THE OPTIMIZATION OF A TRIMARAN FIREFIGHTING VESSEL FOR THE GULF OF GUINEA

CHUKU, A. J.[1*] – DILOSI, A. T.[1]

[1] *Centre of Excellence in Marine and Offshore Engineering, Rivers State University, Port-Harcourt, Nigeria.*

**Corresponding author*
e-mail: azubuike.chuku1[at]ust.edu.ng

(Received 21st October 2025; revised 23rd January 2026; accepted 07th February 2026)

Abstract. Offshore oil, gas, and emerging renewable energy operations are increasingly exposed to severe fire and explosion risks due to the handling of large volumes of flammable materials, complex processing systems, and remote operating environments. Effective offshore emergency response therefore depends critically on the availability of specialized firefighting vessels capable of rapid deployment, high operational stability, and sustained suppression performance. This review examines the optimization of Trimaran firefighting vessels with specific reference to operational demands within the Gulf of Guinea, a region characterized by intensive offshore activity, relatively benign sea states, and growing safety and environmental concerns. The paper synthesizes existing literature on offshore firefighting requirements, vessel speed and response time, hydrodynamic resistance, stability, seakeeping, and firefighting system integration, with emphasis on the inherent limitations of conventional Monohull designs. Particular attention is given to the trade-offs between speed, fuel efficiency, stability, and fire monitor effectiveness, which often constrain Monohull performance during high-intensity firefighting operations. The review highlights how multihull configurations, especially Trimarans, offer superior hydrodynamic efficiency, enhanced transverse stability, increased deck area, and improved operational safety through the decoupling of resistance and stability functions. In addition, the study discusses regulatory frameworks governing maritime fire safety, common offshore fire scenarios, and the performance characteristics of various firefighting agents and systems relevant to offshore applications. A comparative assessment of Monohull, catamaran, Ttrimaran, and alternative advanced hull forms demonstrates the Trimaran’s suitability for high-speed, cost-effective, and stable firefighting operations in the Gulf of Guinea. The review identifies a clear research gap in region-specific optimization of Trimaran firefighting vessels and provides a structured foundation for future design, numerical analysis, and performance optimization studies aimed at improving offshore emergency response capability, safety, and sustainability.

Keywords: *Trimaran, firefighting, emergency response, accidents, rescue*

Introduction

The global maritime operations and offshore industry have become increasingly vital to the world's energy supply, trade, and economic stability. Because of growing global energy demands, offshore activities have expanded beyond conventional oil and gas extraction to also cover the renewable energy sector, including offshore wind farms and tidal energy projects (DNV, 2024; IMO, 2023). This expansion pushes operations into more remote, deeper, and harsher environments, requiring advanced technological solutions, vessel designs, and specialized infrastructure like fixed platforms, Floating Production, Storage, and Offloading (FPSO) vessels, mobile drilling rigs (MODUs), and a diverse offshore supply vessels (ABS, 2022). The scale and nature of these operations that involve the handling of large amounts of hydrocarbons, powerful machinery, intricate electrical systems, and large numbers of personnel, inherently elevate the risk profile. Consequently, fire and explosion hazards remain a paramount concern across all segments of the offshore industry. Incidents on platforms, where volatile substances are

eISSN: 2716-6341
https://doi.org/10.55197/qjoest.v7i1.279

processed and stored, on FPSOs with their integrated production and immense storage capacities, on mobile drilling rigs engaged in high-pressure drilling operations, and even on the essential supply vessels that fuel and support these installations, carry the potential for catastrophic consequences, including severe environmental damage, economic losses, and, even the tragic loss of human life (IOGP, 2021). This risk of fire and explosion highlights the importance of improved safety protocols and offshore firefighting vessels. The importance of offshore emergency response lies in its direct relationship with safeguarding human life, protecting the marine environment, and mitigating large-scale economic losses in a sector beset by risk. Due to their remote locations, often in harsh and unpredictable maritime conditions, offshore installations, such as fixed platforms, FPSOs, mobile rigs, and even supporting supply vessels, face increased challenges when incidents occur (Wozniakowski-Zehenter, 2024a). Unlike land-based emergencies where quick access to resources is often assured, offshore incidents demand self-sufficiency and immediate, specialized intervention. This creates a critical need for specialized vessels designed for rapid and effective response.

The devastating potential of offshore fires, in particular, underscores this need. Such incidents can quickly escalate from localized ignitions to uncontrollable blazes due to the vast quantities of flammable hydrocarbons, interconnected systems, and high-pressure environments characteristic of offshore oil and gas operations (Wozniakowski-Zehenter, 2024b). The consequences are catastrophic: (1) Human Casualties: Fire and explosion are leading causes of fatalities and severe injuries offshore. The Piper Alpha disaster in 1988, which claimed 167 lives, serves as an evidence of the rapid and lethal progression of offshore fires. It also points to the necessity of rapid evacuation and rescue, which specialized vessels facilitate. Even with internal safety measures, an overwhelmed onboard system can trap personnel, making external rescue and suppression capabilities vital. (2) Environmental Damage: Offshore fires frequently lead to significant hydrocarbon releases into the marine environment, causing large scale oil spills and toxic plumes. These can devastate marine ecosystems, coastlines, and ecological balances for years, demanding rapid containment and cleanup efforts that often rely on the capabilities of specialized response vessels (Brkić, 2025; Jesús, 2024). (3) Economic Loss: Beyond the immediate cost of human lives and environmental remediation, offshore fires result in immense financial repercussions. Damage to, or complete loss of, multi-billion-dollar platforms, FPSOs, or drilling rigs can interrupt production, incur massive repair and replacement costs, leading to prolonged operational downtime, and severely impacting company revenues and shareholder value (Wozniakowski-Zehenter, 2024a; Michalis and Myrto, 2012). The cascading economic effects can even extend to the broader energy market.

Therefore, the mission of offshore firefighting vessels is not merely to "put out fires," but to act as a vital, mobile safety net, providing the specialized equipment, highly trained personnel, speed, and sustained operational capability required to minimize these devastating impacts when an offshore emergency strikes. Their design, which prioritizes rapid transit, stability for precision operations, and the integration of powerful suppression systems, is a direct response to these critical safety, environmental, and economic imperatives (EMA, 2025). The evolution of firefighting vessels represents the increasing scale of maritime activities, transitioning from simple onboard suppression capabilities to more specialized and efficient emergency response platforms. Historically, firefighting at sea was primarily an internal affair, relying on the ship's crew and basic equipment like buckets, hand pumps, and ordinary fixed systems, as mandated by early maritime safety conventions (IMO, 1974). Significant maritime disasters, such as the RMS Titanic sinking in 1912, while not a fire incident, profoundly influenced the development of comprehensive safety regulations (SOLAS) that incrementally addressed fire prevention and onboard firefighting measures. However, as global trade expanded and particularly with the advent of the offshore oil and gas industry in the mid-20th century, the scale of potential fires escalated dramatically. The emergence of fixed platforms, mobile drilling units, and later, FPSOs, presented fire hazards far beyond the capacity of conventional shipboard systems or shore-based fire departments. This escalating risk profile led to an increasing demand for more efficient firefighting vessels, transitioning from general-purpose tugs with auxiliary pumps to dedicated Emergency Response and Rescue Vessels (ERRVs) and advanced offshore firefighting (FiFi) vessels. Modern firefighting vessels are no longer just ships with powerful water cannons; they integrate sophisticated dynamic positioning systems for precise station-keeping, advanced automation for optimal water/foam discharge, often incorporating multihull designs to achieve the high speeds and stability crucial for rapid response and effective suppression in the demanding offshore environment (DNV, 2022). This continuous improvement shows the proactiveness of the maritime industry to mitigate the devastating human, environmental, and economic consequences of offshore fire incidents, ensuring that response capabilities keep pace with operational advancements. Firefighting vessels are special service vessels designed with the capability to discharge large jets of water to counteract combustion on offshore structures such as mobile vessels, static ones and so on.

Inherently, this responsibility imbues on such vessels the requirement to be high-speed in order to respond promptly to offshore emergencies. However, this requirement automatically imposes several restrictions on the ship, the first of which is that, since resistance is proportional to speed, as the vessel speed increases, the resistance is also amped up. The next problem is resultant from the first: resistance is proportional to fuel consumption. Therefore, as resistance increases, fuel consumption increases greatly also. This leads to significant increase in operation costs as well as reduction in profits accrued from firefighting operations. Higher fuel consumption also culminates in the increased gaseous emission of the oxides of carbon, nitrogen and sulphur. This is an inherent problem for monohulls- resistance; because of the form of their hulls, there is large scale interaction between the hull and the environment in which they move, hence the introduction of multihulls, as catamarans and trimarans are commonly called, which have far less resistance even for the same size and block coefficient. Generally, as will be seen in Chapter 4, the resistance experienced by a Trimaran will be far less than that of a Catamaran or a single-hull vessel, leading to the least fuel consumption and the greatest speed. Also, for conventional monohull firefighting vessels, stability presents a significant challenge, particularly during high-volume water discharge or in rough sea conditions, directly impacting the precision and effectiveness of firefighting efforts. The immense recoil forces generated by powerful water monitors, capable of discharging thousands of gallons per minute, can induce substantial heeling moments, causing the vessel to list or roll. This dynamic instability is further exacerbated by the "free surface effect" if firefighting water accumulates on deck or in partially filled compartments, leading to a detrimental shift in the vessel's center of gravity and a reduction in its righting arm. In rough seas, the inherent rolling and pitching motions of a monohull, while predictable, can become amplified, making it extremely difficult for operators to accurately aim water jets at a burning target, especially at height or distance. This compromised stability not only endangers the vessel and its crew but also reduces the efficiency of the firefighting operation, potentially prolonging the incident and increasing overall damage by hindering the precise application of extinguishing agents.

The focus on multihull designs, particularly trimarans, for firefighting vessels reintroduces the advantage of increased stability which is important during the firefighting exercise where precision of the water jet determines the speed with which the danger can be resolved. Their broader deck area, compared to monohulls of similar length, allows for more efficient placement of specialized firefighting equipment, such as powerful pumps, monitors, and foam tanks, without compromising maneuverability or creating excessive top-heaviness. This increased deck space also facilitates better logistical support for extended operations, providing room for additional crew, medical facilities, and provisions, which are crucial during prolonged emergency responses offshore. Furthermore, the inherent redundancy of propulsion systems often found in multihulls can provide an extra layer of safety and operational resilience, ensuring the vessel can maintain station and continue firefighting efforts even if one engine room is compromised. It is important to note that different vessels are designed and built to be able to function in different marine environments. Thus, a vessel designed to function within a benign route such as one within the Gulf of Guinea will be unsuitable for a voyage in more turbulent waters such as in the North Sea where wave heights easily exceed seven meters. The reverse is the case as overdesign is a major problem for vessels designed for rougher seas that operate in benign waters. Because of this, vessels are often designed for the route they are expected to operate in. The Gulf of Guinea is home to many important offshore structures such as the Bonga and Bonga West FPSOs, several wind farms, and is a path often taken by many vessels on international voyage, a good number of which carry flammable substances. This begs the need for increased fire safety in the region. Blended with the need for quick, cost-efficient response, this has led to the need of multi-hulled firefighting vessels designed for the Gulf of Guinea specifically.

Despite the clear benefits of multihulls, especially Trimarans, in firefighting applications, their adoption isn't without considerations. The initial build cost for a sophisticated multihull can be higher than that of a comparable Monohull due to the complexity of construction and the need for specialized design expertise. Additionally, while offering superior stability in calm to moderate seas, the motion characteristics of multihulls in very rough seas can be different from Monohulls, potentially leading to specific comfort challenges for the crew, although this is often mitigated by advanced ride control systems. However, the long-term operational savings stemming from significantly reduced fuel consumption and the enhanced operational capabilities and safety features often outweigh these initial investments and design complexities, making multihulls a compelling choice for the future of offshore firefighting. With these in mind, the Design and Optimization of a Trimaran Firefighting Vessel, which this research seeks to review and explore the various firefighting tools, processes and regulations in operation in the Gulf of Guinea.

Literature review

There has been no direct work on the design of firefighting Trimaran specifically for operation in the Gulf of Guinea; however, a series of analogous projects involving multi-hull vessels in challenging environments and for similar purposes do exist, providing useful context.

The primary need for offshore firefighting vessels

Accordingly, the primary role of offshore firefighting vessels is to ensure maritime safety by preventing, detecting, containing, and extinguishing fires and explosions in the challenging offshore environment. While the authors' work focuses on fire safety for all ships, these specialized vessels are designed to act as a mobile and capable extension of global safety regulations. The offshore environment, with its complex platforms and large quantities of hydrocarbons, amplifies the risk of fire and explosion, which is a leading cause of harm. Firefighting vessels are frontline responders, providing an immediate and overwhelming response that can't be sustained by the affected installation itself. Their mission is to mitigate the catastrophic potential of such incidents, which can threaten human lives, the environment, and severe economic losses. Maritime safety rules, such as SOLAS and the FSS Code, form the foundation of fire protection by mandating measures for fire prevention and equipment on all ships. Offshore firefighting vessels exceed these minimum standards. Their mission is to actively provide the ultimate means of fire extinction when a structure's internal systems fail, safeguarding other offshore assets. Their high-capacity fire pumps, water mains, and various extinguishing agents are a scaled-up application of these regulations, designed to combat large, complex offshore fires. Human error contributes to most fires, emphasizing the importance of crew training while a ship's crew is trained for internal firefighting, an offshore firefighting vessel's crew has highly specialized training in large-scale industrial firefighting and rescue operations. Their mission requires not only technical proficiency but also an acute awareness of complex offshore scenarios, which often involve volatile substances and intricate layouts. The authors also touch on the increasing complexity of fire problems, such as those involving lithium-ion batteries. Offshore firefighting vessels are at the forefront of these challenges, integrating "technological advances" and "expert knowledge" into their operations. Their mission involves sophisticated fire detection systems, fire simulation models, and the potential for autonomous fire detection, all aimed at solving complex fire protection problems. Unlike the internal fire protection on most ships, an offshore firefighting vessel's mission is external. Its design allows it to approach and hold station to discharge massive quantities of water or foam onto a burning structure. The vessel's stability and speed are key to this specialized role. Its purpose is to deliver the "sufficient flow capacity and pressure to reach the highest and farthest areas" of a ship or platform from an external position, a capability that far exceeds that of a standard vessel.

Types of offshore structures

The offshore environment hosts a variety of specialized structures, each designed for specific functions in the exploration, production, and transportation of oil, gas, and increasingly, renewable energy. These structures vary significantly in their mobility, permanence, and operational capabilities. Understanding these different types is crucial for grasping the different scenarios an offshore firefighting vessel might encounter.

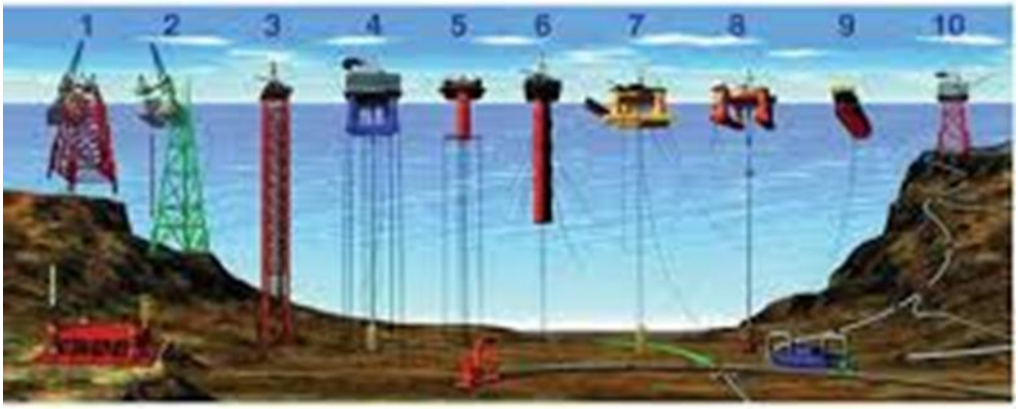

Figure 1. *Offshore structures at various water depths. (1), (2) conventional fixed platforms; (3) compliant tower; (4), (5) vertically moored tension leg and mini-tension leg platform; (6) spar; (7), (8) semi-submersibles; (9) floating production, storage, and offloading facility; (10) sub-sea completion and tie-back to host facility.*

Fixed platforms

Fixed platforms are large, permanent offshore structures directly anchored to the seabed. They are typically used for the long-term extraction of petroleum or gas from fields in relatively shallow to moderate water depths, generally up to around 1,500 feet (450 meters), though some advanced designs can go deeper. They consist of a substructure (often a "jacket"-a lattice framework of steel pipes) or concrete legs, which are piled into the seabed, supporting a spacious topside deck. Examples include Jacket platforms and compliant towers. Sometimes Tension Leg Platforms (TLPs) are grouped here due to their tight moorings.

FPSOs (Floating Production, Storage, and Offloading Vessels)

An FPSO is a floating vessel, typically a converted oil tanker or a purpose-built ship-shaped unit, used by the offshore oil and gas industry for the production, processing, and storage of hydrocarbons, and for offloading processed oil onto shuttle tankers. FPSOs are highly versatile and are particularly effective in remote or deep-water locations where laying expensive long-distance pipelines to shore is not economically viable. They can be moored to the seabed via various mooring systems (e.g., spread mooring or turret mooring) and are designed for continuous operations, often staying on location for 20 years or longer.

Mobile Rigs (Mobile Offshore Drilling Units-MODUs)

Mobile Rigs, formally known as Mobile Offshore Drilling Units (MODUs), are specialized vessels capable of engaging in drilling operations for the exploration or exploitation of resources beneath the seabed. Unlike fixed platforms, MODUs are designed to be moved from one location to another. They are crucial for drilling exploratory wells to identify new oil and gas reserves, as well as for drilling development wells in established fields. Examples include jack-up rigs, semi-submersible rigs, drillships, etc.

Supply Vessels (Offshore Supply Vessels-OSVs)

Offshore Supply Vessels (OSVs), also known as offshore support vessels, are a diverse category of specialized ships designed to support offshore oil and gas exploration and production activities, as well as other maritime operations like offshore wind farms. Their primary mission is to transport goods, supplies, equipment, and personnel to and from offshore installations. They operate on flexible "spot charters" rather than fixed routes. Types of OSVs include Platform Supply Vessels, Anchor Handling Tug Supply (AHTS) Vessels, Accommodation Vessels ("Floatels, specialty OSVs, etc. Many have dynamic positioning (DP) capabilities to hold station precisely near offshore facilities.

The role of vessel speed in offshore firefighting operations

Rapid vessel speed is a basic requirement for effective offshore firefighting operations. The inherent nature of fire, which can escalate exponentially, makes every minute of transit time critically important for containing damage and ensuring safety. Delays in response not only exacerbate physical and economic destruction but also create significantly more hazardous conditions for responders, leading to an increased risk of injury or fatality. Current regulatory response time standards for offshore incidents often fall short in practical application, revealing critical coverage gaps and logistical hurdles amplified by long distances and challenging sea conditions. Traditional monohull vessel designs frequently encounter inherent limitations in balancing the demands of high speed, stability, and seakeeping, which can compromise operational effectiveness, crew comfort, and the precise application of firefighting equipment. To overcome these challenges, advanced multi-hull solutions like catamarans and trimarans, specialized hull forms such as SWATH and emerging technologies including remote-controlled vessels and autonomous systems offer compelling advantages. These innovations are crucial for developing future offshore firefighting capabilities that ensure rapid, safe, and effective intervention against the escalating threat of maritime fires. Offshore environments, encompassing oil and gas platforms, large commercial vessels, and remote marine infrastructure, present unique and severe fire risks. The isolation of these incidents means that immediate, external intervention is often the primary and most effective means of suppression (MDPI, 2025). Unlike land-based fires where local fire departments can respond within minutes, maritime emergencies, particularly those far from shore, necessitate specialized assets capable of traversing significant distances. In the context of maritime firefighting, rapid response extends beyond mere quick dispatch; it requires achieving swift transit to the incident scene and the quick/effective commencement of suppression efforts upon arrival. Vessel speed is therefore a critical determinant of overall response time. Since fire can double in size and intensity in a matter of minutes, every minute of transit time is important for containing damage and ensuring safety. The ability to rapidly reach an offshore incident directly influences the potential for successful damage control and the safety of all personnel involved as further explained.

High vessel speed minimizes primary and secondary damage

The destructive power of fire is immediate and far-reaching. Rapid response is paramount in limiting the initial destructive impact, as intense heat and flames can severely compromise the structural integrity of a vessel or offshore installation. Early intervention is crucial to prevent a fire from reaching its "fully developed" state or "flashover." Flashover is a rapid transition where all combustible items in a compartment ignite, often associated with gas temperatures of 500-600°C, leading to sudden, widespread fire involvement (Quintiere, 2006). Beyond the immediate flames, fire damage is only the beginning of the problem. Smoke, soot, and water used during firefighting efforts can cause extensive secondary damage if not addressed promptly. A swift response from professional fire damage teams involves immediate action to contain and mitigate these secondary threats. Specialized equipment like air scrubbers, hydroxyl generators, and dehumidifiers are deployed to remove airborne contaminants, neutralize odors, and facilitate drying, thereby preventing further deterioration and the risk of mold growth. Prompt action is crucial, as the longer smoke and soot linger, the more difficult and costly the removal process becomes. This step not only safeguards the property but also ensures the safety of occupants and restoration workers during the recovery process. Geometric progression of fire means that delays in response are not merely additive but multiply their negative impact. The concept of "t-squared fires" illustrates this, where fire growth is directly proportional to the square of time. A fire's intensity can double in a matter of minutes. This means that a seemingly small delay in vessel transit time can lead to a disproportionately massive increase in damage, making the window for effective intervention extremely narrow. This emphasizes why speed is not just about reaching the scene but reaching it before critical thresholds like flashover are crossed, thereby preventing exponential damage and making suppression exponentially harder and more resource-intensive. Swift intervention also increases the likelihood of salvaging personal belongings, critical equipment, and even enabling partial or full resumption of operations sooner.

Firefighter and occupant safety

A delayed response creates a significantly more dangerous environment for the firefighters tasked with entering a compartment on fire. Firefighters operate in hazardous environments characterized by extreme heat (often greater than 400°C), the release of noxious gases, and compromised structural integrity, even when wearing full personal protective equipment (PPE) (Ramohale et al., 2025). Rapid arrival reduces the duration of exposure to these life-threatening conditions, directly contributing to their safety. Furthermore, quicker intervention can save lives, especially in cases where victims are in imminent danger, require immediate rescue, or need defibrillation. The ability to restore safe and breathable air quality promptly is also critical before occupants can safely reoccupy affected areas. The safety of firefighters and the effectiveness of their operations are inextricably linked to the speed of response. A delayed arrival not only increases the physical dangers, such as prolonged exposure to extreme temperatures, smoke inhalation, and the risk of structural collapse; but also exacerbates the psychological stress on responders. This heightened stress can potentially lead to errors, reduced performance, and an increased likelihood of injuries or fatalities. Therefore, high vessel speed directly contributes to creating a safer and more manageable operational environment for responders, which in turn enhances their overall efficacy and reduces the human cost of maritime incidents.

Improvement operational efficacy and reduces psychological impact on respond

Regular fire drills and comprehensive training are known to improve operational efficacy, confidence, heat endurance, and teamwork among firefighters (Ramohale et al., 2025). Rapid vessel speed allows these well-trained teams to apply their skills effectively at the earliest possible moment, enhancing overall performance. Moreover, swift response can reduce psychological discomfort, fear, and stress for responders, thereby improving morale and passion. Knowing that assets can reach a scene quickly contributes to a sense of preparedness and capability, producing a more resilient and effective response team.

Economic and reputational consequences of delayed intervention

The financial and reputational ramifications of delayed firefighting response are substantial. Delayed intervention leads to extensive and costly repairs or replacements. The tragic Conception fire in September 2019 serves as a stark example: firefighting efforts were delayed for nearly two hours, resulting in the loss of all 33 passengers and one crewman, and the vessel being a total loss. This incident highlighted how Coast Guard policy at the time deferred firefighting command and control to local officials, who were often less experienced in marine firefighting, and limited the use of Coast Guard assets for independent firefighting. Beyond the direct costs of physical damage, delayed firefighting response, particularly when exacerbated by systemic policy failures or jurisdictional ambiguities, incurs severe indirect economic and social costs. The total loss of life and property, coupled with subsequent lawsuits and significant reputational damage to responsible authorities, underscores that vessel speed is not merely a technical specification but a necessary component within a robust, integrated emergency response system. Unacceptable response times can also result in negative press coverage, lawsuits, and financial penalties. Conversely, prompt intervention helps stabilize affected areas and secure critical assets, minimizing business interruption and reducing economic losses. *Table 1* shows the impact of response time on fire damage and safety outcomes

***Table 1**. Impact of response time on fire damage and safety outcomes.*

Consequence Category	Impact of Rapid Response	Impact of Delayed Response
Damage Control	Minimizes structural compromise; Reduces secondary damage (smoke, soot, water); Prevents mold growth; Salvages belongings and critical equipment; Restores air quality; Stabilizes affected areas, enabling quicker resumption of operations.	Compromised structural integrity; Extensive secondary damage (smoke, soot, water); Increased mold risk; More difficult and costly removal processes; Unsafe air quality; Increased severity and spread (t-squared fires); Greater difficulty in extinguishing the fire.
Safety (Firefighters & Occupants)	Reduces risk exposure for firefighters; Enables timely rescue operations; Ensures restoration of safe and breathable air quality; Enhances firefighter confidence, coordination, and heat endurance; Prevents injuries and fatalities.	More dangerous environment for firefighters; Increased injuries and fatalities for responders; Potential loss of life for occupants; Compromised ability to perform rescue operations effectively.
Economic/Operational	Reduces need for extensive and costly repairs or replacements; Minimizes business interruption; Avoids negative press, lawsuits, and financial penalties.	Extensive and costly repairs or replacements; Significant business interruption and economic losses; Negative press coverage, lawsuits, and financial penalties; Total loss of vessel and lives (e.g., Conception fire).

Challenges of offshore firefighting operations

Regulatory response time standards and coverage gaps

The U.S. Coast Guard's Salvage and Marine Firefighting regulations stipulate specific response times for marine firefighting operations: a firefighting team is required to be on-scene within 8 hours for "nearshore" operations (within 12 miles of shore) and within 12 hours for "offshore" operations (out to 50 miles). These standards necessitate continuous training and exercises for marine salvors' fire teams to ensure compliance. Despite these regulations, significant "dead zones" exist along much of the coast and offshore where emergency fire coverage is absent or severely delayed. This situation worsens with increasing distance from shore and can lead to vessels burning unmitigated for days or being towed into port for land-based firefighting. It is notable that regulations, such as the National Oceanic and Atmospheric Administration (NOAA) proposed vessel speed rule for North Atlantic Right Whales, include exemptions for "Search and Rescue (actively engaged)" and "Enforcement (actively engaged)" vessels, implicitly acknowledging the critical need for speed in emergency response (NOAA, 2022). This recognition of speed's importance in other emergency contexts further highlights the gap in offshore firefighting asset deployment and operational mandates.

Logistical hurdles and resource availability in remote environments

Long distances directly translate into extended transit times, which can span hours or even days, allowing fires to escalate dramatically. This extended time inevitably increases the likelihood of fire escalation, as fires grow in a t-squared manner. Maintaining crews on high alert for rapid dispatch is crucial, but high-speed vessels' availability, type, and capabilities also play a significant role in prompt response. Effective response requires seamless coordination between various agencies and assets, which becomes more complex over long distances and across different jurisdictions. The Conception fire tragically illustrated issues with delayed asset deployment and underutilized equipment due to poor coordination and restrictive policy. Furthermore, in offshore incidents, factors like smoke spread from the fire or adverse natural weather conditions can lead to low visibility, which significantly reduces evacuation speed and increases risk, further complicating rescue and firefighting efforts (Wang et al., 2023). The extended time required for transit amplifies these existing operational hurdles, making high vessel speed necessary to mitigate such negative outcomes, ensuring that resources arrive not just quickly, but also prepared and able to operate effectively in challenging conditions.

Environmental factors affecting transit and operations

Offshore environments are inherently dynamic. High winds, choppy waters, and difficult-to-navigate terrain can significantly slow vessel operations and response times. Vessels must be designed for "seakeeping of paramount importance" to maintain speed and operational capability in adverse conditions. Environmental factors directly influence hydrodynamic resistance and stability (Samaei and Asadian Ghahfarokhi, 2025). For instance, shallow water can dramatically increase wave-making resistance for monohulls in certain speed regimes, reducing effective speed (Radojcic and Bowles, 2010). Operating at low speeds in high winds and choppy waters can be unsafe for many smaller vessels, increasing the risk of swamping or capsizing. This implies that for safety, some vessels need to maintain higher speeds in certain conditions, directly conflicting with environmental speed regulations, such as those aimed at protecting marine mammals. While high speed is unequivocally critical for rapid response, it introduces a complex and often overlooked trade-off with seakeeping and stability, particularly for traditional monohulls operating in adverse offshore conditions. The ability to maintain effective speed and operational capability is severely compromised by rough seas, leading to increased vessel motions (pitch, roll, heave), reduced crew comfort (Motion Sickness Incidence, peaking at 12.5% in Beaufort 3), and even critical safety concerns like water ingress (Samaei et al., 2025). This suggests that simply designing for maximum speed is insufficient; vessels must be designed for sustained effective speed in expected operational environments, necessitating hull forms that balance raw speed with superior seakeeping to ensure crew and equipment functionality and safety upon arrival.

Traditional monohull designs inherent challenges in meeting offshore firefighting requirements

Hydrodynamic resistance and speed limitations

Traditional monohulls often face a trade-off between achieving high speed and maintaining other critical characteristics like stability and seakeeping. Designing for higher speeds (e.g., greater than 20 knots) frequently results in a narrow beam, which can lead to an uncomfortable vessel not well-suited for work or cruising in a seaway. While hull form optimization can reduce resistance (Park et al., 2022), high speeds inherently demand more power. For instance, higher trims (e.g., 5.4 degrees) necessary for speed can increase power demands and hydrodynamic resistance (Samaei et al., 2025). A significant challenge arises in shallow water. Monohulls experience a dramatic increase in wave-making resistance when operating at "critical speeds" (depth Froude number 0.7-1.2). This phenomenon can substantially lower a vessel's achievable speed at constant power or significantly increase the power required to maintain speed, making operations near shore or in shallower offshore areas highly inefficient. For traditional monohulls, achieving the high speeds necessary for rapid offshore response often creates an inherent paradox: the very design elements that reduce resistance for speed (e.g., a narrow beam) can simultaneously compromise seakeeping and crew comfort, rendering sustained high-speed transit in rough offshore conditions impractical or unsafe. Furthermore, the dramatic increase in wave-making resistance experienced in shallow water's "critical region" means that a vessel optimized for deep-water speed may become inefficient or even unable to reach its target speed in coastal approaches or shallower offshore areas. This highlights a fundamental limitation in operational flexibility and efficiency across varied maritime environments, directly impacting response time.

Seakeeping, stability, and crew comfort in adverse conditions

The motion characteristics of traditional monohulls, while sometimes perceived as having a "smoother" motion, can include rhythmic rolling in waves, especially in certain wind conditions. Their pitching periods can be very close to their roll period, potentially leading to uncomfortable "corkscrew motion," particularly noticeable at the bow. Excessive motion can render an entire mission unproductive, making seakeeping paramount for safe, effective, and continuous work on deck and in labs. High pitch, yaw, and heave motions, particularly at higher trims, can significantly impact crew comfort, leading to motion sickness (MSI peaking at 12.5% in Beaufort 3) and even water ingress (Samaei et al., 2025). It is crucial to distinguish between "stability” the ability of a vessel to return to its upright position after being disturbed and "seakeeping" the measure of a stable environment for work. A stiff vessel, while possessing high stability, can afford poor seakeeping due to rapid rolling. The inherent seakeeping limitations of traditional monohulls in adverse offshore conditions directly translate into reduced operational effectiveness and increased risk to human factors. Excessive vessel motion not only physically hinders the ability of crew members to perform critical tasks (e.g., deploying equipment, operating fire monitors, treating casualties) but also leads to severe crew fatigue, motion sickness, and impaired cognitive function. This can compromise safety, decision-making, and the overall efficiency of complex firefighting operations. Therefore, merely achieving "speed to scene" is insufficient if the vessel cannot provide a stable and comfortable enough platform for the crew to effectively fight the fire and manage casualties upon arrival.

Impact on fire monitor operation and equipment effectiveness

Firefighting equipment, particularly high-pressure water monitors, requires a stable platform for effective and safe operation. On land-based aerial platforms, for instance, capacity is commonly reduced by 50% when flowing water due to nozzle reaction forces, and the platform must be leveled within manufacturer guidelines. This principle directly applies to vessel-mounted monitors. Accumulating firefighting water on board a vessel can adversely affect its buoyancy and stability, leading to a list and potential capsizing (USCG, 2025). Fire officers are advised to continuously monitor water accumulation and obtain technical advice from the vessel's master, chief mate, or the U.S. Coast Guard, as decisions impacting stability are complex and vessel-specific. The inherent rolling and pitching motions of monohulls in rough seas can compromise the precision and range of fire monitors, making it difficult to aim effectively and maintain a consistent stream. While some monohulls, such as the Metal Shark Defiant series, are specifically designed for exceptional stability "while underway, at rest, or pumping water", this remains a significant design challenge for the broader category. The effectiveness and safety of vessel-mounted firefighting equipment are directly contingent upon the vessel's dynamic stability. The significant nozzle reaction forces generated during water flow can induce substantial heeling moments, which, when combined with the inherent motion characteristics of traditional monohulls in a seaway, can severely compromise aiming accuracy, reduce effective range, and even endanger the vessel and crew. Therefore, advanced stability features are not merely a comfort or survivability feature but a critical operational enabler, allowing for sustained, precise, and safe fire suppression, especially in dynamic offshore environments where external stabilization platforms are unavailable. This makes the ability to maintain a stable platform under load as crucial as the speed of arrival.

Shallow water performance considerations

Monohulls operating in shallow water, particularly at "critical speeds" (depth Froude number 0.7-1.2), experience a dramatic increase in wave-making resistance. This phenomenon can significantly reduce the vessel's speed at constant power or require substantially more power to maintain speed (Radojcic and Bowles, 2010). This resistance increase can limit a monohull's ability to respond effectively in coastal areas, harbors, or shallower offshore regions, where such conditions are prevalent. It also adversely affects fuel efficiency and operational costs (Radojcic and Bowles, 2010).

Advanced vessel designs and technologies for enhanced offshore firefighting capabilities

To address the inherent limitations of traditional monohulls and meet the demanding requirements of offshore firefighting, advanced vessel designs and emerging technologies offer compelling solutions. *Table 2* attempts to compare key performance characteristics between monohull and multi-hulls.

Table 2*. Comparison of key performance characteristics: Monohull vs. Multi-Hull.*

Characteristic	Traditional Monohull	Catamaran	Trimaran	Small WaterPlane Area Twin Hull (SWATH)
Speed	Often compromised by stability/seakeeping trade-offs;[a] resistance affected by hull form, shallow water effects.[b]	High speed; [c] reduced displacement per hull, minimal drag.[d]	Excellent for high speed; Lighter weight, more specialized for speed.[e]	Not primarily designed for high transit speed but maintains effective speed in rough seas.
Stability	Can be an issue with high center of gravity; prone to rhythmic rolling;[a] Stability issues can impact fire monitor operation.[f]	Excellent stability due to wide footprint; resists rolling; disperses wave energy;[d] "Top-notch for stability" but less suited for rough seas than trimaran.[g]	Incredible stability; central hull for buoyancy, amas for stability; virtually unsinkable; predictable righting moment.[e]	Exceptionally stable; minimizes hull cross-section at surface; reduces motion by up to 75%.[h]
Seakeeping	Can be poor in rough seas; corkscrew motion; Excessive motion can render mission unproductive.[i]	Good seakeeping; reduces pitch and roll.[d]	Good seakeeping; long center hull reduces pitch; narrow hull reduces slamming; amas reduce roll;[e] Can maintain higher average speeds in adverse conditions.[j]	Superior seakeeping; preferred in severe weather; allows safe operations in waves up to 6 meters.[h]
Deck Area	Less working deck area.[a]	Maximized, rectangular deck space.[d]	Larger available deck area;[e] Moderate space below main deck.	Can offer significant deck space depending on design.
Hydrodynamic Resistance	Affected by hull form; dramatic increase in shallow water at critical speeds.[b]	Reduced displacement per hull; minimal drag in shallow waters.[d]	Excellent for high speed due to narrow hulls reducing drag.[k]	Generally higher resistance at high speeds compared to planing hulls due to displacement nature.
Suitability for Fire Monitor Operations	Stability issues can impact precision and range.[i]	Enhanced stability provides a steady platform for equipment.[d]	Superior stability allows for sustained, precise operation of monitors.[e]	Extreme stability ideal for precise, sustained water flow in rough seas.[h]
Crew Comfort	Perceived as better when seated, but can be extreme due to corkscrew motion.[a]	Smooth sailing experience; comfortable ride; roomy interiors.[g]	Exceptional comfort; smooth ride; reduced pitch and roll accelerations;[e] Less seasickness.[l]	Significantly improved comfort due to minimal motion (up to 75% reduction).[h]
Damage Survival	Critical; single hull breach can be catastrophic.[e]	Enhanced resilience; capsizing "extremely unlikely"; Single-engine get-home capability.[g]	Major advantages for damage survival; "virtually unsinkable"; predictable stability; reserve buoyancy from cross deck.[e]	High inherent stability; multiple hulls provide redundancy; can maintain buoyancy even with damage to one hull.

Note. Adapted from Radojcic and Bowles (2010).

Multi-Hull solutions: Catamarans and Trimarans for speed, stability, and deck space

Multi-hull designs, specifically trimarans, offer a solution to the often-conflicting demands of offshore firefighting than traditional monohulls. They inherently resolve many of the monohull's critical trade-offs by effectively decoupling stability from hull slenderness, thereby enabling both high speed and superior seakeeping simultaneously.

Chuku et al. (2024), informed that when running at low speed inside or below 12 knots, it is evident that the EDDI for all of the vessels was improved due to their short length, breadth, draft, and prismatic coefficient. This is due to the observation that lowering these settings causes the EEDI achieved value to fall. This can be problematic for the ship's intact stability. Catamarans (twin-hull designs) provide superior stability due to their wider footprint, distributing buoyant forces along outer edges and significantly reducing rolling motion. Their dual hulls work in tandem to disperse wave energy, reducing pitch and roll, making them ideal for open water and rough conditions. Catamarans also offer maximized, rectangular deck space, which is crucial for accommodating the diverse array of firefighting equipment, rescue gear, and personnel required for complex incidents. High-performance examples like the SAFE 3812 Fire Rescue Boat can achieve impressive speeds up to 55 knots with high agility, demonstrating their capability for rapid response. Trimarans (three hulls) are excellent for high speed, often being lighter and more specialized than catamarans. Their unique design separates the requirements for resistance (achieved by a long, narrow central hull) from stability (provided by smaller side hulls, or amas), allowing for incredible flexibility in hull design. This configuration results in good seakeeping, significantly reducing pitch motions and roll accelerations making for a gentle ride even in challenging seas. Trimarans boast larger available deck areas and moderate space below deck, further enhancing their utility for firefighting missions. They also offer major advantages for damage survival, being described as "virtually unsinkable" and providing predictable stability even if an ama submerges, due to the inherent reserve buoyancy of the cross deck. The 63m SAR Trimaran exemplifies the ability to maintain higher average speed comfortably and safely in adverse conditions due to its inherent stability and wave-piercing bow design. This demonstrates that multi-hulls are not just faster alternatives but fundamentally more robust, versatile, and safer platforms for comprehensive offshore emergency response, representing a paradigm shift in vessel design for this critical mission.

The evolution beyond traditional monohulls to specialized hull forms like Trimarans, or highly optimized V-shaped planing hulls, represents a shift towards mission-specific hydrodynamic design. This approach allows for overcoming the inherent compromises of general-purpose monohulls by prioritizing specific performance attributes crucial for offshore firefighting. Advanced hull form design, utilizing Computational Fluid Dynamics (CFD), allows for optimization towards minimum resistance, improved fuel efficiency, and enhanced maneuverability. ST Engineering's Heavy Fire Vessel (HFV), classified Fi-Fi III, and exemplifies this with an optimized hull for speed (20 knots) and unparalleled pumping capacity. Similarly, SAFE Boats employ optimized V-shaped hulls with performance fins for high speed (up to 55 knots) and agility in rough water. The use of advanced computational tools enables precise optimization, leading to vessels that are not just faster, but also more effective and safer platforms for their highly demanding roles, ensuring that the vessel's design directly supports the operational imperative. Oludi and Chuku (2024) states that the static analysis of mooring systems ignores the effect of hydrodynamic force caused by wave and current. Therefore, it is recommended that, in the design of statically mooring lines, factors of safety should be considered to account for the hydrodynamic force caused by wave and current.

Overview of shipboard firefighting systems

Fire suppression on board ships is important to maritime safety, relying on fundamental principles to combat combustion effectively. These principles are derived from understanding the fire triangle (heat, fuel, oxygen) and the fire tetrahedron, which adds the chemical chain reaction as a fourth essential element. By disrupting any of these components, a fire can be extinguished. In a situation where the free surface effect becomes too much, knowing the power required to propel a ship enables the naval architect professional to select the adequate propulsion plant and also to determine the amount of fuel storage required.

Main categories of fire extinguishing agents: Applications and limitations

Diverse fire extinguishing agents are employed on ships, each with specific applications and limitations: (1) Water: As the most widely used agent due to its abundance, water is highly effective for Class A fires (involving solid combustibles like wood, paper, and textiles) by cooling the fuel below its ignition temperature. However, water is unsuitable for electrical fires or fires involving flammable liquids, as it can conduct electricity or spread the burning liquid, creating dangerous situations. Its effectiveness also diminishes in freezing conditions. (2) Foam: Foam extinguishers work by spreading a layer over the burning material, smothering the fire by cutting off oxygen and preventing re-ignition. They are particularly effective on Class B fires (flammable liquids such as petrol or oil) and are versatile for environments with mixed fire risks. However, foam should not be used on electrical fires due to its water content. (3) CO2 (Carbon Dioxide): Carbon dioxide extinguishers are ideal for Class C fires (electrical fires) because they leave no residue and do not damage sensitive equipment. They extinguish fires by displacing oxygen, effectively smothering the flames. Despite these advantages, CO2 systems have limitations, including limited reach and coverage for larger fires. Rapid discharge can cause cold burns if not handled properly, and in confined spaces, the displaced oxygen can create a hazardous environment, posing a serious risk to personnel. Consequently, strict evacuation protocols are necessary before CO2 release.

(4) Inert Gases (e.g., Nitrogen): These gases are used to displace oxygen, primarily in the cargo tanks of tankers (especially oil and chemical tankers of 8,000 DWT and above) to prevent the formation of flammable atmospheres. The oxygen limit for inert gas supplied to cargo tanks is typically maintained around 5%. Inert gas can be generated from exhaust gases or dedicated nitrogen generators. Limitations include potential contamination from exhaust gases and the necessity for shore supply or onboard generators for continuous inerting. (5) Dry Chemical Powder (DCP): Dry powder extinguishers are versatile, effective against Class A, B, and C fires, and specialized types exist for Class D fires (combustible metals). They primarily work by interrupting the chemical chain reaction of combustion. A key limitation is that caution is required when using them in confined spaces, as the powder can obscure vision. (6) Wet Chemical: Specifically designed for Class K fires, which involves cooking oils and fats, wet chemical extinguishers are commonly found in commercial kitchens. In this project, the focus will be on the use of sea water for firefighting due to its abundance and effectiveness in handling offshore fires.

Regulatory frameworks governing fire protection and extinguishing systems on ships

The maritime industry operates under a framework of international regulations to ensure fire safety. The primary instruments are the International Convention for the Safety of Life at Sea (SOLAS) and the International Code for Fire Safety Systems (FSS Code). (1) SOLAS Chapter II-2: Fire Protection, Fire Detection and Fire Extinction: This chapter of SOLAS provides comprehensive fire safety provisions applicable to all ships, with specific, detailed measures tailored for passenger ships, cargo ships, and tankers. It covers a wide range of aspects, including the use of non-combustible materials in ship construction, standards for fire tests for divisions (e.g., A-class and B-class divisions that prevent smoke and flame passage), and general requirements for fire detection and extinguishing systems. SOLAS II-2 also mandates the carriage of spare charges for fire extinguishers on board. (2) FSS Code (International Code for Fire Safety Systems): Developed by the International Maritime Organization (IMO) under the SOLAS Convention, the FSS Code is a primary document that establishes stringent standards for fire prevention, detection, and suppression on ships. Its objectives are to reduce fire risks, enhance emergency preparedness, and ensure a consistent global application of safety standards across commercial and passenger vessels.

Beyond these, the FSS Code also includes requirements for visual and audible alarms, redundant power supplies for fire safety systems, and specific test and inspection protocols to ensure equipment functionality. Emergency Escape Breathing Devices (EEBDs) and low-location lighting systems are also mandated to facilitate safe evacuation. Both SOLAS Chapter II-2 and the FSS Code differentiate their requirements based on the type of vessel (e.g., passenger ships, cargo ships, tankers) and specific areas within a ship (e.g., machinery spaces, cargo holds, accommodation areas, galleys). For instance, inert gas systems are mandatory for oil and chemical tankers of 8,000 DWT and above. Machinery spaces are required to be separated from living areas by Class A boundaries, constructed of steel or equivalent material, capable of preventing smoke and fire passage for at least 60 minutes. This regulatory framework is highly proactive in fire safety, emphasizing not just the installation of equipment but also continuous improvement through ongoing practices. The FSS Code, for example, highlights the importance of regular fire drills, comprehensive crew training, and diligent maintenance.

Fixed versus mobile firefighting systems

Shipboard firefighting strategies integrate both fixed and mobile systems, each offering distinct advantages and disadvantages depending on the fire scenario.

Common fixed firefighting systems on ships

Fixed firefighting systems are permanently installed on a vessel and are designed to protect specific compartments or areas. Examples include fixed gas systems (such as CO2 or inert gas) typically found in machinery spaces and cargo holds, water mist systems, sprinkler systems for accommodation areas, and deck foam systems on tankers. Advantages: (1) Rapid Response: Fixed systems, especially those with automatic detection, can activate quickly, allowing for rapid suppression of a fire before it escalates. (2) Extensive Reach and Capacity: They are engineered to effectively cover large or hazardous areas, providing suppression capability within their designated zones. (3) Automated Operation: Automation minimizes the need for human intervention in dangerous, smoke-filled, or high-heat environments, thereby enhancing crew safety. (4)

Water Mist Specific Benefits: Water mist systems offer several distinct advantages, including being safe for personnel, providing fast extinguishment, being environmentally friendly, causing minimal water damage, and having low recharging costs and short downtime after discharge. Their fine mist droplets are more penetrative than traditional sprinklers and also act as a smoke suppressant.

Disadvantages: (1) CO2 Risks: Fixed CO2 systems, while effective, pose a serious risk to personnel by displacing oxygen. This necessitates a mandatory evacuation of the area and a time delay before discharge, which can paradoxically allow minor fires to escalate during the evacuation period. (2) Sprinkler Limitations: Traditional sprinkler systems may be less effective if the seat of the fire is shielded from the sprinkler head, preventing direct water application. (3) Aerosol System Costs: While aerosol systems can be cheaper to install initially, their canisters or generators require replacement every 5 to 7 years, leading to recurring significant expenses. (4) System Failure Potential: Fixed systems can fail due to inadequate maintenance, improper sealing of compartments, or late activation, compromising their intended protective function.

Common mobile firefighting equipment

Mobile firefighting equipment provides flexibility and direct intervention capabilities for localized incidents or as a supplement to fixed systems. Common mobile equipment includes fire hoses, portable extinguishers (containing water, foam, CO2, or dry powder), fire axes, portable foam applicators, wheeled (mobile) fire extinguishers, and essential firefighter's outfits. Firefighting ships also fall within this category. (1) When Preferred or Necessary: Mobile systems are crucial for the initial response to a fire, for tackling localized incidents, or for addressing fires in areas not adequately covered by fixed systems. They offer the flexibility of direct application by trained crew members. Limitations in Large-Scale Emergencies: (1) Limited Reach and Capacity: Portable equipment is inherently insufficient for combating large-scale, rapidly spreading fires, lacking the volume and sustained discharge capacity required. (2) Crew Exposure: Mobile firefighting necessitates personnel directly approaching the fire, exposing them to significant hazards such as intense heat, hazardous materials, high voltages, and high-pressure hydraulic lines. (3) Equipment Quality and Compatibility: The effectiveness can be hampered by the quality and compatibility of shipboard personal protective equipment (PPE), which may include older steel bottle self-contained breathing apparatus (SCBA) and lightweight gear not suitable for intense heat. Additionally, hoselines might feature non-standard or incompatible couplings. (4) Human Factor Vulnerabilities: The reliability of mobile systems is susceptible to human error, such as fire doors being tied open for convenience, or systems failing to operate effectively due to lack of maintenance or delayed activation by crew. The effectiveness of mobile firefighting relies so much on human factors, including crew training, equipment quality, and strict adherence to established procedures. The challenges highlighted, such as inadequate PPE, incompatible equipment, and human errors, show that the capability of mobile firefighting is not solely about the availability of equipment. It requires ensuring that the crew is comprehensively trained, properly equipped, and disciplined enough to utilize the equipment correctly under extreme stress. This makes human factors a significant area of vulnerability and a critical limitation in managing large-scale emergencies at sea.

Fundamental difference when a vessel is designed to fight external fires

The mission and capabilities of a vessel designed for external firefighting differ from those focused on internal protection. (1) Internal Mission: The core mission of standard shipboard systems is defensive: to protect the vessel's own integrity, its crew, and its cargo from internal fire threats. (2) External Mission: In contrast, a vessel designed for external firefighting, known as a Firefighting (FiFi) vessel, has an offensive mission: to combat fires on other vessels or offshore structures. This mission demands that the vessel has specialized equipment capable of projecting large volumes of extinguishing agents over significant distances. (3) Capability Difference: FiFi vessels are equipped with powerful pumps and water cannons (monitors) that boast high capacities (ranging from 600 m^3/h to 10,000 m^3/h) and impressive throwing lengths and heights (e.g., 85-150m length, 45-70m height). Furthermore, they often incorporate self-protection water spray systems (deluge systems) to shield the vessel itself from the intense heat and flames of an external incident. This distinction represents a strategic shift from defensive self-protection to offensive external intervention. Standard shipboard systems are inherently designed to protect themselves from internal threats, acting as a last line of defense for the vessel's survival. FiFi systems, however, are engineered to project immense force outward to protect other assets or structures. This difference in mission requires different design parameters, particularly concerning pump capacity, monitor range, and the critical need for self-protection against the extreme external thermal demands.

Conventional internal firefighting systems: Insufficient for external offshore fires

Conventional internal firefighting systems are insufficient for combating large-scale external offshore fires due to several factors, some of which are listed: (1) Scale and Intensity of Offshore Fires: Offshore fires, particularly those involving high-pressure hydrocarbon-based fuels (jet fires) or extensive pool fires, are typically far larger and more intense than the internal fires for which standard shipboard systems are designed. (2) Limited Capacity and Reach: Internal systems lack sufficient pump capacity, monitor range, and water reserves required to effectively engage such large-scale, high-momentum fires from a safe and effective distance. Their design parameters are not scaled for external, high-energy incidents. (3) Structural Vulnerability of Offshore Platforms: Offshore platforms often feature unprotected structural steel and hydrocarbon-handling equipment that can fail rapidly (within minutes) when exposed to direct flames. Their layouts often lack adequate separation between high-risk equipment items. Conventional internal ship systems are not engineered to provide protection against such severe external thermal demands or to prevent the quick degradation of an external facility. (4) Escalation Risk: Offshore facilities are highly susceptible to explosion damage and incident escalation due to the close spacing of high-pressure equipment, potentially inadequate ventilation, and a reliance on active water spray systems that can themselves be compromised by local explosions. Internal ship systems cannot prevent such large-scale escalation. (5) Continuous Fuel Source: Many offshore fires involve a continuous release of fuel from wells or pipelines, demanding sustained, high-volume suppression capabilities that internal ship systems are not equipped to provide. This underscores the necessity for dedicated, high-capacity external firefighting assets like FiFi vessels to effectively address these high-consequence scenarios, as standard vessels cannot provide the required offensive capability.

Different FiFi classes (FiFi 1, FiFi 2, FiFi 3): Differentiating criteria

FiFi classes are notations assigned by leading classification societies such as DNV, ABS, and Lloyd's Register. These classifications denote a vessel's specific firefighting capabilities, which are determined by stringent criteria which include: (1) Total Pump Capacity: The aggregate volume of water that can be delivered per hour. (2) Number and Range of Monitors: The quantity of water cannons and their maximum throwing length and height. (3) Foam Capacity: The ability to store and proportion foam concentrate for specific fire types. (4) Water Spray/Self-Protection Systems: Systems designed to protect the firefighting vessel itself from intense heat. Higher FiFi classes often mandate more sophisticated water systems and imply greater redundancy in fire pumps and power generation, which is crucial for maintaining operational effectiveness in the event of component failure. *Table 3* summarizes the minimum requirements for each FiFi class, as specified by various classification societies.

***Table 3**. FiFi classifications and minimum requirements.*

Criterion	FiFi 1	FiFi 2	FiFi 3
Min. Number of Fire Monitors	2	3-4	4
Total Water Capacity (m³/h)	2400	7200	9600
Min. Throw Length (m)	120	150	150 (water), 180 (DNV)
Min. Throw Height (m)	45	70	70 (water), 110 (DNV)
Min. Number of Fire Pumps	1-2	2-4	2-4
Foam Monitors	Optional (some end users)	Mobile, high-expansion foam generators	2 fixed low-expansion foam monitors (300 m³/h each, 50m height)
Min. Fuel Holding Time (H)	24	96	96
Number of Hose Hydrants (each side)	4 (DNV)	4 (DNV), 8 (ABS)	8 (DNV, ABS)
Self-Protection System	Permanently installed water spray system	Permanently installed water spray system	Permanently installed water spray system

Emphasis on FiFi 1

FiFi 1 represents the foundational class for dedicated offshore firefighting capabilities, going beyond standard shipboard systems. (a) Minimum Requirements for a FiFi 1 System include the following: (1) Pump Capacity: A FiFi 1 system must have a total water capacity of not less than 2400 m³/h (10560 GPM). This is typically achieved with two 1200 m³/h fire pumps or a single 2400 m³/h pump. (2) Number of Monitors: At least two fire monitors are required. (3) Throwing Length: The minimum throwing length for water in still air must be 120 meters. (4) Throwing Height: The minimum throwing height must be 45 meters. (5) Self-Protection: A permanently installed water spray (deluge) system is mandatory to protect the vessel's hull and superstructure from external heat and flames during firefighting operations. (6) Hose Connections: DNV rules specify the provision of a hydrant on each side of the ship with four hose connections. (7) Fuel Holding Time: The system must be capable of continuous operation of all fire monitors for a minimum of 24 hours.

(b) Typical Components of a FiFi 1 System include the following: (1) Dedicated Fire Pumps: These are the heart of the system, often driven by dedicated diesel engines or via power take-off (PTO) from the vessel's main engines. (2) Fire Monitors: High-capacity water/foam cannons that project extinguishing agents over long distances. (3) Foam Concentrate Tanks and Proportioning Systems: While optional for FiFi 1 by some class rules, these are commonly included for enhanced fire suppression, particularly for oil fires. (4) Water Spray/Deluge Systems: For self-protection of the vessel. (5) Remote Control System: Allows operators to control pumps and monitors from a safe distance, typically from the wheelhouse. (6) Piping Network: Extensive suction and discharge lines to transport water from sea chests to pumps and then to monitors and hose connections. (7) Ancillary Equipment: Includes various valves, gauges, and electrical components necessary for system operation and monitoring.

(c) Design Considerations for Integrating a FiFi 1 System into a Vessel: (1) Pump Room Arrangement: Critical attention is given to the design of suction and discharge piping to minimize turbulent water flow and ensure a consistent, sufficient water supply to the pumps. Suction lines should be as short and straight as practicable, with a maximum design water velocity typically not exceeding 2 m/s. (2) Piping Network Design: The piping system from the pumps to the water monitors must be separate from the piping system supplying hose connections for mobile firefighting equipment. The system should also incorporate arrangements to prevent pump overheating at low delivery rates, and all pipes must be protected against corrosion. (3) Power Requirements: FiFi systems demand significant power, often relying on the vessel's main engines or auxiliary power units. Classification societies impose strict requirements for power availability, such as ABS rules mandating 20% of engine power to remain available for station-keeping and maneuvering during firefighting operations. (4) Monitor Placement: Monitors must be strategically placed to ensure optimal coverage of the target with minimal obstruction, while also maintaining necessary visibility from the wheelhouse and control station during water spraying. (5) Sea-water Inlets and Sea Chests: These must be designed to ensure an even and sufficient supply of water to the pumps. Their location is crucial to prevent water supply impedance from the ship's motions or the water flow to and from thrusters or main propellers. Importantly, sea-water suctions for firefighting pumps should not be arranged for other purposes. (6) Reaction Forces: The high-powered water jets from monitors generate significant recoil forces. The vessel's propulsive power must be sufficient to counteract these forces, with ABS rules stipulating that reaction forces should not exceed 80% of propulsive power, triggering alarms and automatic power reduction if this threshold is approached. (7) Alignment: Precise alignment of FiFi pump systems, with clearances as tight as 0.05mm for the pump shaft's seal and bearing, is vital for efficiency and lifespan. Laser alignment services are often employed to achieve and maintain this precision.

The performance of a FiFi system depends on mechanical, hydrodynamic, and operational factors. For instance, pump capacity and throwing range are directly influenced by the hydrodynamic efficiency of the water intake design and the mechanical precision of pump alignment. These factors, in turn, are constrained by the vessel's propulsive power, which must counteract the significant recoil forces generated by the monitors while maintaining hydrodynamic stability and station-keeping. Challenges and Limitations Associated with FiFi 1 Systems: (1) Pump Recoil Forces: The high-powered water jets from the monitors generate large recoil forces. These forces can significantly affect the vessel's stability and ability to maintain station, necessitating sufficient propulsive power to effectively counteract them. (2) Water Intake Considerations: Ensuring a sufficient and uninterrupted water supply to the fire pumps is a continuous challenge. Issues such as low supply pressure from the source, blockages or restrictions in the suction line, or cavitation (formation of vapor bubbles due to pressure drops) can impede pump performance. The design of sea chests and inlets must prevent any impedance to water flow. (3) Maintenance: Fire pumps and their associated systems demand regular extensive maintenance to ensure reliability. This includes routine inspections, performance assessments like flow tests, proper lubrication, battery checks for diesel-driven pumps, alignment checks, and maintenance of critical components such as impellers, casings, and pressure relief valves. Neglecting these can lead to issues like overheating, cavitation, or leakage, severely compromising the system's effectiveness during an emergency. (4) Operational Complexity: Integrating high-powered firefighting systems with the vessel's propulsion and maneuvering systems requires intricate design and extensive testing to ensure harmonious operation and prevent adverse interactions. (5) Cost: The specialized nature of FiFi systems, including their powerful pumps, monitors, and complex integration, makes their construction and maintenance a significant financial investment.

Fundamentals of dynamic positioning

Dynamic Positioning (DP) systems provide precision and flexibility in vessel station-keeping and are a transformative technology in offshore operations in that they enable a vessel to automatically maintain its position and heading, or follow a predetermined track, by controlling its own propulsion and thrusters. This automated control system continuously counteracts external environmental disturbances such as wind, waves, and currents, eliminating the need for traditional anchoring or mooring systems.

Key components of a DP system and their interaction

A DP system comprises several components that work in harmony to achieve precise station-keeping: (1) DP Control System: Often referred to as the "brain" of the system, the DP control system processes data from various sensors and position reference systems. It calculates the necessary adjustments to maintain the vessel's position and heading and then sends precise commands to the thrusters. This system typically includes multiple computer systems, operator displays, and alarm systems. (2) Position Reference Systems (PRS): These systems provide accurate, real-time information about the vessel's geographical position. Common types include Differential Global Positioning Systems (DGPS), hydroacoustic positioning systems (using underwater beacons), and taut wire systems (measuring relative position to the seabed). (3) Environmental Reference Systems: These sensors measure the external forces acting on the vessel. Examples include anemometers for wind speed and direction, motion reference units (MRU) to detect vessel motion (roll, pitch, heave) and wave height, and current meters to measure water current velocity. (4) Thrusters and Propellers: These are the actuators of the DP system, generating the necessary forces and thrust to counteract environmental disturbances and maintain the vessel's desired position and heading. (5) Power System: This subsystem supplies all necessary power to the DP system. It encompasses prime movers (engines), generators, electrical switchboards, distribution systems (cabling), and uninterruptible power supplies (UPS) to ensure continuous operation even during power fluctuations. The interaction among these components forms a continuous, real-time feedback loop for environmental adaptation. The DP control system constantly monitors environmental conditions and the vessel's actual position via its array of sensors and PRSs. It then utilizes a sophisticated mathematical model of the vessel, which is continuously updated and refined using techniques like Kalman filtering, to calculate the precise thruster outputs and steering angles required to counteract any detected forces. This ensures that the vessel maintains its desired station with high accuracy.

Main advantages of using DP systems in offshore operations

The adoption of DP systems has brought numerous benefits to offshore operations. The following are some of the advantages: (1) Precise Station-Keeping: DP systems enable vessels to maintain exact positions for extended periods, which is necessary for highly sensitive operations such as firefighting, offshore drilling, subsea construction, diving support, and various scientific research activities. (2) Eliminating Anchor Handling: DP removes the logistical challenges and risks associated with deploying and retrieving anchors. This is particularly advantageous in deep waters, areas with congested seabeds (e.g., pipelines, subsea templates), or environmentally sensitive ecosystems where anchoring is impractical or harmful. (3) Operating in Deep Water: DP systems facilitate operations in water depths where traditional anchoring methods are simply impossible, thus facilitating resource exploration and development. (4) Enhanced Operational Flexibility and Safety: DP significantly reduces the risk of accidents caused by vessel drift or loss of position by minimizing human error in station-keeping. It also allows for quick setup and easy repositioning. (5) Improved Efficiency and Productivity: By enabling vessels to maintain position reliably even in harsh weather conditions, DP systems reduce operational downtime and increase overall productivity.

Classification of DP systems

Dynamic Positioning systems are classified into different equipment classes by international bodies and classification societies based on their levels of redundancy and fault tolerance. Classification societies such as DNV, ABS, and Lloyd’s Register issue rules for dynamically positioned ships, interpreting the guidelines provided by the International Maritime Organization (IMO), particularly IMO MSC/Circ. 645 (IMO, 2025). These classifications define the degree of redundancy and operational reliability of a DP system: (1) IMO DP Equipment Class 1 (Corresponding notations: DPS-1, DYNPOS-AUT, DP(AM)): This class provides basic automatic and manual position and heading control under specified environmental conditions but lacks redundancy to withstand single component failures. A single fault in any active component or system within the DP setup may lead to a complete loss of position. (2) IMO DP Equipment Class 2 (Corresponding notations: DPS-2, DYNPOS-AUTR, DP(AA)): This class incorporates redundancy in its active systems. It requires at least two independent computer systems for control. Redundancy extends to power generation, thruster systems, and position reference systems to ensure that a single active fault does not lead to a loss of position. This often involves a split-bus power system arrangement. A single fault in an active component or system (e.g., generators, thrusters, switchboards, remote-controlled valves) should not result in a loss of position. However, a loss of position may still occur following the failure of a static component, such as cables, pipes, or manual valves. (3) IMO DP Equipment Class 3 (Corresponding notations: DPS-3, DYNPOS-AUTRO, DP(AAA)): This class provides full redundancy, including physical separation of critical components. It is designed to withstand any single failure, including a completely burnt fire subdivision or a flooded watertight compartment, without loss of position. It demands at least two independent computer systems with an additional, separate backup system. These critical systems must be physically separated by A60 class divisions (fireproof and watertight bulkheads) to withstand fire or flooding in any one compartment. A power management system (PMS) with redundancy and blackout prevention functionality is also required. All critical components, including power, thrusters, control, and position reference systems, must be redundant and physically segregated to ensure continued operation even if an entire compartment is compromised. *Table 4* shows IMO DP equipment classes and redundancy levels.

***Table 4**. IMO DP equipment classes and redundancy levels.*

IMO DP Equipment Class	Corresponding Class Notations (ABS, LRS, DNV)	Description of Redundancy Level	Impact of Single Fault (Loss of Position)	Key Redundancy Requirements
Class 1	DPS-1, DYNPOS-AUT, DP(AM)	No redundancy	May occur	Basic automatic/manual control; UPS for 30 min operation of control/sensors/PRSs
Class 2	DPS-2, DYNPOS-AUTR, DP(AA)	Redundancy in active systems	Should not occur (from active fault); May occur (from static fault)	Two independent computer systems; Redundancy in power generation, thrusters, PRSs; Split-bus power system common
Class 3	DPS-3, DYNPOS-AUTRO, DP(AAA)	Full redundancy with physical separation	Should not occur (from any single failure, incl. compartment fire/flood)	At least two independent computer systems with separate backup; Physical separation by A60 divisions; Redundant PMS with blackout prevention

DP 1 system and required minimum capability in terms of equipment and redundancy

Dynamic Positioning Class 1 systems represent the entry level for automated station-keeping with stipulated minimum Requirements in Terms of Equipment and Redundancy. According to IMO MSC/Circ. 645, the foundational guideline for DP systems, a DP 1 system is characterized by its lack of redundancy, meaning that a single fault within the system can potentially lead to a loss of position. This class provides automatic and manual control for maintaining the vessel's position and heading under specified maximum environmental conditions. However, while a DP 1 system does not feature redundancy for its primary operational components, it is typically required that the control system, console, displays, alarm systems, and reference systems maintain operational capability for at least 30 minutes in the event of a main power system failure. This is achieved through uninterruptible power supplies (UPS).

Design considerations for integrating a DP 1 system into a vessel

Integrating a DP 1 system into a vessel requires careful design considerations to maximize its effectiveness within its inherent limitations. The following details design considerations for optimal performance. (1) Thruster Placement for Optimal Control Authority: The design and placement of thrusters and propellers are crucial for achieving good position control, especially in varying environmental conditions. The location and geometrical arrangement of these propulsors must be optimized for effective force generation and maneuverability. (2) Power Supply Arrangements: The power supply system, encompassing prime movers, generators, switchboards, and distribution networks, must be designed with high flexibility. This allows it to handle sudden and potentially irregular changes in power demand from the thruster system. A critical requirement for DP systems, even Class 1, is that the control system, console, displays, alarm systems, and reference systems must be able to operate for at least 30 minutes in the event of a main power system failure, typically supported by uninterruptible power supplies (UPS). (3) Sensor Locations: Position reference systems (PRS) and environmental sensors (e.g., wind sensors, motion reference units) must be strategically located to provide accurate and reliable data to the DP control system. Proper placement minimizes interference and ensures optimal data acquisition. (4) Mathematical Model Integration: The DP system relies on a sophisticated mathematical model of the vessel, which incorporates information about wind and current drag, as well as the precise location of the thrusters. This model is continuously corrected and refined using techniques like Kalman filtering, ensuring that the system's calculations for thruster output and steering angles are as accurate as possible. (5) System Integration: All DP subsystems, including control, power, thrusters, and sensors, must be seamlessly integrated. Careful attention to cabling and routing is essential to ensure reliable communication and operation across the entire system.

DP 1 systems enhances safety compared to manual maneuvering or anchoring, in emergency response

Despite its lack of redundancy, a DP 1 system offers substantial safety enhancements over traditional manual maneuvering or anchoring, especially in emergency firefighting response scenarios as the following depicts. (1) Precision and Stability: DP 1 provides significantly improved vessel control, predictability, positional accuracy, and maneuverability compared to manual control. This is vital for maintaining an optimal distance from an incident and for achieving precise water jet aim during firefighting operations. (2) Reduced Human Error and Workload: By automating the complex task of position-keeping, DP 1 systems inherently reduce the potential for human error, which is a significant contributor to maritime incidents. This automation also minimizes crew workload and fatigue, allowing personnel to focus their attention on critical emergency tasks rather than continuous vessel maneuvering. (3) Eliminates Anchor Risks: DP 1 avoids the inherent risks associated with anchor handling, such as anchor dragging, entanglement with subsea infrastructure, or damage to sensitive ecosystems. This is particularly beneficial in deep or congested waters where anchoring is impractical or hazardous. (4) Quick Set-up: DP systems allow for rapid deployment and station-keeping without the time-consuming process of deploying and retrieving anchors, enabling a quicker response to emergencies. (5) Emergency Response Context: In an emergency, even a DP 1 system provides a stable and controlled platform for initial response. This allows for a more controlled approach and engagement with an incident, which manual maneuvering or anchoring cannot reliably achieve in dynamic or rapidly evolving situations. It enables the vessel to respond efficiently to sudden environmental changes, maintaining a consistent operational stance. (6) Safety of Personnel: A stable and predictable platform, maintained by DP, minimizes risks to crew members who are operating firefighting equipment, managing hoses, or conducting rescue operations near the hazard. The effectiveness of a FiFi system is fundamentally dependent on the vessel's ability to maintain precise station-keeping. Without DP, a vessel attempting to fight an external fire would struggle to hold an optimal distance, accurately aim its water jets, and avoid collisions in dynamic and often unpredictable environmental conditions.

The Trimaran Hull form stability complements DP system precision for firefighting

The combination of a trimaran hull form and a DP system is a synergistic design choice. The trimaran's passive stability reduces the external forces and motions that the active DP system would otherwise need to continuously counteract. This, in turn, enhances the DP system's precision and efficiency. The following elaborate on the concept. (1) Reduced Vessel Motion: The three-hull configuration of a trimaran significantly limits the vessel's movements (such as roll, pitch, and heave) even in rough seas, providing a remarkably stable platform. (2) Enhanced DP Performance: With less inherent vessel motion to counteract, the DP system's thrusters and control algorithms can operate more efficiently and precisely in maintaining the vessel's exact position and heading. This translates directly into more accurate water jet aim and improved overall control during critical firefighting operations, where precision is paramount. (3) Improved Workability: The combination of a stable hull and precise DP allows the vessel to maintain its operational position in higher sea states (e.g., up to significant wave heights of 3.5–4.0 meters for some designs), thereby extending its workability and operational flexibility in challenging offshore environments. (4) Crew Comfort and Safety: The reduced vessel motion contributes to greater comfort and safety for the crew, mitigating fatigue and improving their ability to perform complex tasks effectively during prolonged emergency operations.

The need for high-speed vessels designed specifically for the Gulf of Guinea

A vessel must be designed for its specific route to ensure safety, efficiency, and economic viability. A generic design cannot account for the unique environmental, operational, and regulatory factors that vary significantly from one maritime route to another. Environmental Conditions: The physical design of a vessel, including its hull form and stability, is critically tailored to the typical sea states and weather patterns it will encounter. A ship designed for the relatively calm waters of the Mediterranean Sea, for instance, would be ill-equipped to handle the powerful waves and unpredictable storms of the North Atlantic Ocean. The structural strength and freeboard are calculated based on the maximum anticipated wave heights and bending moments for a given route to ensure the vessel can operate safely without suffering damage. High-speed vessels designed specifically for the Gulf of Guinea are essential for effective and safe maritime operations, as their design is tailored to meet the region's unique challenges. The trimaran's inherent stability and reduced hydrodynamic resistance enable the vessel to achieve higher speeds and greater fuel efficiency, which is vital for rapid response across the region's vast and dispersed offshore oil fields. This is particularly important for addressing security threats, such as piracy, which is highlighted as a major problem in the Gulf of Guinea. Furthermore, a route-specific design is crucial for ensuring the vessel can handle the specific environmental conditions, optimizing the hull for the prevailing sea states to maximize safety and operational efficiency. This combination of a route-optimized hull and specialized equipment ensures the vessel is both a rapid responder and a highly capable platform, directly addressing the key operational demands and safety concerns of the region's maritime domain.

The most significant gap is the absence of any past work on a firefighting trimaran specifically for operation in the Gulf of Guinea. While components exist, their integrated application for this precise role (firefighting) and region (the Gulf of Guinea) is an area for novel development. This apparent absence is therefore not a void of knowledge, but an absence of a direct, pre-existing integrated solution, implying that the task is not to replicate an existing design but to create and optimize proven technologies and design principles for a new application.

Conclusion

Offshore firefighting vessels constitute a critical component of maritime safety systems, particularly in regions with dense offshore infrastructure and hydrocarbon activities. The literature consistently identifies offshore fires as high-consequence events, with rapid escalation driven by large fuel inventories, complex process systems, and remote operating environments. Unlike land-based emergencies, offshore incidents rely heavily on mobile external intervention, making specialized firefighting vessels indispensable for life safety, environmental protection, and asset preservation. Previous studies document the evolution of firefighting vessels from conventional tugs and auxiliary craft to dedicated Firefighting (FiFi) vessels equipped with high-capacity pumps, long-range monitors, and dynamic positioning systems. Vessel speed is repeatedly highlighted as a dominant performance parameter as fire growth follows a geometric (t-squared) progression, rendering response time a critical determinant of damage severity and survivability. However, achieving high transit speed while maintaining operational stability presents a fundamental design challenge. Hydrodynamic investigations show that traditional monohull designs suffer from inherent trade-offs between speed, resistance, seakeeping, and stability. Increased resistance at higher speeds leads to excessive fuel consumption and emissions, while shallow-water effects further degrade performance in coastal and offshore shelf regions. During firefighting operations, monohulls are particularly vulnerable to stability degradation due to monitor recoil forces, free-surface effects, and wave-induced motions, which compromise firefighting accuracy and crew safety.

Recent literature increasingly supports multihull configurations as an effective means of resolving these trade-offs. Catamarans and Trimarans exhibit reduced hydrodynamic resistance, improved fuel efficiency, and superior transverse stability compared to monohulls. Among these, Trimaran hull forms are shown to offer distinct advantages by decoupling resistance and stability requirements: a slender central hull minimizes drag, while side hulls provide substantial righting moments. Empirical and numerical studies report improved seakeeping, reduced roll accelerations, enhanced deck area utilization, and greater precision in fire monitor operation. Despite these demonstrated advantages, existing studies primarily focus on generic multihull performance or vessels designed for harsh environments such as the North Sea. There is limited research addressing region-specific optimization of firefighting vessels, particularly for benign-to-moderate sea states such as those prevalent in the Gulf of Guinea. Consequently, the integration of Trimaran hydrodynamics, firefighting system requirements, and regional environmental conditions remains insufficiently explored in current literature. Absence of region-specific design studies for firefighting vessels optimized for the Gulf of Guinea’s environmental, operational, and infrastructural characteristics. There is limited integration of hydrodynamic optimization and firefighting performance, particularly regarding monitor recoil forces, stability, and station-keeping requirements. More so, there appears to be insufficient comparative analysis between monohull, catamaran, and trimaran configurations under firefighting operational loads. In addition, the apparent lack of holistic optimization frameworks combining speed, resistance, fuel efficiency, emissions, stability, and FiFi system integration for offshore firefighting missions. Proposing a Trimaran-based firefighting vessel concept optimized specifically for the Gulf of Guinea. Integrating hydrodynamic performance, stability analysis, and firefighting system requirements within a unified design framework. Demonstrating how trimaran configurations can simultaneously enhance response speed, operational stability, and energy efficiency compared to conventional monohulls. Providing engineering insights relevant to offshore safety vessel design, supporting future regulatory, operational, and design decision-making in emerging offshore regions.

Acknowledgement

This research is self-funded.

Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

REFERENCES

[1] American Bureau of Shipping (ABS) (2022): Rules and Guides. – ABS Web Portal 4p.
[2] Brkić, D. (2025): Fire Hazards Caused by Equipment Used in Offshore Oil and Gas Operations: Prescriptive vs. Goal-Oriented Legislation. – Fire 8(1): 22p.
[3] Chuku, A.J., Okoronkwo, C.A., Nwufo, O.C., Uche, R., Nwaji, G.N. (2024): Effects of Energy Efficiency Design Index on Resistance, Hydrostatics and Ship Design Using Hughes-Prohaska Method. – International Journal of Advances in Engineering and Management 6(01): 399-418.
[4] Det Norske Veritas (DNV) (2024). Energy transition outlook 2024. – DNV 261p.
[5] Det Norske Veritas (DNV) (2022): Rules for classification of ships-July2021 edition. – DNV 7p.
[6] Energy Maritime Associates (EMA) (2025): A guide to offshore support vessels. – EMA Web Portal 30p.
[7] International Association of Oil & Gas Producers (IOGP) (2021): Safety performance indicators-2020 data (Report No. 2021pb001). – IOGP Web Portal 3p.
[8] International Maritime Organization (IMO) (2023): Decarbonization of shipping: IMO strategy for reducing GHG emissions from ships. – IMO 13p.
[9] International Maritime Organization (IMO) (1974): International Convention for the Safety of Life at Sea (SOLAS), 1974. – IMO 6p.
[10] Jesús, V. (2024): Rapid response systems for oil spills in offshore areas. – Inspenet Web Portal 8p.
[11] Michalis, C., Myrto, K. (2012): Safety of offshore oil and gas operations: Lessons from past accident analysis. – JRC Publications Repository 60p.
[12] National Oceanic and Atmospheric Administration (NOAA) (2022): Amendments to the North Atlantic Right Whale Vessel Strike Reduction Rule. – NOAA Web Portal 3p.
[13] Oludi, K., Chuku, A.J. (2024): Static Analysis of Mooring Lines for Station keeping of Offshore Structures. – International Journal of Advances in Engineering and Management 6(2): 218-238.
[14] Park, S.W., Kim, S.H., Kim, Y.I., Lee, I. (2022): Hull form optimization study based on multiple parametric modification curves and free surface reynolds-averaged navier–stokes (RANS) solver. – Applied Sciences 12(5): 19p.
[15] Quintiere, J.G. (2006): Fundamentals of fire phenomena. – John Wiley & Sons 38p.
[16] Radojcic, D., Bowles, J. (2010): On high speed monohulls in shallow water. – In SNAME Chesapeake Power Boat Symposium, SNAME 19p.
[17] Ramohale, M.R., Mokaleng, B.B., Monnye, N. (2025): The impact of fire drills on firefighters' performance. – Jàmbá-Journal of Disaster Risk Studies 17(2): 7p.
[18] Samaei, S.R., Asadian Ghahfarokhi, M. (2025): Hydrodynamic performance and stability optimization of high-speed monohull vessels with chine hulls: A computational and experimental approach. – International Journal of Maritime Technology 21(1): 12-27.
[19] U.S. Coast Guard (USCG) (2025): A best practices guide to vessel stability. – US Department of Homeland Security 65p.

[20] Wang, T., Wang, Y., Li, X., Wang, J. (2023): Evacuation performance on offshore platforms under different visibility conditions. – Physica A: Statistical Mechanics and its Applications 620: 25p.
[21] Wozniakowski-Zehenter, M. (2024a): Emergency response time offshore. – Identec Solutions 10p.
[22] Wozniakowski-Zehenter, M. (2024b): Why emergency preparedness is important in offshore operations. – Identec Solutions 16p.