# PRACTICAL EXPERIENCE AND OPERATIONAL REQUIREMENTS FOR ON-BOARD RISK MANAGEMENT UNDER MARGINAL STABILITY CONDITIONS

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**SUMMARY**

This paper focuses on the second part of the workshop title, the operational safety of ships. Using experience gained from three tours aboard a U.S. Coast Guard 270-foot medium endurance cutter, including a tour as commanding officer, the author investigates their employment. This ship class shares many of their operational handling characteristics of other corvette-sized ships. While one of the most stable platforms from a damage control perspective, the 270-foot cutters are described by Jane's Fighting Ships as "Very lively in heavy seas because the length to beam ratio is unusually small for ships required to operate in Atlantic conditions." A fairly shallow draft also contributes to this "liveliness." This behavior extends into lower sea states where ships of this tonnage should be expected to operate effectively, creating shiphandling challenges for operators.

These challenges can be mitigated by inherent and ancillary design considerations. When the design process requires ships with high beam width and low length along the waterline, efforts must be made to increase not only static stability but also those stability factors that contribute to evolutions conducted in dynamic realms. Configuration of boat decks and flight decks can be designed for reduced crew and equipment motion, exposure to the elements and the dangers they present. Operators must understand remaining limitations and the operational envelope these limitations dictate.

**NOMENCLATURE**

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| C4ISR | Command, Control, Communications, Computers, Intelligence, Surveillance, Reconnaissance |
| CI/BI | Capsize and Broach Indices |
| CPB | Coastal Patrol Boat |
| DC | Damage Control |
| DDS | Design Data Sheet |
| HEC | High Endurance Cutter |
| HIFR | Helicopter In Flight Refueling |
| MEC | Medium Endurance Cutter |
| MIF | Motion Induced Fatigue |
| PQS | Personnel Qualifications Procedures |
| RHIB | Rigid Hull Inflatable Boat |
| VERT-REP | Vertical Replenishment |

## 1. INTRODUCTION

Ship operators applaud recent calls for greater communication and cooperation between ship designers and operators. Recognition of the need for close alignment between the two communities during all phases of ship design and service life promises greater ship utility and safer operation. Designers can provide ship commanders and operators better information on how best to employ ships, how best to identify and avoid risk, and how best to mitigate risks that have been identified and determined to be required to be taken. Operators best understand effects of marginal stability situations on operations. Sharing this understanding provides designers with important knowledge.

Ship commanding officers steadfastly seek to minimize exposure to conditions that imperil their vessels. Emergencies or operational requirements may force them towards a point where there is potential for diminished stability and beyond that point, disaster. They are therefore most interested in gaining as much reserve static and dynamic stability as can be afforded. These situations, fortunately, are rare. More common are conditions and situations when a commander desires a more stable platform from which to conduct operations, albeit sometimes under fairly challenging conditions. This short discussion focuses on employment of undamaged ships, steps needed to reduce the potential for loss of their stability, and possible courses in the design of new ships that afford a crew a more stable platform from which to conduct their business.

As an historical aside, ship designers and engineers have been motivated by this last goal of providing more stable platforms—derived mainly by the need for stable gun decks. In one instance, this goal was pursued through what now appears to be a somewhat unorthodox approach. The German engineer Otto Schlick and the American inventor Elmer Sperry used gyroscopes to stabilize ships, although not through the types of systems one might think of today. In 1912, the U.S. Navy installed a Sperry gyro aboard the 433-ton USS *Worden*. The gyro wheel itself weighed two tons and was 50 inches in diameter. The spinning of this massive gyroscope effectively neutralized rolls, decreasing them from 30 degrees to six. The forces it created, however, exerted excessive strain on the ship's structure. Later, in World War I the U.S. Navy installed another gyro weighing 25 tons in a 10,000-ton ship to achieve the same effect. It was only following the conclusion of WWI that engineers turned to installing smaller gyros linked to stabilizing fins (Hughes 106-110).

### 1.1 U.S. COAST GUARD SHIPS

The U.S. Coast Guard operates several classes of ocean-going vessels. The largest range from three polar ice breakers to twelve 378-foot 3,200 LT *Hamilton* class ships, equivalent to frigates in size and mission, and designated by the U.S. Coast Guard as High Endurance cutters (HECs). There are two classes of Medium Endurance Cutters" (MECs): thirteen 270-foot, 1800 LT *Bear* class and eighteen 210-foot 1,000 LT *Reliance* class cutters. (N.B. "Cutter" is the official and traditional nomenclature for U.S. Coast Guard ships. It hearkens back to the first cutter-rigged ships in the Service.) This paper concentrates on the *Bear* class that shares many operational handling characteristics of other corvette-sized ships. While one of the most stable platforms from a damage control perspective, the 270-foot cutters are described by Jane's Fighting Ships as "Very lively in heavy seas because the length to beam ratio is unusually small for ships required to operate in Atlantic conditions." A fairly shallow draft (14.5 ft) also contributes to this "liveliness." This behavior extends into lower sea states where ships of this tonnage should be expected to operate effectively, creating shiphandling challenges for operators.

Many of the negative aspects of the 270-foot MEC seakeeping characteristics are attributable to cost-driven compromises made during its design cycle. Attention to the results of these compromises along with reinforcement of the need to strengthen the dialogue between designers and users should be emphasized within the U.S. Coast Guard ship community. This is especially so now since the Service is in the early stages of selecting an integrated system of ships, aircraft, and support capabilities, the Deepwater Capability Replacement Program. The envisioned $15 billion 20-year program seeks to renovate, modernize, and/or replace the Coast Guard's entire inventory of ships and planes with an integrated system of surface, air, C4ISR, and logistics capabilities. The expense and expanse of the program emphasizes the need to ensure the best possible designs are selected, developed, and introduced. This, in turn, punctuates the call for greater cooperation between engineers and operators.

## 2. OPERATIONAL AREAS OF CONCERN FOR STABILITY

With the exception of polar icebreakers, Coast Guard ships of the ocean-going classes are armed and have military, law enforcement, and search and rescue responsibilities, as well as others. They are most often involved in one of three types of operations. These are transit, helicopter operations, and boat operations. Transit includes traveling from homeport to operational areas and between assigned areas of operation. Helicopter operations include launch and recovery, Vertical Replenishment (VERTREP) and Helicopter In-Flight Refueling (HIFR). While the first two are limited to helicopters the ship is certified to carry, the latter two can be conducted with nearly any size of properly equipped helicopter. These last two operations can also be conducted when flight deck motion parameters for embarkable helicopters have been exceeded. Boat operations include launch, recovery, and alongside evolutions.

Although conditions that affect stability, and therefore impinge on operations, are not limited to weather, it is the effect of winds, seas, and icing that most often and most severely hamper operations. A second consideration is loading. Most often this is thought of in terms of new equipment, stores, fuel and ballast. More prescient planners and managers also consider lifetime weight growth. These all require careful consideration by operators and particularly in the last instance, by decision and policy makers.

There is, however, an operational concern as well. The U.S. Coast Guard finds itself regularly called upon to transfer to its ships large numbers of passengers. Examples of large groups that might be taken aboard are survivors of disasters at sea, humanitarian evacuees, and migrants. Numbers of people taken on can easily exceed three hundred. Like other warships, Coast Guard cutters have very limited passenger spaces. For the most part, extra personnel are lodged on the level immediately above the main deck. On 378-foot HECs and 270-foot MECs, as many of these people as possible are afforded the helicopter hangar with spillover onto the flight deck (that is, if the ship is close enough to shore or another ship to transfer the helicopter. On a slightly smaller class of ship, the 210-foot medium endurance cutter, tarps and awnings are rigged over the forecastle and flight deck to afford some protection from the elements. The numbers of people, the accoutrements required to provide sanitation and protection, and their location above the main deck create a significant negative impact on stability. The current stability criteria used by the U.S. Coast Guard and U.S. Navy, Design Data Sheet (DDS) 079-01, accounts for this to some degree in its criteria regarding the crowding of passengers to one side of the ship. Doctrine and operational guidance covering crowd control seek to mitigate the effect by limiting movement and in particular surges of large groups of people across the deck, but the concern remains.

## 2.1 HEAVY WEATHER AVOIDANCE AND SURVIVAL

One of the most critical transit operations for small combatants is storm avoidance. Generally speaking, traditionally hulled small combatants of the corvette and frigate size are speed limited. When it comes to heavy weather operations, ship commanders face an overwhelming dearth of advice. A standard text for U.S. Coast Guard and Navy shiphandling, Crenshaw's *Naval Shiphandling*, states that for ships in rough seas, but not experiencing hurricane strength winds, it is the seas that most effect a ship and it is rolling that should first be addressed. The advice offered is to generally run with the seas at a speed a few knots higher or lower than the speed of the waves (Crenshaw 1975, 147). In mountainous seas associated with hurricanes and typhoons the guidance is to maintain power, buoyancy, and stability—worthwhile goals in all cases. In regard to shiphandling, the author offers arguments for and against running with the seas, heading into them, and doing nothing—that is, stopping the engines and lying to. For destroyer types, this last advice is discounted while its application for merchant hulls is given due consideration. The previous advice to run down seas is applied to combatants caught in all but the most severe hurricane weather where direction is shifted to keeping the bow heading into the seas.

So, for those heavy weather conditions with the exception of the most severe hurricane conditions, Crenshaw offers the general guidance of running with the seas. What the text fails to cover is how to avoid the worst conditions. For that, another standard text, *Knight's Modern Seamanship*, offers specific guidance for ships caught within the circulation of a cyclone. A ship directly ahead of the storm's center should bring the wind on the starboard quarter and make best speed. A ship in the "navigable semicircle" (in the Northern hemisphere, the semicircle to the left of the storm path) is advised to put the wind broad on the starboard quarter and make best speed. A vessel caught in the "dangerous semicircle" is encouraged to bring the wind onto the starboard bow and make as much headway as possible (Noel 1989, 499). Since cyclonic winds curve in towards a storm's center, this guidance places waves on the port quarter for the first two situations and on the starboard quarter for the third.

A summary of the heavy weather advice offered the mariner can be stated as "except for the worst case (caught in the heart of a hurricane), a ship should place the seas on a quarter." Unfortunately, it is with the seas on the stern or quartering that yields the greatest risk for broaching and capsizing.

## 2.2 HEAVY WEATHER OPERATIONS

Not all storms may be avoided. This can be due to lack of anticipatory information, lack of adequate speed or seaway to avoid a storm track, or mission requirements. While purposeful exposure of one's ship to potentially fatal weather should be avoided at nearly all costs, mission requirements may force a commander into a decision balancing potential severe repercussions at the hand of weather with a compelling need to attempt a mission. Inaccurate forecasting, impartial information regarding location and on scene weather, or other similar less-than-perfectly known factors, as well as mission exigencies and humanitarian concerns may force a ship commander into areas where winds and seas imperil a ship. Search and rescue is a major mission area for the U.S. Coast Guard and one that often forces this kind of calculus.

Since heavy and extreme weather conditions present one of the greatest threats to a ship's stability and since avoidance and mitigation requires the ship to present an aspect that is less than optimal, one would think that there would be a fairly well-developed body of information available to the mariner on how to best handle a ship in these conditions. Unfortunately, with the exception of the avoidance advice described above, there is very little. One group of authors advocates the development of aids such as polar diagrams, capsize and broach indices to provide ship operators with risk management information (Alman, *et al* n.d., 21). Ship commanders endorse this whole-heartedly.

## 2.3 OPERATIONS AT ENVIRONMENTAL LIMITS

*Bear* class cutters are stationed along the east coast of the United States. They routinely operate from the Northwest Atlantic to the Caribbean. Members of the class have also operated on the Pacific coast from Alaska to the Equator. Class members have circumnavigated South America and for the last five years a 270-foot cutter has also deployed to the Baltic, Mediterranean, and in one case, the Black Seas.

With 270-foot MECs ranging across large expanses of the oceans, encountering severe weather is inevitable. The prudent mariner will always attempt to avoid the path of large storms and hurricanes. If in a port in the path of a hurricane, ships will routinely sortie for evasion. When underway, and given the ability of today's meteorologists to forecast potential events well in advance, ships will divert away from the forecasted path of an approaching hurricane. However, for the reasons stated above, this is not always possible. Multiple reasons can appear to conspire, leaving the commander with fewer options than one might expect. For example, 270-foot MECs have a maximum speed of 19.5 knots under optimal conditions. In the seas that one may expect near an approaching hurricane, the speed available to the ship commander is much less, limiting the angle of escape courses from the path of the oncoming storm. Proximity to shore may further reduce options. In some circumstances, the best alternative to running from the storm is seeking safe haven. This author served aboard a *Bear* class cutter operating in the Caribbean basin before the path of Hurricane Gilbert in September 1988. This Category 5 hurricane had winds associated with it that were measured as high as 160 knots. The speed of the storm's westward advancement compared with the ship's maximum available speed coupled with its location in the central Caribbean closed off avoidance options. The ship sought shelter at U.S. Naval Base Guantanamo Bay, Cuba. Upon arrival at the mouth of the harbor the crew found it disconcerting to pass the larger (and faster) U.S. Navy ships heading outbound for hurricane evasion. Injury was added to insult when, having berthed and secured for the anticipated meteorological assault, the ship was recalled into the hurricane to assist a U.S. ocean-going tugboat on fire and drifting into Cuban waters. During the height of the Cold War, to prevent the potential political fallout of having a U.S. registered ship *in extremis* in Cuban waters, hazarding the cutter was apparently deemed a necessary risk. That the ship was able to rendezvous with, take into tow, and safely rescue the tug is a testament to the capabilities of the *Bear* class designers, builders, and crew.

Mission requirements that force operations in adverse weather conditions exacerbate other factors that compound difficulties regarding stability. A ship that is in no danger of capsize can still be—in terms of mission effectiveness and crew comfort—very unstable. Helicopter and boat operations are both severely hampered by deck motion. Likewise, underway replenishment can be very challenging for a ship displaying a lively ride while alongside a large supply ship. While inclusion of active fin stabilization and other design features of 270-foot MECs mitigate some of these operational challenges, particularly in the roll dimension, pitch limitations often make helicopter and boat launching difficult, if not impossible. Slow speed alongside maneuvers such as towing and personal and small boat recovery present even greater challenges since they often must occur at velocities below that at which fins are effective. An important difference lies between the helicopter and boat operations, however, that again points to the need for better quantified information. U.S. Coast Guard shipboard helicopter operations are governed by well-defined motion limits spelled out in the *Helicopter Operational Procedures Manual* (COMDTINST M3710.2A). This publication sets pitch and roll limits for the conduct of launch and recovery operations. These limits are fairly severe and all the more so for nighttime evolutions. To illustrate, nighttime pitch limits for the HH-60J Jayhawk helicopter embarked on a 270-foot MEC are +/- 1°. Given the very short bow of a 270-foot MEC and the relatively short length overall, this is a very difficult parameter within which to remain. It effectively denies a commander use of this class of helicopter at night in all but sheltered waters.

While some ship commanders may view helicopter operational limits as overly restrictive, shipboard boat operations suffer from an opposite situation. There is little empirically based information available advising commanding officers on how to conduct boat operations in marginal conditions. Likewise, there are few published guidelines suggesting what conditions operations should be suspended. Anecdotal information passed along either directly from commander to commander, or in after-action reports, or in findings of mishap investigations serve these purposes.

Design also affects boat operations. Most oceangoing U.S. Coast Guard cutters have boat decks on the level above the main deck, approximately amidships. On the 270-foot MEC the boat deck for the 26-foot motor surf boat is located there while a 7-meter RHIB is launched from a single-arm davit located on the main deck on the fan tail. Both positions afford advantages and disadvantages. The amidships placement allows for an easier establishment of a weather lee for the boat and boat deck during hoisting. However, the height of these locations exposes the boat and crew to the uncomfortable condition of swinging on the falls for a greater time and at a greater height. 378-foot HECs and 210-foot MECs can somewhat ameliorate this situation through the use of frapping lines controlled from the main deck air castle directly below. The 270-foot MEC is slab sided and therefore cannot avail itself of this technique.

On the 270-foot MEC, the RHIB's location on the fantail necessitates the use of a quartering or following sea for launch and recovery. This, again, subjects the ship to a less than optimal ride. Most 270-foot commanding officers prefer to adjust the ship's speed to slightly faster than the prevailing wave speed so as to present the RHIB with a bow-on sea and to ensure the active fin stabilizers are effective. The speed required can often be considerable.

One further class of U.S. Coast Guard ship and its boat deck need be considered. The relatively new 87-foot Coastal Patrol Boat (CPB) is equipped with a stern launching system for its RHIB. This is the first experience of this type of system for the U.S. Coast Guard. Other navies have employed the system successfully. But there have been several mishaps on U.S. Coast Guard cutters associated with the launching system. One can be fairly certain that a contributing factor to these accidents was a lack of experience in launching from astern coupled with a lack of information on how these ships should be operated to afford the most stable platform from which to conduct small boat operations. This again leads to a call for more knowledge to the operators.

### 2.4 PERCEPTION

A large area of disparity exists between observers regarding conditions and their effects. Members of ship's company including those with meteorological training offer often largely divergent estimates of sea state. Wave height estimates are subject to debate. Identification of the direction of movement of the primary sea waves and swells and the detection of secondary but significant wave systems compound the range of opinions. The lack of consensus extends to the primary stations involved in flight deck and boat deck evolutions. The perceptions of bridge team, flight/boat deck members, and helicopter/boat crews vary widely with the degree of variability proportionate to the severity of the weather. What can be perceived as acceptable conditions for one station may be seen as intolerable to others. Instrumented studies verify not uncommon occurrences of vertical accelerations in excess of 0.3g and in at least one instance, 0.4g measured at the pilothouse of a 270-foot MEC (Minnick, Cleary and Sheinberg 1999, 12). The pilothouses on the class of ship are fairly high (height of eye of approximately 45 feet) and fairly far forward (approximately 50 feet from the bow). Motion at the flight or boat decks can be perceived as less than that felt by the bridge crew. On the other hand, with the RHIB boat deck on the fan tail and in following seas, the perception of wave height can be much greater than that perceived by the bridge. This points to the need to develop instrumentation beyond the inclinometer to better inform ship commanders of actual ship motion at important stations and equipment or aids to allow more quantifiable measurement of sea states. The study cited above demonstrated the ability to capture quantifiably the acceleration limits that define the "go/no-go" criterion for boat operations on this class of vessel. This was a 0.2g vertical acceleration, experienced either in the pilothouse or at a boat station. The data gathered must be able to be easily injected in to operational risk management assessment tools that factor the various elements beyond environmental conditions to yield a more comprehensive assessment before any go/no-go decision is made.

Another aspect of ship motion that must be addressed in more quantifiable terms is the effect of ship motion on the crew. Modern seasickness medication is a boon to today's cuttermen, but it is not a panacea. The medication attenuates but does not alleviate the effects of seasickness. Also, it does not prevent—and can aggravate—Motion Induced Fatigue (MIF). The study cited above also compared MIF between the crews of a 378-HEC and 270-MEC operating side-by-side in the Bering Sea. The study found significant differences in the severity of ship movement (for example, a 30-40 percent greater vertical acceleration on the 270-foot MEC) but no differences in reported sea sickness (although there was a significantly higher incidence of the use of anti-seasickness medication on the 270-foot MEC). One indicator of fatigue, the time to complete tasks, showed a significant difference between the two crews with 29 percent fewer of the crew of the 270-foot MEC reporting an ability to complete tasks in "normal time" (Minnick, Cleary, and Sheinberg 1999, 13). In interpreting this self-report data, one should not discount the possibility of natural competition between the crews as a potential source for skewing the data. *Bravado* and *esprit de corps* combined with the potential for the crews to perceive the comparison of two ships of different classes as a competition might create a reluctance to accurately report MIF. That the smaller ship was brought into the operational area of the larger one to see how it might perform in that environment might motivate its crew to under-report its MIF to a greater degree than for the 378-HEC's. Experience strongly indicate that MIF can be the source of serious degradation in crew and cutter performance.

The current drive to reduce ship personnel allowances further emphasizes personnel and equipment safety issues. This was a major consideration for the selection of the 87-foot CPB's stern launch system that was designed to require only one person to conduct launch and recovery of the small boat and its crew. Reduced crew sizes are but one dimension of the difficulty operating a ship in moderate to heavy seas and creating crew safety and fatigue concerns. Shrinking fleets and increased responsibilities within navies and coast guards around the globe place greater burdens on ships and crews, increasing their exposure to less-than-optimal operating conditions. "Human stability curves" addressing ship motion over time and its effects on personnel need to be developed and employed.

## 3. TRAINING AND EDUCATION

Once a ship's design cycle is complete and it is introduced, responsibility for its employment shifts towards (but not solely upon) the operators. Engineers must continue to be part of the employment team with responsibility for ensuring proper configuration management and guarding against inevitable weight growth and their effects on operational stability. For operators and their leadership, responsibilities include ensuring commanders and crew are familiar with ship characteristics and limitations. To date in the U.S. Coast

Guard, this has been done through a semi-formal personnel qualification standards (PQS) and damage control (DC) training program. The primary sources of instruction for these programs at the unit level are fellow crewmembers, supported by pipeline training, a smattering of recurrent classroom courses, and ship training availabilities. These provide a generally broad but shallow knowledge of stability issues for all but the Engineer Officer and the Damage Control Assistant.

Deck officers receive very little formal classroom and practical hands-on experience related to operational stability. In the past, sources of first-hand experiences were limited to sea stories told by those who survived, literally or figuratively, operations conducted at stability extremes. With the availability of simulators ranging from desktop personal computer applications to full-motion bridge simulators, deck officers can experience the effects of extreme stability situations with realistic fidelity. Such training should be mandated for senior enlisted and officer crew members.

## 4. CONCLUSION

The Coast Guard has been employing 270-foot MECs since the mid-1980s. With over fifteen years of experience with this class, these ships have ably demonstrated their capability. They have also presented areas where ships of this size may be improved. Lessons learned from these areas afford U.S. Coast Guard Deepwater designers and the designers of other naval surface ships opportunities to design and build ships that are safer and more capable across a greater range of environmental and operational spectra. The first lesson is to concentrate energy on designing ships that are inherently more tolerant of heavy weather and the motion imparted on the ship by it. This includes positioning important operational stations at places that minimize vertical and transfer acceleration, and exposure of equipment and crew. The second lesson is the requirement to develop onboard instrumentation to capture a greater knowledge of ship's motion. This information should then be provided to the commander during operation of the vessel in a usable manner like polar plots and capsize/broaching index (CI/BI) information. A third lesson is the need to establish continuous attention to stability and stable platform considerations during modeling and simulation, testing and evaluation, introduction, and operational lifetime stages to include operator education, training, and operational guidelines.

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