



Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

Davies Ojo Ajewole¹, Ademola Oluwabusola Habib²

¹Geography and Environmental management, University of Ilorin, Kwara State

<https://orcid.org/0009-0007-3577-3467>

²Nigerian Institute for Marine and Oceanography Research (NIOMR)

<https://orcid.org/0009-0008-8910-5488>

Published Online:

06 March 2026

Article DOI:

<https://doi.org/10.55677/CRB/I3-01-CRB2026>

License:

This is an open access article under the CC

BY 4.0 license:

<https://creativecommons.org/licenses/by/4.0/>

ABSTRACT: Ship maneuverability remains a cornerstone of maritime safety and operational efficiency, particularly under the influence of environmental stressors such as wind and ocean currents. This study presents a comprehensive analysis of how these forces, individually and in combination, impact vessel handling across diverse operational contexts, with focused case studies from Nigerian ports: Lagos (Apapa), Bonny River, and Calabar. Utilizing a mixed-methods approach, including literature synthesis, incident analysis, expert survey (n=59), and theoretical modelling, the research identifies critical vulnerabilities in current navigational practices and evaluates the efficacy of technological and operational countermeasures. Findings reveal that crosswinds exceeding 25knots and tidal currents above 3knots significantly compromise lateral control, especially for vessels with high windage areas (e.g., container ships) or deep drafts (e.g., tankers). The compounding effect of simultaneous wind and current forces increases navigational risk by up to 70% in confined channels. While tug assistance and pilot expertise remain highly effective (rated 4.7/5), adoption of advanced technologies like Dynamic Positioning Systems (DPS) remains low (12% of surveyed vessels). Real-time environmental data integration is inconsistently available (41%), and simulation-based training is underutilized (29%). The study proposes a three-pillar framework for improvement: (i) Enhanced crew training using scenario-based simulators, (ii) Strategic deployment of DPS and AI-enhanced predictive routing tools, and (iii) Infrastructure and policy upgrades in high-risk ports. Recommendations include standardized “green window” scheduling during slack tides, mandatory environmental briefings pre-berthing, and regulatory incentives for DPS adoption. This research contributes actionable, regionally contextualized insights to bridge the gap between theoretical hydrodynamics and real-world ship handling, supporting global efforts to enhance maritime resilience in an era of climate volatility and increasing vessel scale.

KEY WORDS: Ship maneuverability, wind forces, ocean currents, dynamic positioning, Nigerian ports, maritime safety, pivot point, simulation training, environmental navigation, case study analysis.

Cite the Article: Ajewole, D.O., Habib, A.O. (2026). *Operational Vulnerability of Large Vessels under Combined Wind-Current conditions in Port operations: Tugboats, DPS and Simulation training*. *Current Research Bulletin*, 3(3), 44-51.

<https://doi.org/10.55677/CRB/I3-01-CRB2026>

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

1. INTRODUCTION

Maritime transport facilitates over 80% of global trade, making the safe and efficient maneuverability of ships not just an operational concern, but a global economic imperative (UNCTAD, 2024). As vessels grow larger with Ultra Large Container Ships (ULCS) now exceeding 400 meters, the aerodynamic and hydrodynamic forces exerted by wind and currents pose increasingly complex challenges to navigation, particularly during critical low-speed operations such as docking, undocking, and transiting narrow channels. The grounding of the 'Ever Given' in the Suez Canal in 2021, attributed to 40-knot crosswinds and inadequate real-time response, cost the global economy an estimated \$9 billion per day and underscored the catastrophic potential of mismanaged environmental forces (Kishk & Kholeif, 2022).

Yet, while such high-profile incidents capture headlines, daily near-misses in ports like Lagos and Bonny remain underreported, creating a false sense of security. This study addresses a critical gap: most existing research examines wind or currents in isolation, often in idealized or open-ocean conditions. Few studies analyze their combined, real-time impact in developing maritime regions with unique environmental and infrastructural constraints such as Nigeria's Harmattan winds or Bonny River's 5-knot tidal surges. The objective of this study is to quantify the individual and combined impacts of wind and currents on ship maneuverability across vessel types; analyze real-world incidents in Nigerian waters to identify systemic vulnerabilities and successful mitigation strategies; and evaluate the effectiveness of current technological (DPS, ECDIS, AIS) and operational (tugs, pilotage, training) countermeasures. The study focuses on commercial vessels operating in Nigerian coastal and port environments. Data is drawn from NPA incident logs, expert surveys, and academic literature between 2000 and 2024, using the triangulation methods to ensure robust and actionable insights.

2. LITERATURE REVIEW

Ship maneuverability is fundamentally governed by Newtonian mechanics; wherein external environmental forces interact with internal propulsion and control systems to influence vessel motion. Wind, an aerodynamic force, acts primarily on the vessel's above-water profile—including the superstructure, containers, and cranes. The magnitude of this aerodynamic force can be expressed as $F = \frac{1}{2} \rho_{air} V_{wind}^2 A_{exposed} C_d$ (Faltinsen, 2005). For instance, a 30-knot beam wind can generate lateral forces exceeding 50 tons on an Ultra Large Container Ship (ULCS). Similarly, currents, classified as hydrodynamic forces, act on the submerged hull, causing drift that can be estimated as $V_{current} \times \sin(\theta)$, where θ is the angle between the ship's heading and the current direction (Oltmann, 2013). Empirical evidence shows that a 4-knot cross-current can displace a Very Large Crude Carrier (VLCC) by over 100 meters in just five minutes.

The concept of the pivot point, the theoretical center of rotation of a vessel, is central to understanding maneuverability. This point is not fixed but shifts dynamically depending on vessel motion. When the vessel is stopped, the pivot point lies amidships; when making headway, it shifts forward to about one-quarter of the ship's length from the bow; and when making sternway, it moves aft by a similar proportion. Trim also significantly influences this dynamic: a stern-heavy vessel's pivot point tends to move further aft, increasing its susceptibility to wind from the forward quarters (Sailing Vessel Handling, 1999). The interaction between the pivot point (P) and the center of wind effort (W) is crucial, when misaligned, they create a turning lever that magnifies wind effects. For example, a beam wind acting on a vessel making headway (with P forward and W amidships) produces a strong moment that turns the bow into the wind.

Wind: The Invisible Hand

Wind remains one of the most persistent and unpredictable environmental forces affecting ship maneuverability. Crosswinds are particularly hazardous, causing lateral drift (leeway) and necessitating constant rudder corrections. Container ships and roll-on/roll-off (RoRo) vessels, due to their high windage areas, are especially vulnerable. Headwinds, on the other hand, reduce speed, increase fuel consumption, and may result in loss of steerage at low revolutions per minute (RPM). Conversely, tailwinds can cause overshoot during berthing and diminish rudder effectiveness. Gusts pose additional challenges, especially during low-speed maneuvers, as they can induce sudden and unpredictable yaw moments (Bowditch, 2017).

Currents: The Silent Push

Currents exert an equally critical influence, though their effects are often less visible. Tidal currents are predictable yet powerful, sometimes exceeding 5 knots during spring tides in locations like the Bonny River, thereby reducing rudder authority at low speeds (Dubbeldam, 2019). River currents are more variable, particularly around bends such as those in the Calabar River, leading to set and drift that complicate navigation. Ocean currents, while more stable, affect transoceanic voyage planning by influencing estimated time of arrival (ETA) and fuel efficiency, as exemplified by the Gulf Stream's impact on Atlantic crossings.

The Compounding Effect

The interaction between wind and current is non-linear and often counterintuitive. For example, a headwind combined with a following current can reduce water flow over the rudder, leading to a loss of steerage. Conversely, a tailwind with an opposing current may cause broaching, a sudden, uncontrolled turn that can endanger vessel stability. The combination of crosswind and cross-current presents the

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

greatest hazard, producing maximum lateral drift. Empirical research by Zheng and Zhang (2021) indicates that this interaction increases collision risk by approximately 3.2 times compared to single-force conditions.

Mitigation: Technology and Human Skill

Modern navigation integrates both technological systems and human expertise to mitigate environmental effects. Dynamic Positioning Systems (DPS), which use thrusters and GPS to maintain vessel position, are nearly 90% effective, though their implementation remains costly (Fossen, 2011). Bow and stern thrusters offer lateral control but are typically effective only at speeds below 5 knots. Tug assistance, while a traditional approach, remains the most reliable, with surveys indicating that 89% of mariners rate it as the most effective support during maneuvers. Nonetheless, the human factor remains dominant—studies suggest that between 75% and 96% of maritime incidents involve human error, often due to diminished situational awareness under stress (Rothblum, 2000). Simulation-based training programs have been shown to reduce such errors by up to 60%, highlighting the critical role of continuous skill development in ensuring safe and efficient ship handling.

METHODOLOGY

A mixed-methods design was adopted to ensure both triangulation and analytical depth in understanding the combined effects of wind and current on ship maneuverability. This approach integrated quantitative, qualitative, and theoretical components, thereby providing a comprehensive evaluation of the phenomena under investigation. The study began with an extensive literature review involving 47 peer-reviewed articles sourced from Scopus and Web of Science databases. The search focused on the keywords “ship maneuverability,” “wind-current interaction,” and “dynamic positioning.” These studies provided the theoretical and empirical foundation for analyzing external environmental influences and control mechanisms affecting ship handling.

Three detailed case studies were then examined to provide contextual insight into real-world maritime incidents. The first case, in Lagos (2019), involved a container ship that experienced a near-miss during a 35-knot Harmattan crosswind. The second, in Bonny River (2018), concerned a crude tanker that lost control under a 5-knot ebb tide. The third case, in Calabar (2019), analyzed a bulk carrier collision with a dolphin structure caused by combined wind and current effects. Data for these incidents were obtained from Nigerian Ports Authority (NPA) logs, Nigerian Maritime Administration and Safety Agency (NIMASA) reports, and pilot debriefs.

Additionally, an expert survey was conducted using a 22-question questionnaire distributed to 86 Nigerian maritime professionals, including captains, harbor pilots, and port operations managers. A total of 59 valid responses were received, representing a 68% response rate. This instrument was designed to capture both quantitative assessments (such as frequency of maneuvering difficulties) and qualitative insights (such as professional judgments on control effectiveness). The study also incorporated theoretical modeling to analyze pivot point dynamics and force interactions, drawing on established naval architecture principles (Newman, 1977; Faltinsen, 2005)

Quantitative data were analyzed using SPSS version 28, with descriptive statistics used to summarize response patterns and identify trends. Correlation analysis examined relationships such as wind speed versus reported maneuvering difficulty, while analysis of variance (ANOVA) tested differences in drift rates across vessel types. Qualitative data, including open-ended survey responses and detailed incident narratives, were subjected to thematic analysis using NVivo 14, enabling pattern recognition and interpretation of recurring concepts. Triangulation was employed to enhance validity by cross-verifying findings from the survey, case studies, and existing literature. This integrative approach ensured that the results were not only statistically sound but also practically relevant, reflecting real-world maritime dynamics.

RESULTS AND ANALYSIS

Survey results revealed that 83% of respondents reported “Frequent” or “Very Frequent” maneuvering difficulties when operating under crosswinds exceeding 25 knots. Quantitative analysis further showed that container ships experienced 2.3 times more lateral drift than tankers under identical conditions, a difference that was statistically significant at $p < 0.01$. The Lagos (2019) case provided a vivid example: a 35-knot beam wind induced an 8° leeway angle on a container vessel approaching berth. Timely tug intervention and the pilot’s situational awareness were instrumental in averting a collision. This incident underscores the critical role of both human expertise and mechanical assistance in counteracting environmental disturbances during ship maneuvers.

Table 1: Wind Impact by Vessel Type (Survey, n = 59)

Vessel Type	Avg. Drift Rate (M/MIN) @ 30knt	Most Affected Maneuver
Container Ship	4.2	Docking
Bulk Carrier	2.8	Channel Transit
Tanker	1.9	Anchoring
Passenger Ship	3.5	Turning

Source: Authors

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

The survey results reveal that vessel response to crosswinds varies significantly by type, reflecting differences in design geometry, windage area, and operational profile. At a standardized wind velocity of 30 knots, container ships exhibited the highest average drift rate of 4.2 meters per minute, with docking identified as the most affected maneuver. This finding aligns with the vessel’s large vertical surface area and high superstructure, which create a substantial aerodynamic profile. During docking operations, when speed is low and rudder effectiveness is reduced, even moderate crosswinds can induce significant leeway, necessitating constant corrective input from tugs and thrusters.

Bulk carriers, by contrast, recorded a moderate drift rate of 2.8 meters per minute, with channel transit identified as the maneuver most affected. Their relatively lower superstructure height and more compact hull form provide some protection against lateral forces. However, when transiting narrow channels, especially at reduced speed for navigational safety, the hydrodynamic balance becomes more delicate. In such confined waterways, wind-induced drift can push the vessel off its intended track, increasing the risk of grounding or bank contact.

Tankers displayed the lowest drift rate at 1.9 meters per minute, with anchoring operations most affected. The lower windage of tankers, owing to their flat deck design and absence of high superstructures, reduces aerodynamic exposure. Nevertheless, during anchoring, when propulsion is minimal and the ship’s head is not fully controlled, even mild crosswinds can cause the vessel to swing around its anchor, affecting positioning accuracy and potentially leading to anchor drag.

Passenger ships showed a relatively high drift rate of 3.5 meters per minute, with turning identified as the maneuver most influenced by wind. Their design, featuring multiple decks, high freeboard, and a broad beam, results in a considerable sail area that captures wind effectively. During turning maneuvers, especially at low speeds or in restricted waters, the large windage can induce asymmetric forces that compromise directional control and increase the risk of over- or under-turning.

Current Impact: Survey and Case Evidence

Survey responses indicated that tidal currents remain one of the most persistent navigational challenges in Nigerian inland and coastal waters. Specifically, 76% of pilots identified tidal currents as a “major challenge” in the Bonny River, where strong ebb and flood tides significantly influence ship handling, particularly during berthing and unberthing operations. The pilots noted that tidal strength and direction often vary unpredictably due to seasonal and meteorological influences, making precise control and planning essential for safe maneuvering.

The Bonny River case (2018) provides a clear illustration of this challenge. During an ebb tide of approximately 5 knots, a crude oil tanker experienced a 40% reduction in rudder effectiveness. The strong current decreased the relative water flow over the rudder, limiting the vessel’s steering response despite full helm input. The situation was successfully managed through the combined use of bow thrusters and tug assistance, which restored control and enabled the ship to maintain its intended heading. This case highlights the vulnerability of large vessels in high-current zones and underscores the necessity of auxiliary propulsion support under such conditions.

Similarly, the Calabar River case (2019) demonstrated the complex effects of current interaction in confined waterways. As a bulk carrier navigated a river bend, the cross-current was amplified by the channel’s curvature, resulting in an estimated 3-meter lateral set during final approach. This unanticipated drift complicated alignment with the berth and required prompt corrective action from the pilot and tug operators. The incident emphasizes how river geometry can intensify hydrodynamic forces, creating localized zones of strong set and drift that challenge even experienced navigators.

Table 2: Current Severity in Case Studies

Location	Max Current	Maneuver Affected	Key Mitigation
Bonny River	5.2 knots	Course-keeping	Tug + Bow Thruster
Calabar	3.8 knots	Docking	Slack Tide Timing
Lagos Channel	4.0 knots	Undocking	DPS (1 vessel)

Source: Authors

Table 2 highlights the varying severity and operational impact of current forces across three major Nigerian waterways, Bonny River, Calabar River, and Lagos Channel, illustrating how local hydrodynamic conditions influence maneuvering strategy and risk management. In the Bonny River, the maximum current velocity of 5.2 knots was recorded, making it the most hydrodynamically challenging of the three locations. The strong tidal flow significantly affected course-keeping, particularly during outbound transits where vessels were exposed to ebb currents. Under these conditions, the current exerts lateral and longitudinal forces that can overpower the rudder, resulting in yaw instability or unintentional deviation from the planned track. Effective mitigation in this case relied on the combined use of tugs and bow thrusters, which provided additional directional control and counter-thrust to offset the current’s influence. This response underscores the importance of mechanical assistance in maintaining control when natural

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

hydrodynamic forces exceed the ship's inherent maneuvering capacity.

The Calabar River, with a maximum current of 3.8 knots, presented its greatest challenges during docking operations. The river's bends and variable depth profile tend to amplify cross-current effects, causing set and drift as vessels approach berth. Pilots mitigated this risk primarily by timing maneuvers to coincide with slack tide, a period of minimal current velocity that provides a short but safer operational window for precision berthing. This practice demonstrates the role of tactical timing and situational awareness as cost-effective strategies for reducing current-related hazards without heavy reliance on additional power or external assistance.

In the Lagos Channel, the maximum current reached 4.0 knots, posing a notable risk during undocking operations, particularly for large container vessels. The strong outbound flow can accelerate vessel movement once lines are released, increasing the likelihood of unintended yaw or contact with adjacent structures. To mitigate this, one vessel employed a Dynamic Positioning System (DPS), which utilized thrusters and GPS feedback to maintain position and heading stability. Although effective, the deployment of DPS highlights the growing dependence on advanced technological solutions to supplement traditional pilotage in high-traffic or hydrodynamically complex ports.

Combined Wind-Current Effects

Survey findings revealed that the interaction of wind and current represents the most challenging environmental condition for ship maneuvering in Nigerian waters. An overwhelming 91% of respondents reported encountering combined wind-current forces frequently, indicating that such scenarios are a routine aspect of port and channel operations. The simultaneous action of aerodynamic and hydrodynamic forces complicates control because each force affects the vessel in different planes, wind primarily influencing the above-water profile and current acting on the submerged hull. When these forces act in non-parallel directions, they create conflicting moments that can overwhelm steering corrections, especially at low speeds.

Empirical evidence from the survey further supports this risk assessment: 78% of recorded near-miss incidents occurred under combined wind and current conditions. Respondents consistently described these situations as "deceptive," noting that vessels often appear stable until small heading deviations rapidly escalate into significant lateral drift or uncontrolled yaw. Such interactions are particularly hazardous during close-quarters operations, such as docking, undocking, or channel transit, where minimal clearance leaves little room for recovery once control is compromised.

Simulation results provide a vivid illustration of the severity of these compounded effects. When a container ship was subjected to a 30-knot crosswind combined with a 3-knot cross-current, the model showed a lateral drift of approximately 80 meters within five minutes. In practical terms, this displacement is enough to cause a berth collision in congested terminals such as those in Apapa, where spacing between vessels and infrastructure is limited. The simulation underscores how even moderate environmental forces, when combined, can exceed the corrective capacity of standard propulsion and steering systems.

Mitigation Effectiveness (Survey Ratings 1-5)

Table 3: Mitigation Tool Effectiveness & Availability

Tool	Avg. Rating	Availability
Tugboats	4.7	95%
Bow/Stern Thrusters	3.9	68%
Dynamic Positioning (DPS)	4.9	12%
Real-time Wind/Current Data	3.2	41%
Simulation Training	4.5	29%

Source: Authors

The data on mitigation tools reveal a clear disparity between effectiveness ratings and availability, underscoring the technological and infrastructural gaps affecting navigational safety in Nigerian maritime operations. Tugboats emerged as the most widely available and one of the most effective mitigation tools, with an average effectiveness rating of 4.7 (on a 5-point scale) and 95% availability across surveyed ports. Their high reliability and operational flexibility make them indispensable during berthing, undocking, and emergency control situations. The near-universal presence of tugs reflects their central role in compensating for environmental challenges such as strong crosswinds and tidal currents, particularly where onboard maneuvering aids are limited.

Bow and stern thrusters received a moderate rating of 3.9 and an availability of 68%, indicating that while effective for fine control at low speeds, they are not universally fitted across all vessel classes or terminals. Their limited thrust output at higher speeds and vulnerability to current flow reduce their utility in high-energy environments like Bonny River or Lagos Channel. Nonetheless, they remain a valuable complement to tugs, particularly for vessels operating in moderately confined berthing areas. Dynamic Positioning Systems (DPS) achieved the highest effectiveness rating of 4.9, signifying their superior precision and control in counteracting combined environmental forces. However, their availability is only 12%, largely restricted to specialized offshore support vessels and high-value tonnage such as LNG carriers. The limited deployment of DPS highlights a technological gap between Nigerian port

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

operations and global best practices, suggesting that cost and system complexity remain significant barriers to widespread adoption. The availability of real-time wind and current data was relatively low at 41%, with a modest average rating of 3.2. Despite its moderate effectiveness, the importance of such data cannot be overstated, it provides pilots and masters with critical situational awareness for preemptive decision-making. The limited access to real-time environmental data across Nigerian ports points to a need for investment in meteorological and hydrodynamic monitoring infrastructure to enhance operational planning and risk mitigation. Finally, simulation training was rated highly effective (4.5) but reported low availability (29%). This finding reflects a strong recognition of the value of simulator-based training in enhancing situational awareness, decision-making, and response under stress. However, the limited access to advanced maritime simulators within Nigeria constrains the potential impact of such programs. In summary, the data illustrate that traditional, mechanical aids such as tugboats remain the cornerstone of maritime safety, while modern technological solutions like DPS and simulation training, though highly effective, are underutilized due to limited access and high implementation costs. Enhancing availability of both advanced tools and real-time environmental data would significantly strengthen the maritime sector's resilience to environmental challenges.

DISCUSSION

Despite notable advancements in ship design and navigation technology, wind and current forces continue to pose significant operational risks to maritime safety. The persistence of these threats can be attributed to three enduring systemic gaps, training, technology, and data. The training gap remains a critical weakness. Only 29% of surveyed crews receive regular simulation-based training, leaving the majority reliant on theoretical knowledge without sufficient practical reinforcement. As one senior officer remarked, "We know the theory, but without practicing in simulators, we freeze when the wind hits 35 knots." This statement underscores the vital role of experiential learning in building situational reflexes under extreme conditions. Simulation training has proven effective in reducing human error rates by up to 60%, yet its limited adoption restricts the development of consistent, high-confidence maneuvering skills across the sector.

The technological gap further compounds the challenge. Dynamic Positioning System (DPS) adoption remains below 15%, largely due to high installation and maintenance costs. Moreover, real-time environmental data integration on Electronic Chart Display and Information Systems (ECDIS) is either unreliable or entirely absent in 59% of recorded operations, depriving pilots of essential information for preemptive decision-making. Without accurate, live data on wind and current vectors, even experienced navigators must rely on visual cues and instinct, increasing operational uncertainty during critical maneuvers. Lastly, the data gap contributes to systemic underestimation of risk. Minor incidents and near-misses are routinely underreported, leading to incomplete safety records that distort risk modeling and resource allocation. The absence of comprehensive reporting mechanisms prevents ports and regulators from identifying high-risk zones, seasonal trends, or recurrent operational failures, thereby perpetuating the cycle of reactive rather than proactive risk management.

The Nigerian Context: Unique Challenges

Nigeria's maritime environment presents distinct and compounding natural and infrastructural challenges that heighten the impact of wind and current forces. During the Harmattan season, strong northeasterly winds of 30–40 knots frequently occur, carrying dust and reducing visibility across ports such as Lagos. These gusty conditions not only increase aerodynamic drag on vessels but also impair optical navigation systems and line-of-sight coordination between pilots and mooring teams. The Bonny River, a critical artery for crude oil exports, experiences some of the strongest tidal currents in West Africa, often exceeding 5 knots during spring tides. Navigating these waters demands precise timing, pilots often describe berthing operations as requiring "millimeter-perfect accuracy." When coupled with limited tug availability or mechanical failures, the risk of drift or collision increases dramatically. Compounding these environmental hazards is a clear infrastructure lag. Many Nigerian ports lack essential meteorological and hydrodynamic instruments such as anemometers, current sensors, and DPS-equipped pilot boats. This absence limits real-time monitoring and adaptive response capabilities. As a result, even skilled pilots must operate under information deficits that compromise their ability to make timely and data-driven maneuvering decisions.

Climate Change: The Looming Multiplier

Looking ahead, climate change is poised to amplify existing maritime risks. Studies by Wang et al. (2015) and others predict that rising sea surface temperatures and shifting global wind patterns will intensify both wind speeds and current variability in coastal regions. Such changes imply a higher frequency of extreme events similar to the 'Ever Given' blockage of the Suez Canal, which was partially attributed to strong crosswinds. For ports like Lagos and Calabar, which are already operating near or beyond their designed capacity, this environmental volatility presents a serious operational and economic threat. Without systematic upgrades to port infrastructure, simulation training programs, and environmental monitoring networks, Nigeria's maritime system risks becoming increasingly vulnerable to the combined effects of stronger winds, unpredictable currents, and rising sea levels. The challenge is therefore not only technical but strategic, requiring coordinated national policy interventions to enhance maritime resilience in the face of a changing climate.

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

RECOMMENDATIONS

Ship operators must prioritize human preparedness and adaptive decision-making. Simulation training should be made mandatory, with at least 20 hours annually dedicated to practicing complex wind-current interactions. This hands-on exposure allows crews to internalize emergency responses and avoid reaction paralysis during real events. Furthermore, pre-voyage environmental briefings must integrate real-time MetOcean data including wind, tide and current forecasts, into passage planning to enable proactive maneuver adjustments. Finally, operators should standardize tug protocols, mandating tug assistance for vessels exceeding 200 meters in length when environmental forces surpass thresholds of 25 knots of wind or 3 knots of current, to ensure sufficient control margins in restricted waters.

Port Authorities (NPA and Related Agencies) should invest in Dynamic Positioning System (DPS) infrastructure, providing subsidies for pilot boats and incentives for shipboard installations to improve maneuverability in high-risk zones. Additionally, real-time monitoring systems must be deployed: installing anemometers and current meters at key channel entrances, with data continuously broadcast over VHF/AIS to support pilot decisions. To reduce environmental exposure, ports should also implement “Green Windows,” operational scheduling systems that align critical maneuvers, such as docking or undocking, with slack tide or low-wind periods, to minimize the probability of drift incidents.

At the policy level, regulatory bodies must modernize standards to match evolving risks. The SOLAS Convention should be amended to require DPS or equivalent control systems for Ultra Large Container Ships (ULCS) operating in confined waterways. Moreover, the creation of regional training hubs, such as a West African Maritime Simulation Center, would centralize skill development and harmonize operational competence across ports. Regulators should also drive innovation through AI-driven risk modeling, integrating historical and real-time data to forecast high-risk operational windows and inform both vessel routing and port scheduling systems.

Naval architects should prioritize windage reduction, lowering or reshaping superstructures to minimize crosswind drag. Future ship designs must also integrate thruster systems with DPS, enabling automatic course correction when vessels experience sudden environmental stress. Additionally, hull geometry should be refined to stabilize the pivot point, minimizing forward shifts at low speeds, a critical factor in maintaining maneuvering control under adverse wind-current conditions.

CONCLUSION

Wind and currents are immutable forces of nature, but their impact on ship maneuverability is not inevitable. This study demonstrates that with targeted investments in human capital (training), technology (DPS, sensors), and governance (policy, infrastructure), the maritime industry can dramatically reduce navigational risk. The Nigerian case studies offer a microcosm of global challenges and solutions. As vessel sizes grow and climate patterns shift, the lessons here are universally applicable: reactive navigation must give way to predictive, integrated, and resilient ship handling. The sea will always be wild. Our response must be smarter.

REFERENCES

1. Baatz, Y. (2014). *Maritime Law*. Informa Law from Routledge.
2. BBC. (2021). Ever Given: Suez Canal blockage sparks global shipping crisis. Retrieved from <https://www.bbc.com>
3. Becker, T., Hu, Y., & Bruns, A. (2020). Advances in Dynamic Positioning Systems for Enhanced Ship Maneuverability. *Journal of Marine Engineering and Technology*, 19(2), 67–84.
4. Bryman, A. (2012). *Social Research Methods* (4th ed.). Oxford University Press.
5. Chauvin, C., Lardjane, S., Morel, G., Clostermann, J. P., & Langard, B. (2013). Human and organisational factors in maritime accidents: Analysis of collisions at sea using the HFACS. *Accident Analysis & Prevention*, 59, 26–37.
6. Chen, X., & Fang, Q. (2019). Analysis of Ship Maneuverability in Confined Waters under Wind and Current Effects. *Ocean Engineering*, 182, 45–58.
7. Chislett, M. S., & Chapman, R. J. (1975). The behaviour of ships in currents. *Ocean Engineering*, 2(4), 221–230.
8. De Kat, J. O., & Peters, A. H. L. (1984). Wind Loads on Ships. *Ocean Engineering*, 11(6), 489–504.
9. Dubbeldam, J. L. (2019). Tidal Current Effects on Ship Handling in European Ports. *Journal of Navigation*, 72(4), 889–905.
10. Faltinsen, O. M. (2005). *Hydrodynamics of High-Speed Marine Vehicles*. Cambridge University Press.
11. Fossen, T. I. (2011). *Handbook of Marine Craft Hydrodynamics and Motion Control*. Wiley.
12. Houttuin, P. (2020). Maritime Accident Analysis: Wind and Current Effects on Vessel Handling. *Maritime Safety and Security Research Journal*, 7(1), 23–41.
13. International Maritime Organization (IMO). (2020). *Maritime Safety Committee Report on Ship Maneuverability*. London: IMO Publishing.
14. Jones, R., & Pearce, M. (2022). *Navigational Challenges in Modern Shipping: The Role of Technology and Human Factors*.

Operational Vulnerability of Large Vessels under Combined Wind-Current Conditions in Port Operations: Tugboats, DPS and Simulation Training

Journal of Navigation, 75(3), 489–507.

15. Kishk, S. M., & Kholeif, S. E. (2022). Lessons learned from the Ever Given grounding incident: A review. *Maritime Policy & Management*. <https://doi.org/10.1080/03088839.2021.1967832>
16. Lee, C. H., & Yang, S. H. (2003). A Study on the Effect of Currents on Ship Maneuverability. *Journal of the Society of Naval Architects of Korea*, 40(4), 11–22.
17. Lu, R., Zhang, Y., & Meng, Q. (2015). Optimal route planning for a ship in dynamic currents. *Ocean Engineering*, 110, 147–157.
18. *Marine Policy*, 62, 68–74.
19. Meier, K., Håkansson, L., & Berg, H. (2019). Training and Simulation for Ship Maneuverability in Adverse Weather Conditions. *Maritime Policy & Management*, 46(1), 24–39.
20. Newman, J. N. (1977). *Marine Hydrodynamics*. MIT Press.
21. NIMASA. (2021). *Maritime Safety in Nigerian Waters: Challenges and Opportunities*. Nigerian Maritime Administration and Safety Agency Report.
22. Oltmann, P. (2013). Wind and Current Effects on Ship Handling. *The Journal of Navigation*, 66(4), 519–532.
23. Rothblum, A. M. (2000). Human error and marine safety. *Proceedings of the National Safety Council Congress and Expo*, Orlando, FL.
24. *Sailing Vessel Handling and Seamanship*. (1999). Pivot Point Dynamics. U.S. Naval Institute Press. pp. 53–70.
25. Schröder-Hinrichs, J. U., Hollnagel, E., & Baldauf, M. (2011). From Titanic to Costa Concordia: A century of lessons not learned. *WMU Journal of Maritime Affairs*, 10(2), 151–167.
26. Wang, X., Li, C., & Gao, Y. (2015). The impact of climate change on maritime safety.
27. Watson, R. (2013). Technology and operations management in the maritime sector: Challenges and opportunities. *Journal of Maritime Research*, 10(3), 321–334.
28. Zheng, W., & Zhang, L. (2021). Evaluating Maneuvering Strategies for Ships under Current and Wind Forces: Case Study Approach. *Applied Ocean Research*, 108, 102–115.