge and effectiveness under the most severe circumstances.

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